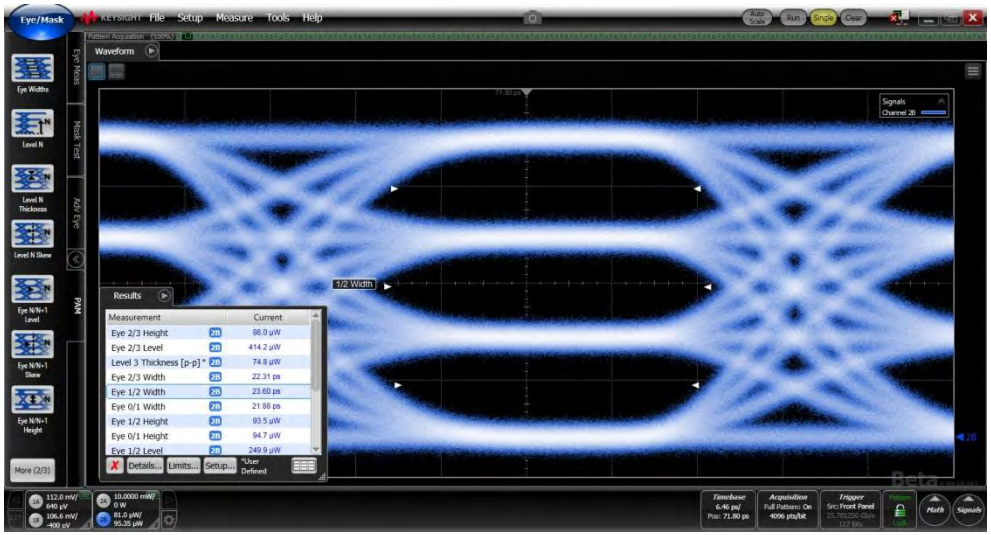
Parametric Test and Measurement for 400 Gb/s



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Big ticket items being addressed

- Page 9: **C2C CDAUI-8**: Test data from industry products
  - Discussion of definitions and process for PAM4 measurements
  - Requested within ad-hoc calls
- Page 11: **C2M CDAUI-8**: test data
  - Test procedures including PAM4
- Page 17, 21: **500m and 2 km SMF PMD**:
  - The PAM4 discussion from C2C leverages directly into any PAM4 optical discussion as the measurement tools are applicable to optical or electrical signals
- Page 13, 14, 16, 19, 20: **10km, 2km and 500m SMF PMD**:
  - 50 Gb/s NRZ optical reference receiver
  - Not listed directly in the big ticket slide

Significant progress for PAM4 in T&M since clause 94: What is available today?

- Multiple vendors providing waveform analysis solutions
- Multiple vendors providing pattern generation
- Early solutions coming out for error detection

PAM4 Pattern Generation at 25 Gbaud

- Using standard NRZ pattern generators
  - Multiplexing two NRZ streams to generate one PAM4 data stream (at the same baud rate)
  - Combiner kits ease multiplexing process
- Using arbitrary waveform generators
  - Direct generation of PAM4 signals (65 GSa/s->32 Gbaud)
  - Direct generation of stress signals
  - Customized equalization

Image from Tektronix

PAM4 Error detection

– Use multiple NRZ error detectors
  - Divide signals and send to each error detector
  - Example: Set three thresholds (unique level for each error detector)
  - Post processing software required to sort out the fact that three decisions are made on each symbol
  - High sensitivity required to accommodate power division

