Measurement problems for serial optics
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- **Accurate bathtub curves for transmitter jitter verification**
- **Producing reliable stressed eyes for receiver verification**

Test and measurement perspective and developments for transceiver verification

- Several problems identified
- Implications of the problems
- Identifying some sources of the problems
- Potential solutions
- Results to date

Transmitter jitter verification problems

- **Bathtub jitter: Great in theory but difficult to achieve in practice**
- **Functional devices appear out of specification**
- **Questions on the limitations of the test equipment**

Receiver verification through stressed eye sensitivity tests

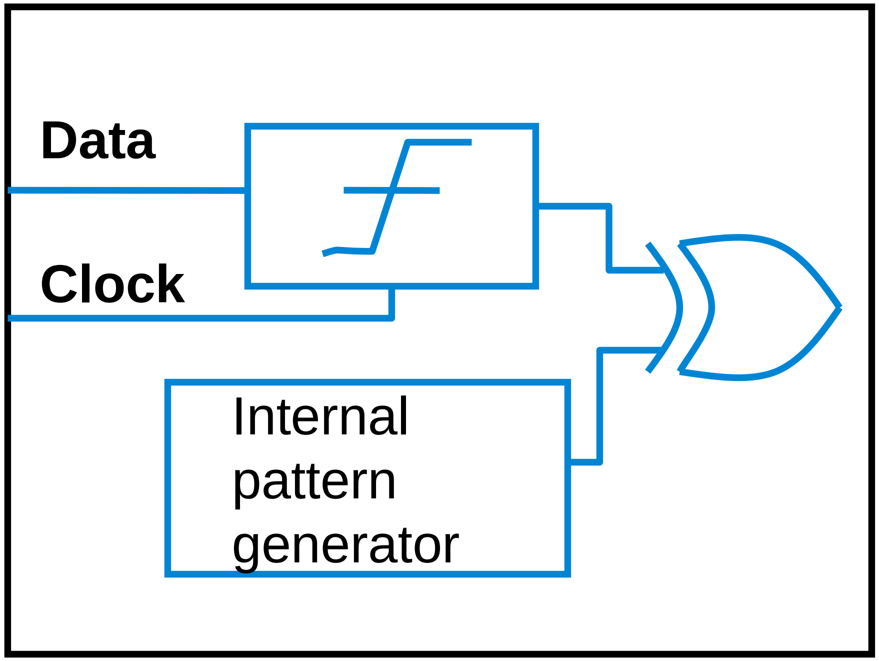
- Again...great theory but difficult to achieve at the bench
- Difficult to build the various components of the degraded signal in a systematic, well controlled manner
- High power penalties to tolerate stress
- Test equipment also suspect

We have taken a two-pronged approach to producing accurate bathtub curves

- **Optimization of the error detector in BER test sets**
- **Alternate measurement approach based on high-speed sampling oscilloscopes**

Bathtub curves: Test equipment limitations

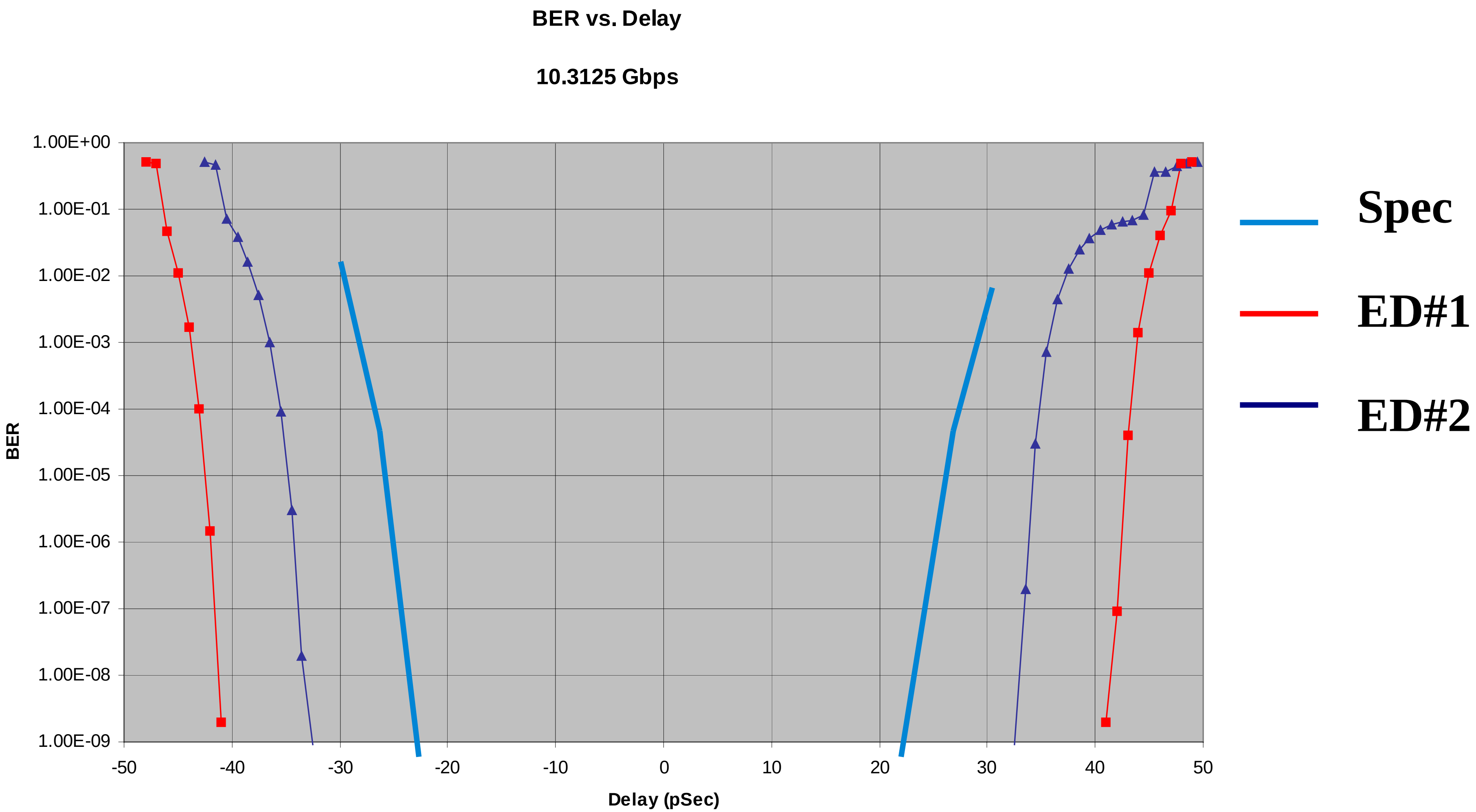
- BERT error detectors prefer the ideal regenerated signal
- Sampled at the ideal point in time
- Sampled at the ideal signal level
- Bathtub curve violates all of the above