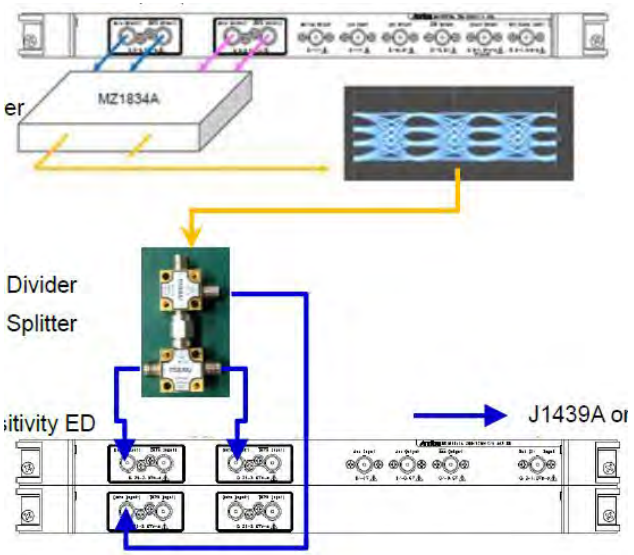


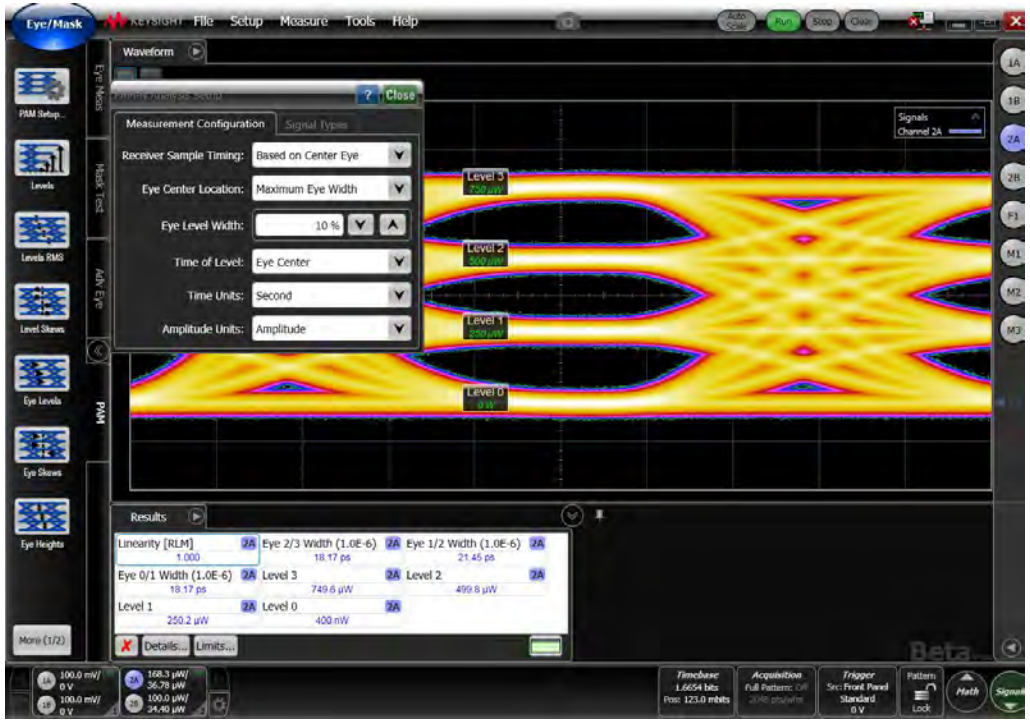
Image from Anritsu

Implications of using FEC when making BER measurements

– Please allow disabling of FEC to allow BER measurements of the uncorrected hardware