Transmitter bathtub curves

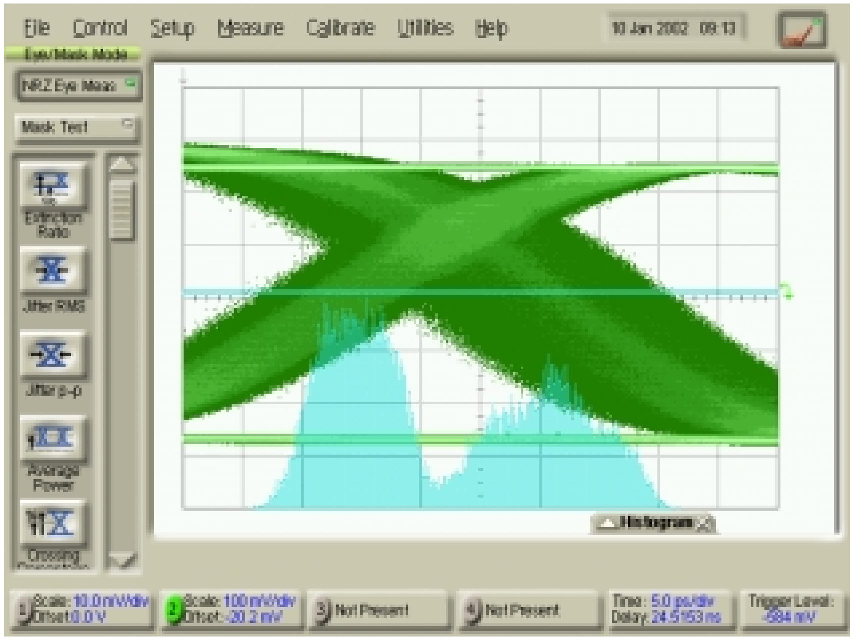
- A “raw” transmitter signal is being presented to the error detector
  - Significantly different situation than checking for error on the output of a receiver / decision circuit
- Although the functionality of an error detector is logical in concept, it is built with high-speed circuitry
  - RF / analog performance limitations
  - Depending upon the quality of the design, there can be pattern dependencies etc that can mask the quality of the signal being measured
- The typical error detector may not be viable for 10 GbEn transmitter bathtubs

The quality of the error detector can have a significant effect on the bathtub curve



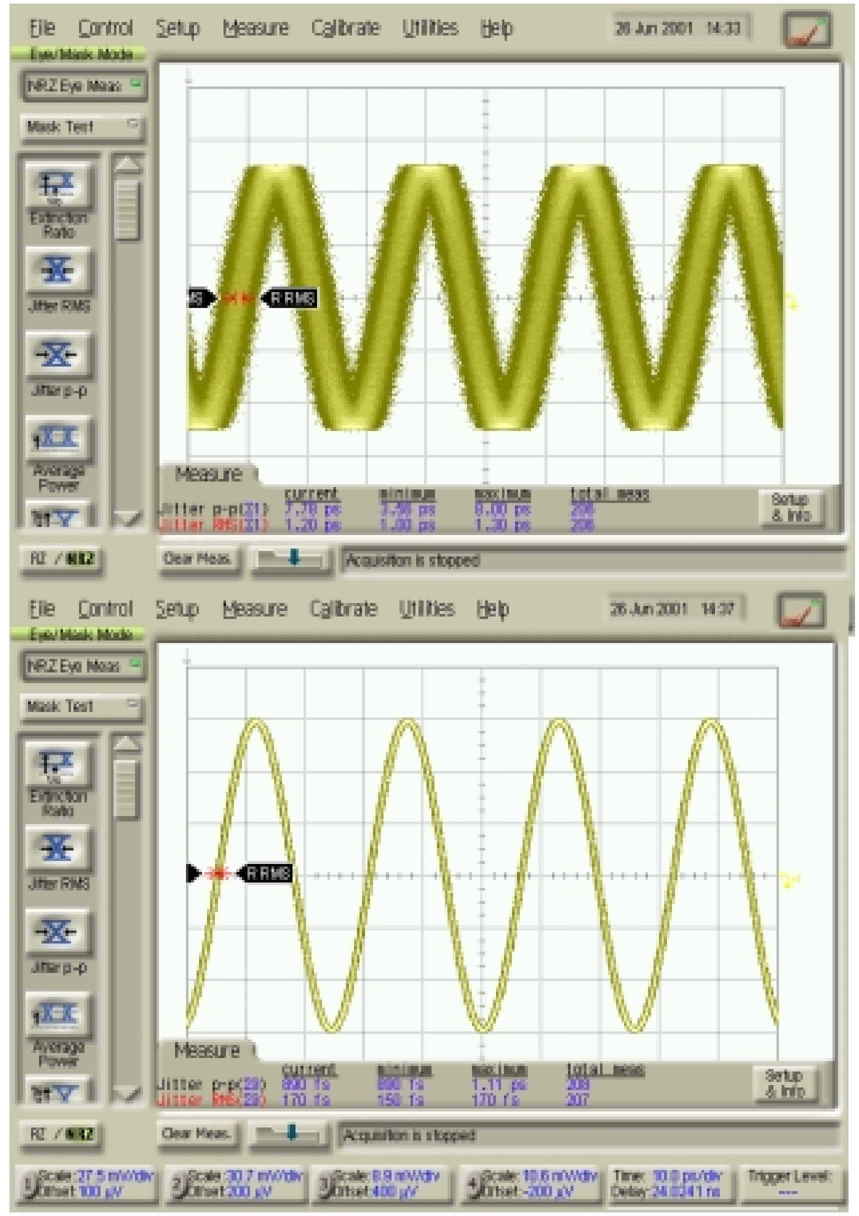
Jitter can also be characterized using a wide-bandwidth oscilloscope

- Histogram at the eye diagram crossing point
- Simple, but with limitations
    - Oscilloscope jitter can mask true performance
    - Need to differentiate random from deterministic
    - Difficult to assess low probability events



Clean up the oscilloscope

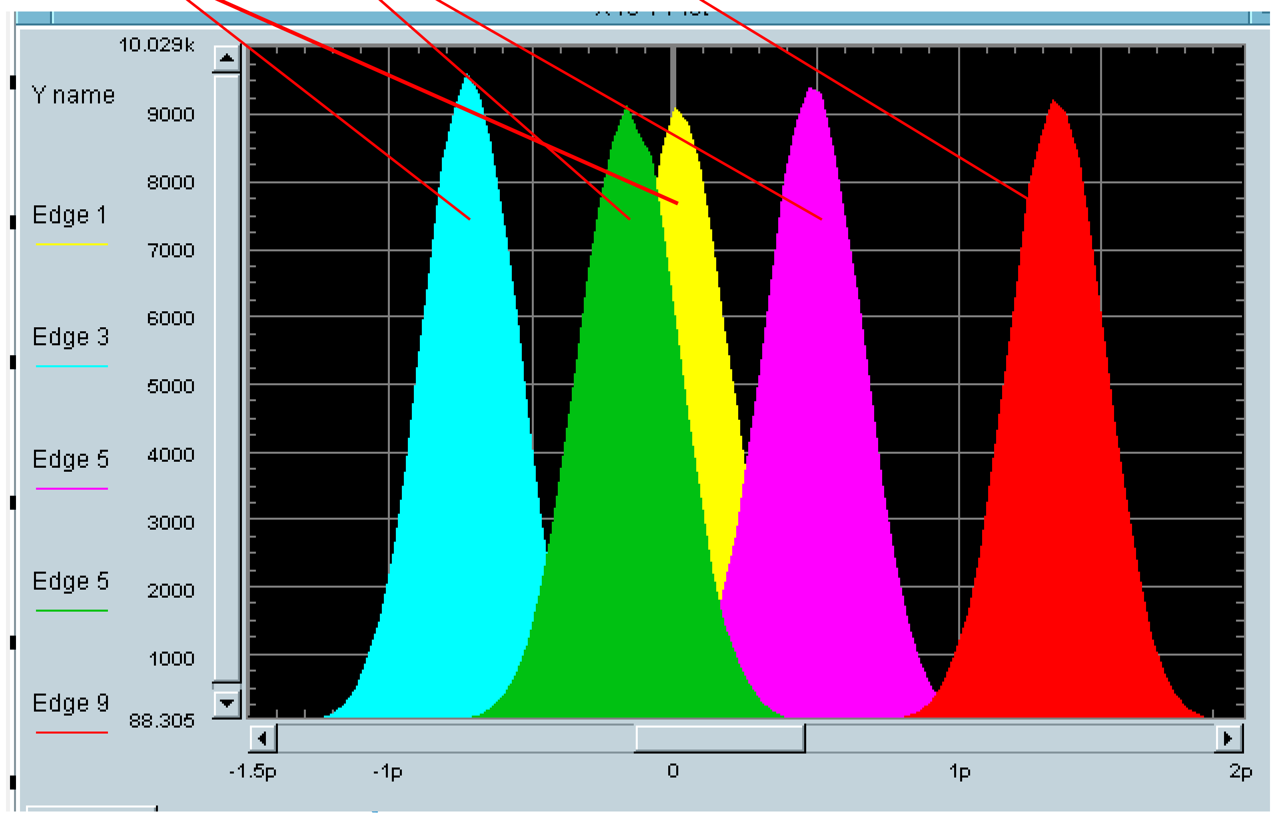
- **Scope jitter has been reduced from the 1 ps rms level to well below 200 fs**
- **Removes virtually all of the oscilloscope contribution to a jitter measurement**