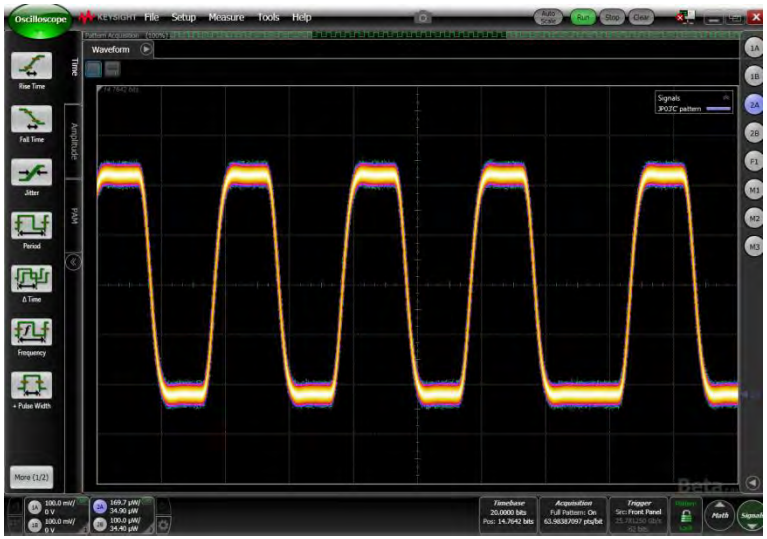
PAM4 Waveform Analysis

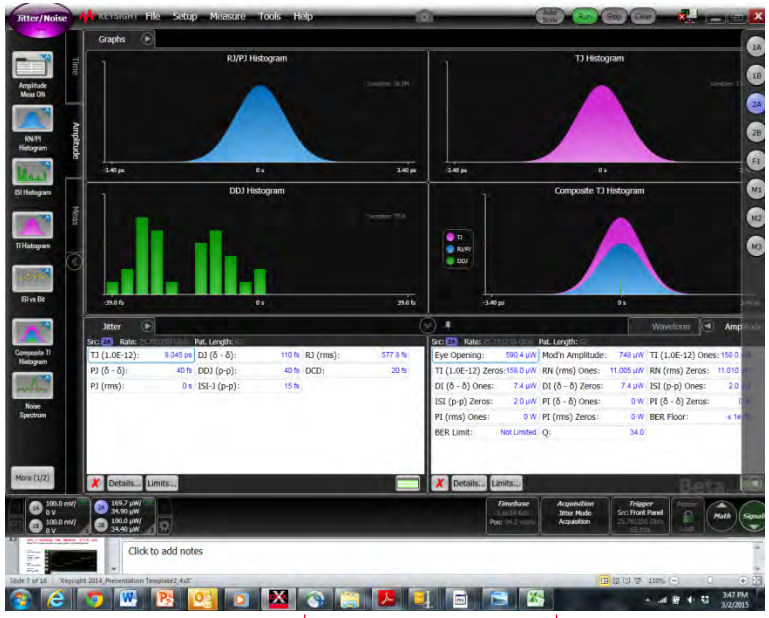
- Oscilloscope vendors have, or are developing PAM4 analysis capability
- For IEEE 802.3bs, rather than extracting key parameters solely from the eye-diagram, a multi-pass approach is recommended
  - Leverage work of clause 94



Uncorrelated parameters (noise, random jitter, even-odd jitter etc.)