With the scope jitter removed, develop a methodology to extract the various elements of jitter from the signal

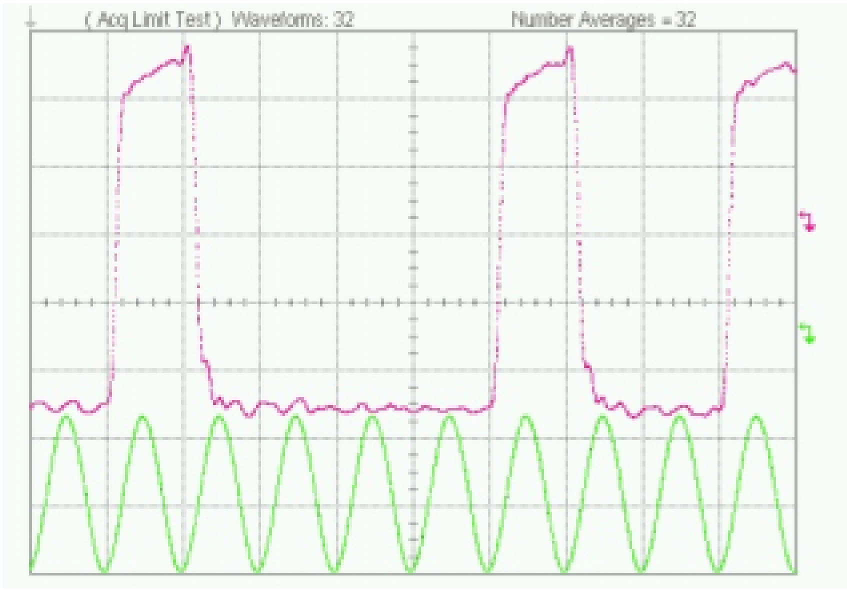
RJ = 334 fs

- Agilent 70843C Pattern Generator
- Agilent 83433 Transmitter
- Agilent 86100B DCA
    - 86115B dual optical module
    - 86107 precision time base
- PRBS7, 10.3125Gb

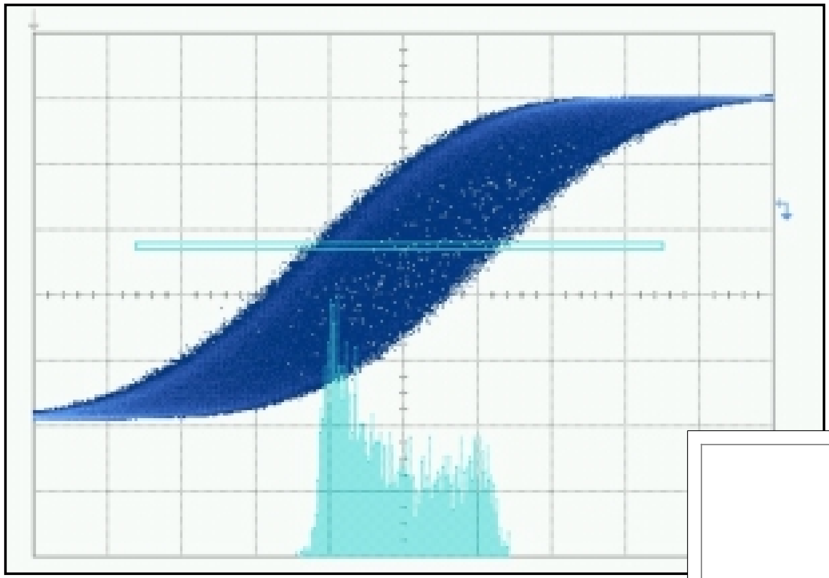


Examine the data edge locations relative to the ideal

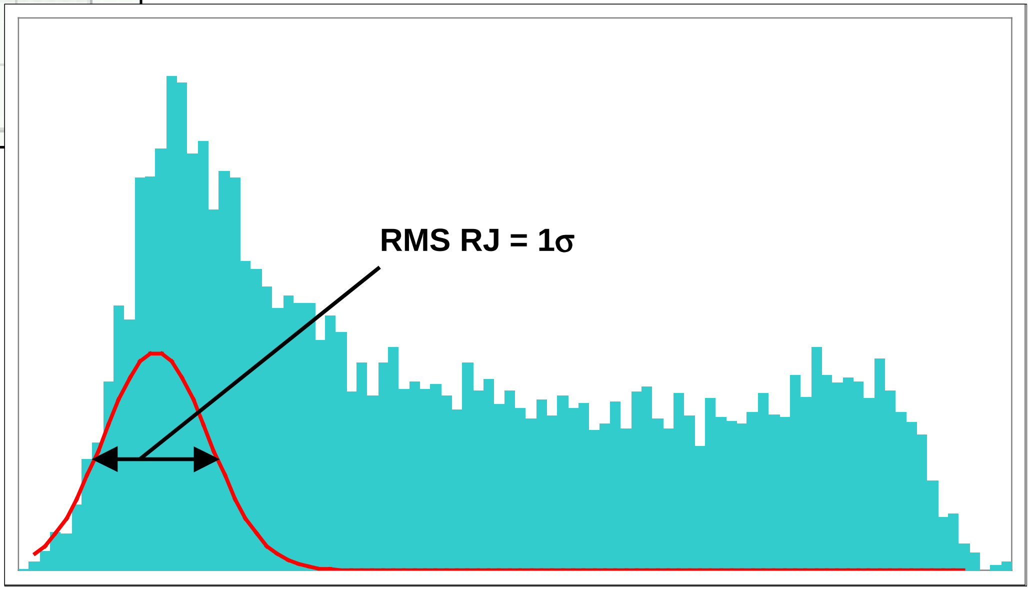
- **Clock signal serves as the ideal time reference**
- **Long patterns consume time**
- **Techniques being developed to optimize the analysis for time efficiency**



Examine a data edge to determine the RJ of a pattern



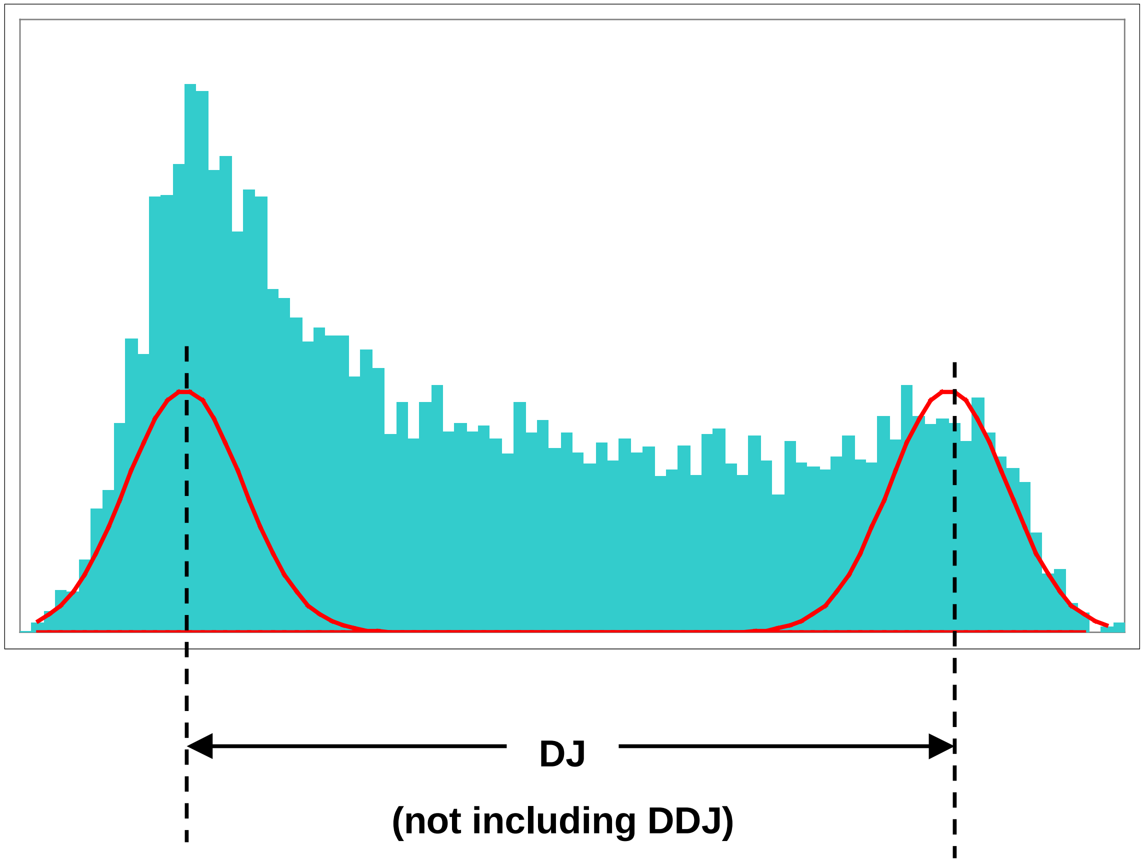
A histogram of edge locations for a particular edge is created...



...and then a normal distribution is found that matches the tail of the histogram.