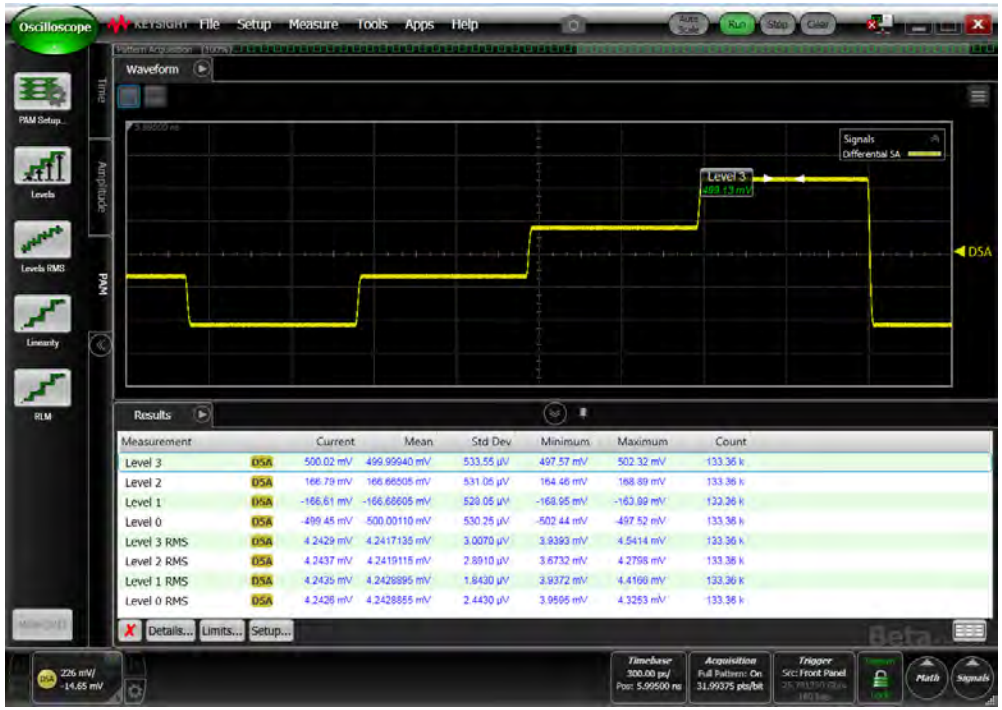
- Generate the JP03B clock pattern
- Perform a jitter and amplitude analysis to extract the uncorrelated signal components
- * A modified form of JP03B (JP03C?) is recommended to avoid DCD being confused with even-odd jitter in the presence of ISI (see backup slides)





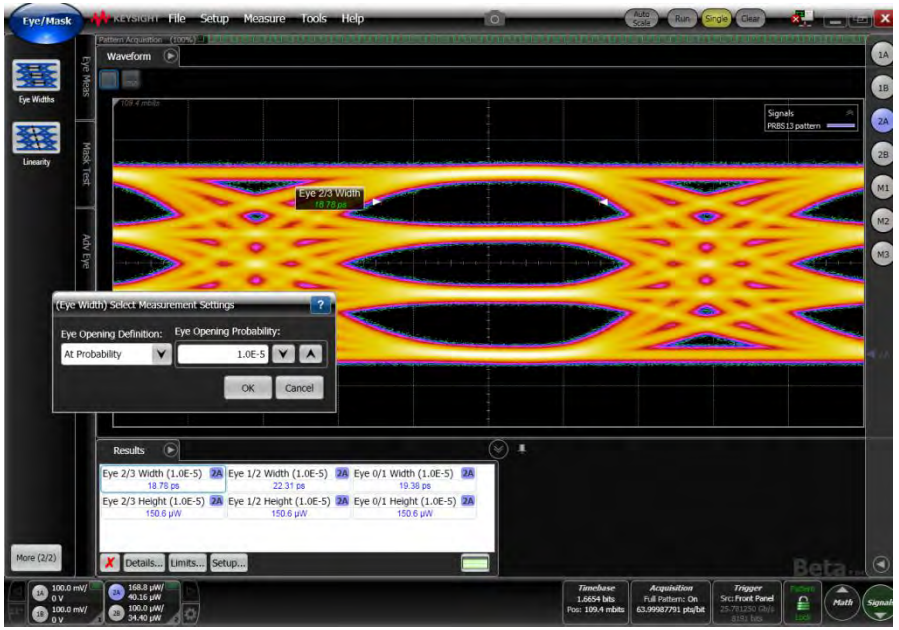
Linearity and noise

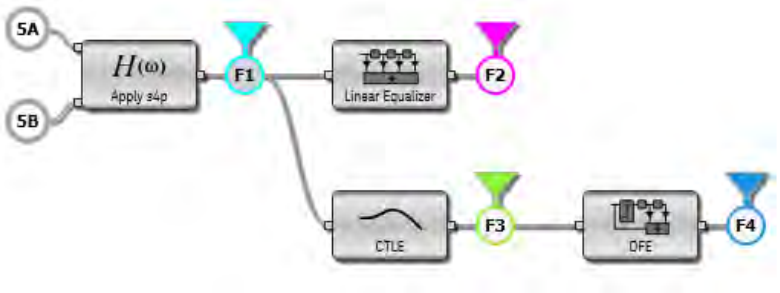
- Generate the linearity pattern (long runs at each signal level)
- Extract Level ‘N’, Level N ‘rms’, linearity, and other parameters that assess the integrity of the PAM levels
- Characterized in the absence of inter-symbol interference
  - Like ‘OMA’ in optical system, assumes the link budget deals with ISI elsewhere



Eye opening

- With uncorrelated and linearity parameters determined, characterize the eye openings (eye height, eye width)
- PAM4 waveform more sensitive than NRZ to any scope frequency response aberrations
- CTLE etc. can be applied
- Advanced signal processing issues (e.g. virtual CTLE)
  - Pattern Lock required. Long patterns prohibitive (No PRBS31. Consider SSPR type patterns http://www.ieee802.org/3/bs/public/14_07/anslow_3bs_03_0714.pdf)
  - Transforms do not correctly process uncorrelated signal components (effectively removed, similar to if trace averaging is used). But these parameters were measured in step one on clock pattern