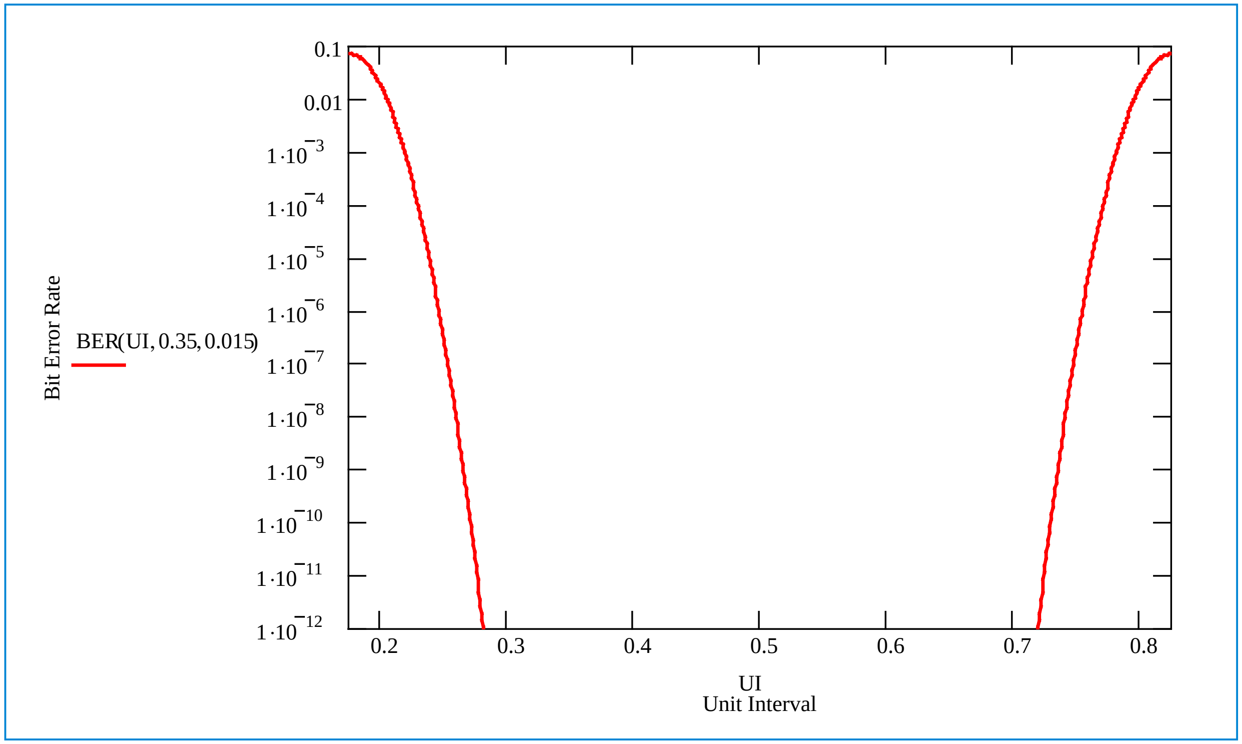
Must also account for DJ that is not DDJ

The remaining jitter is the DJ not accounted for in the DDJ measurement. This is primarily composed of periodic jitter (PJ).



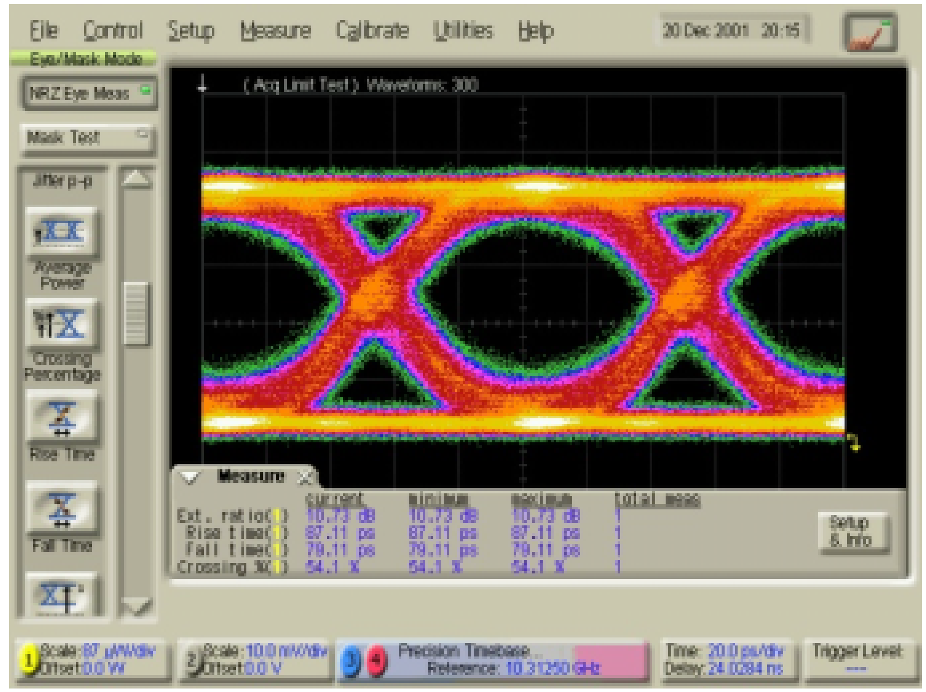
Bathtub curve is reconstructed from the measured and derived jitter elements

$$BER(UI, DJ, RJ) := 10^{-\left[A - B\cdot\left(\frac{UI - 0.5DJ}{RJ}\right)^{2}\right]} + 10^{-\left[A - B\cdot\left(\frac{1 - UI - 0.5\cdot DJ}{RJ}\right)^{2}\right]}$$