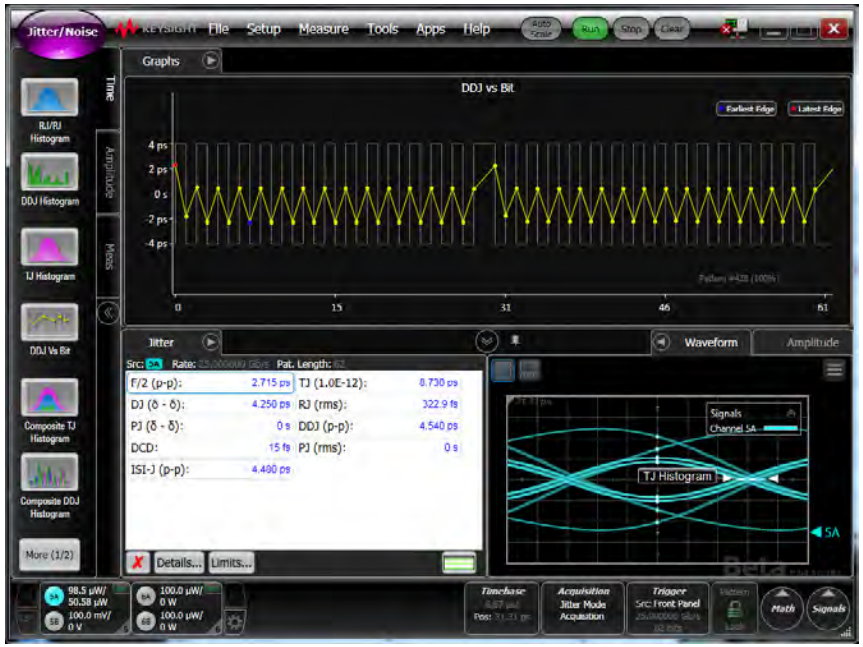
50 Gb/s NRZ optical waveform analysis

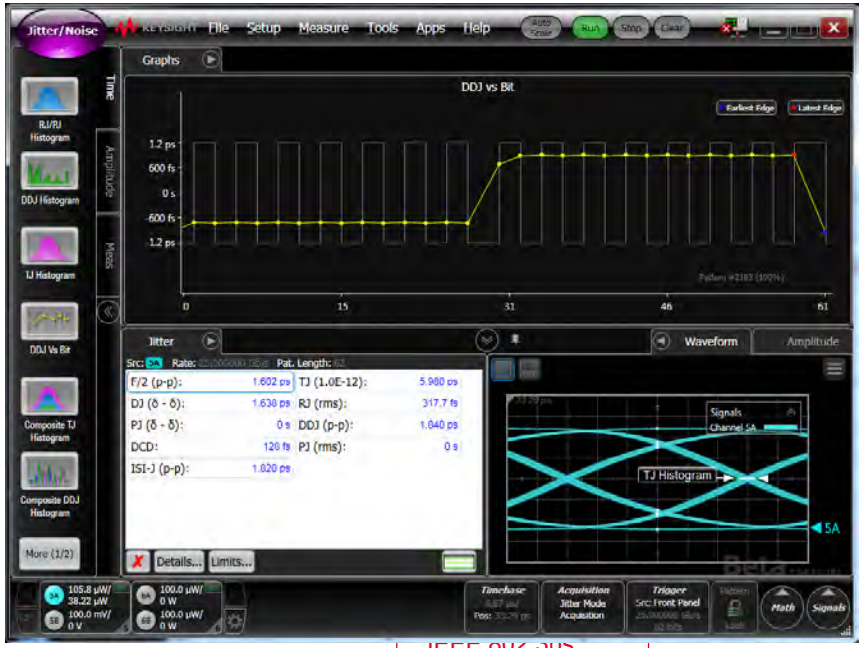
- NRZ optical transmitters have historically been observed with an optical scope with the following characteristics:
  - Fourth order Bessel response
  - -3dBe bandwidth at 75% of the data rate
- Exists in a pattern-locked scenario (signal processing required to create the ideal response. Consider SSPR type data patterns)
- Likely to eventually be implemented without pattern length restrictions