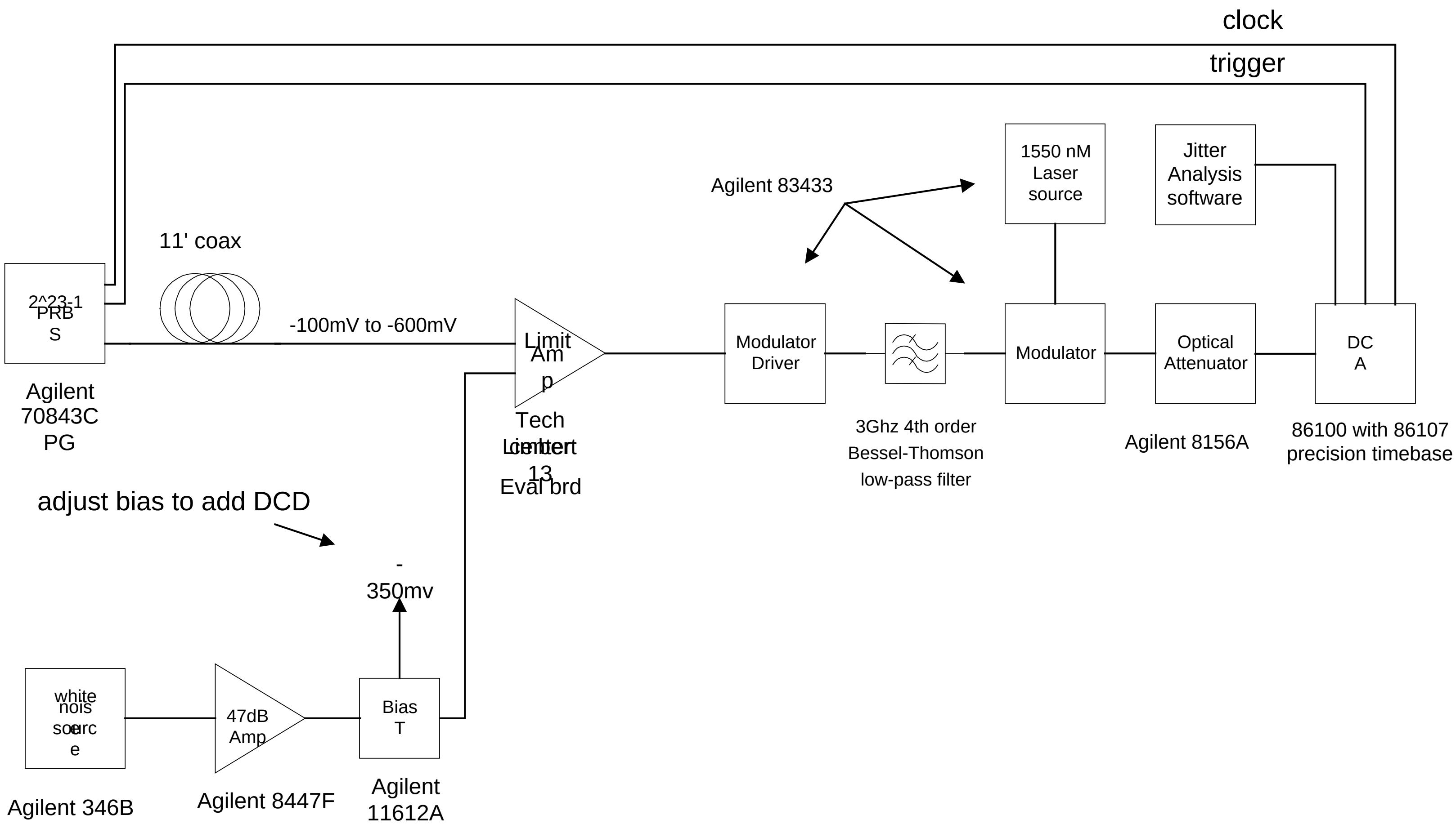


Stressed eye receiver sensitivity

- Construction of the stressed eye requires a precision analysis of jitter at any point in the "stress chain"
- Both RJ and DDJ must be accurately known
- Using the oscilloscope based jitter analysis for verification
  - Linear, wide-bandwidth optical and electrical channels coupled with jitter analysis technique