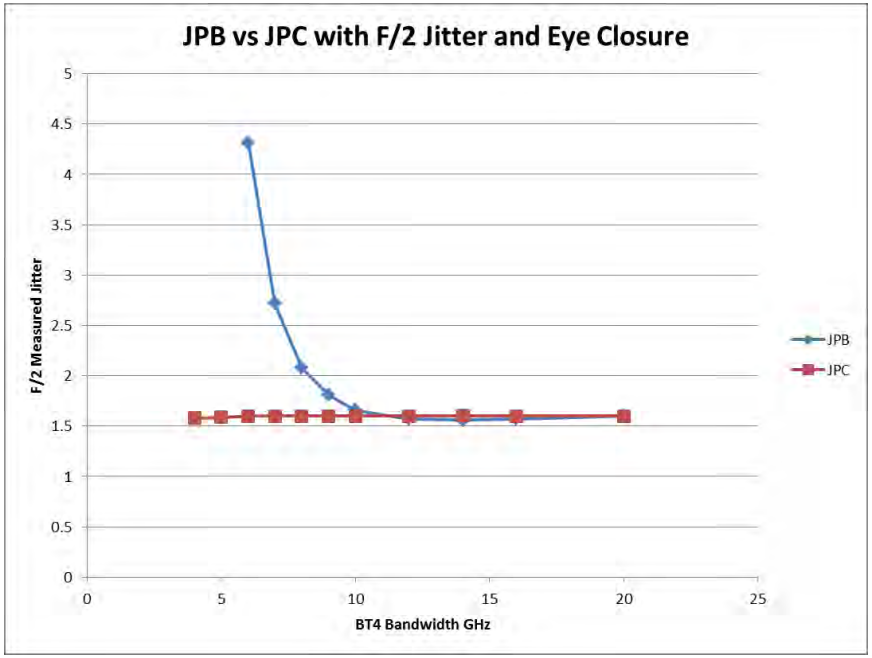
Backup slides

JP03B vs JP03C pattern

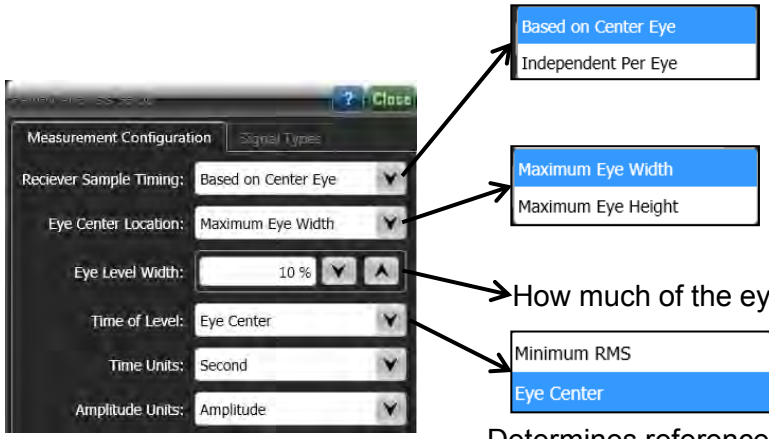
- Add 2 bits to the 62 bit JP03B pattern
  - An extra 0 placed mid pattern and an extra 3 at the end of the patter
- Minimizes DCD being interpreted as F/2 (even-odd) jitter in the presence of ISI







Configuring PAM4 measurements and possible underlying definitions



Measurements are relative to:
a. Center Eye (one RX sample time for all eyes)
b. Each eye independently
(each eye has independent RX sample times)

Eye center is based on “Receiver Sample Timing” and :
a. Max Eye Width
b. Max Eye Height

How much of the eye will be used to determine the mean of the Eye Level

1% to 25%

Determines reference for “Level” measurements.

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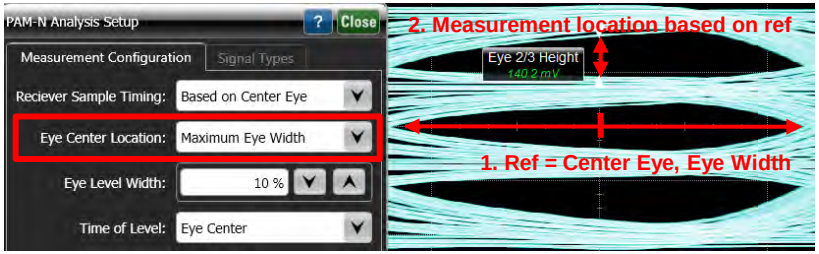
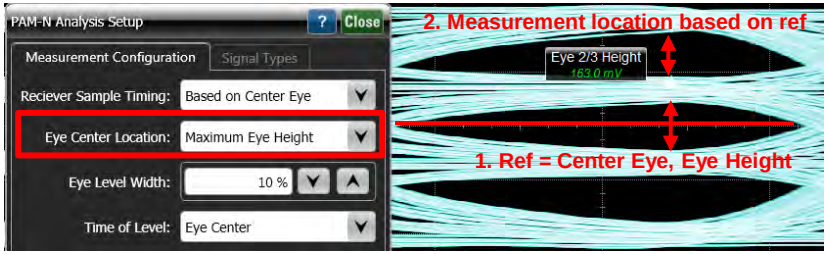
1. Locate Receiver timing reference (using center eye or each eye independently, as selected)
2. Locate Eye Center (EW or EH) of the eye identified in #1.

Reference – Max Eye Width of Center Eye



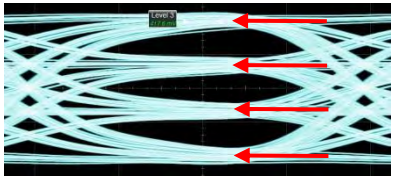
Reference – Max Eye Height of Center Eye



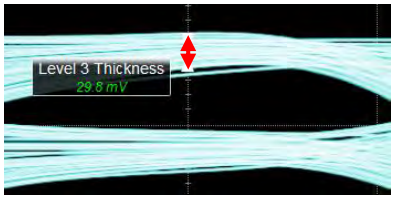
Reference – Max Eye Height, each eye is independent (top eye shown here)

Configuring PAM4 measurements and possible underlying definitions

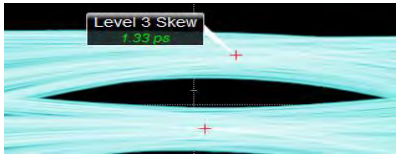
- Report mean voltage (or power) of each level
- defined by setup



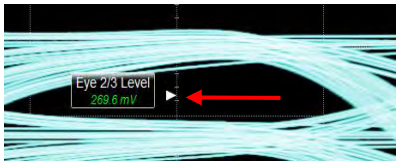
- Report “Thickness” of each level at location defined by “Time of Level” in Setup… (Eye Center or Minimum RMS)



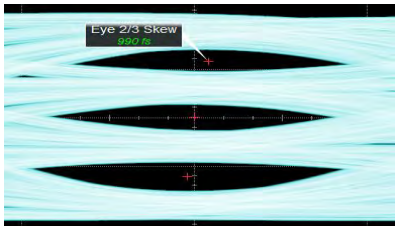
- Report skew of each level at location defined by “Time of Level” in Setup… (Eye Center or Minimum RMS)
- If configured for “Eye Center” of “Center Eye”, all skew = 0.



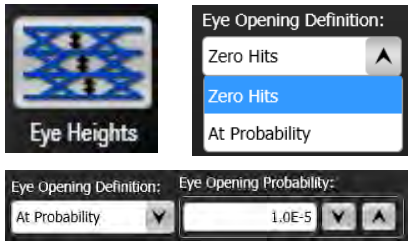
- Report mid-point of each EYE level as defined by settings in Setup…



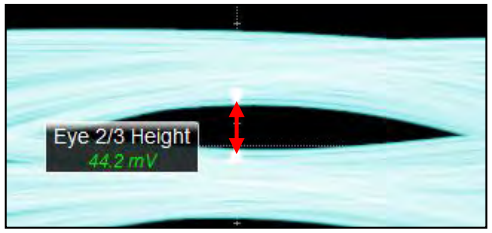
- Report skew of each EYE level as defined by settings in Setup…
- If based on Max EH of Center Eye, skew of center eye = 0 (this is the reference for the other eyes)



Built-in measurements in Eye/Mask mode



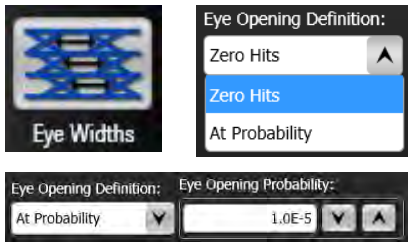
- Report Eye Height at a location determined by setup…>
- Based on measured data only (no extrapolation)



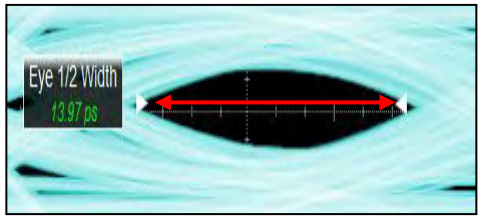
Measurement		Current
Eye 2/3 Height	F1	44.2 mV

Measurement		Current
Eye 2/3 Height (1.0E-5)	F1	? 48.0 mV

Measurement		Current
Eye 2/3 Height (1.0E-5)	F1	46.2 mV



- Report Eye Width at a location determined by setup
- Based on measured data only (no extrapolation)



Measurement		Current
Eye 2/3 Width (1.0E-5)	F1	? 11.77 ps

Measurement		Current
Eye 2/3 Width (1.0E-5)	F1	11.77 ps

- Level Separation Mismatch Ratio (normally measured as a bit pattern rather than an eye per Clause 94)
- Ideal R_{LM} = 1 (Clause 94 Spec R_{LM} > 0.92)

Measurement		Current
RLM	F1	0.964