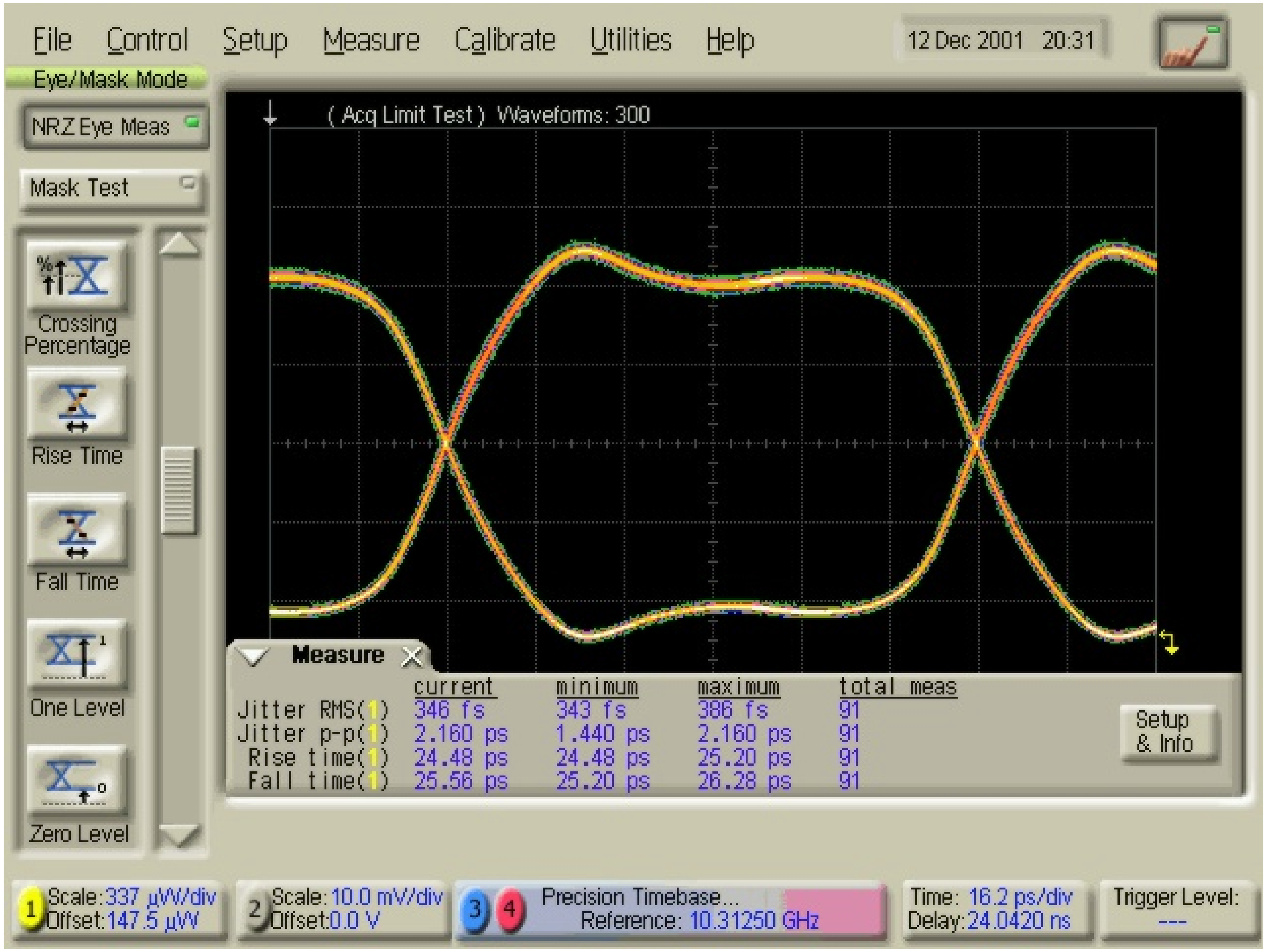


Optical Stressed Eye Generation Setup

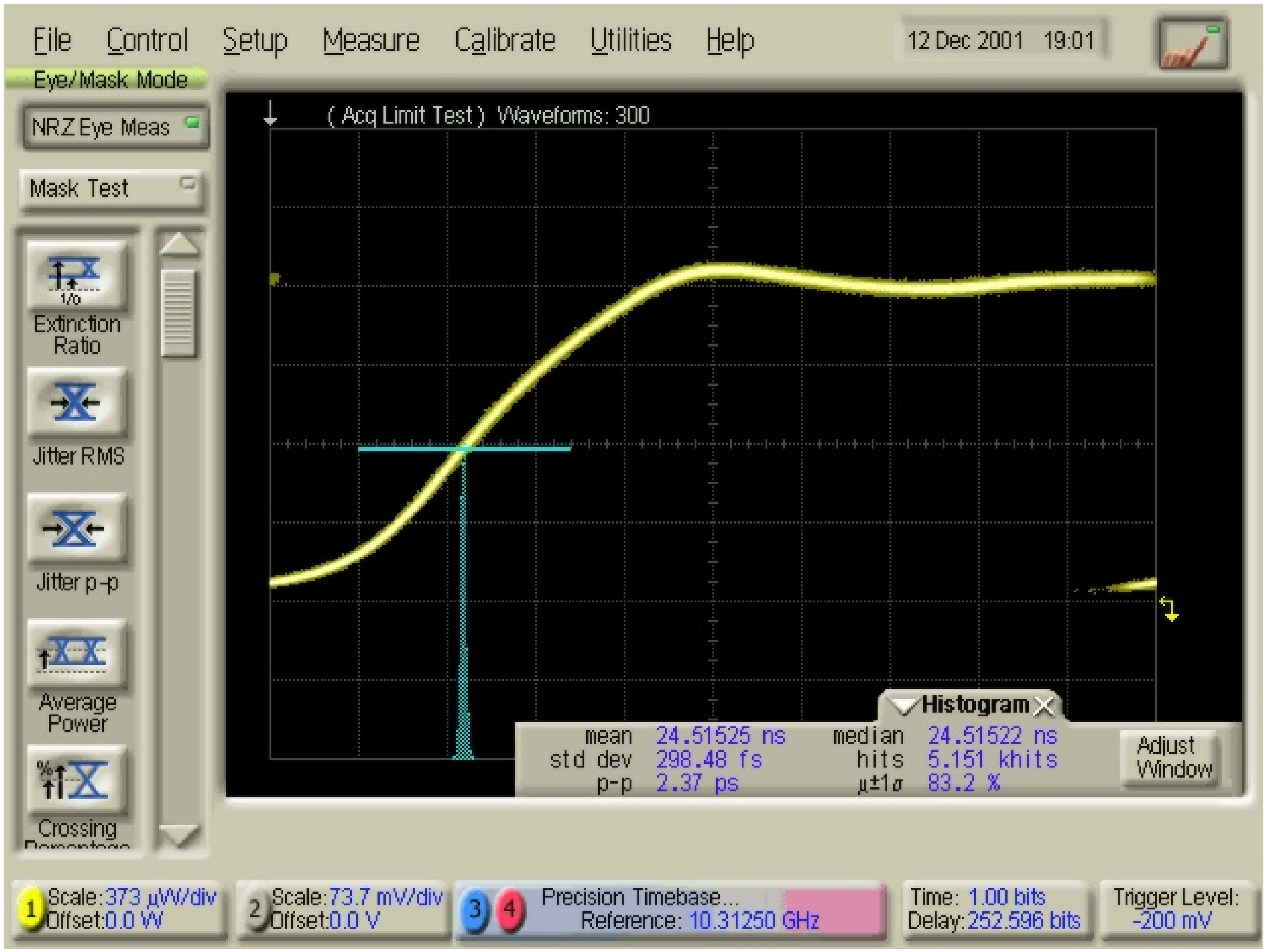


A review of our lab results

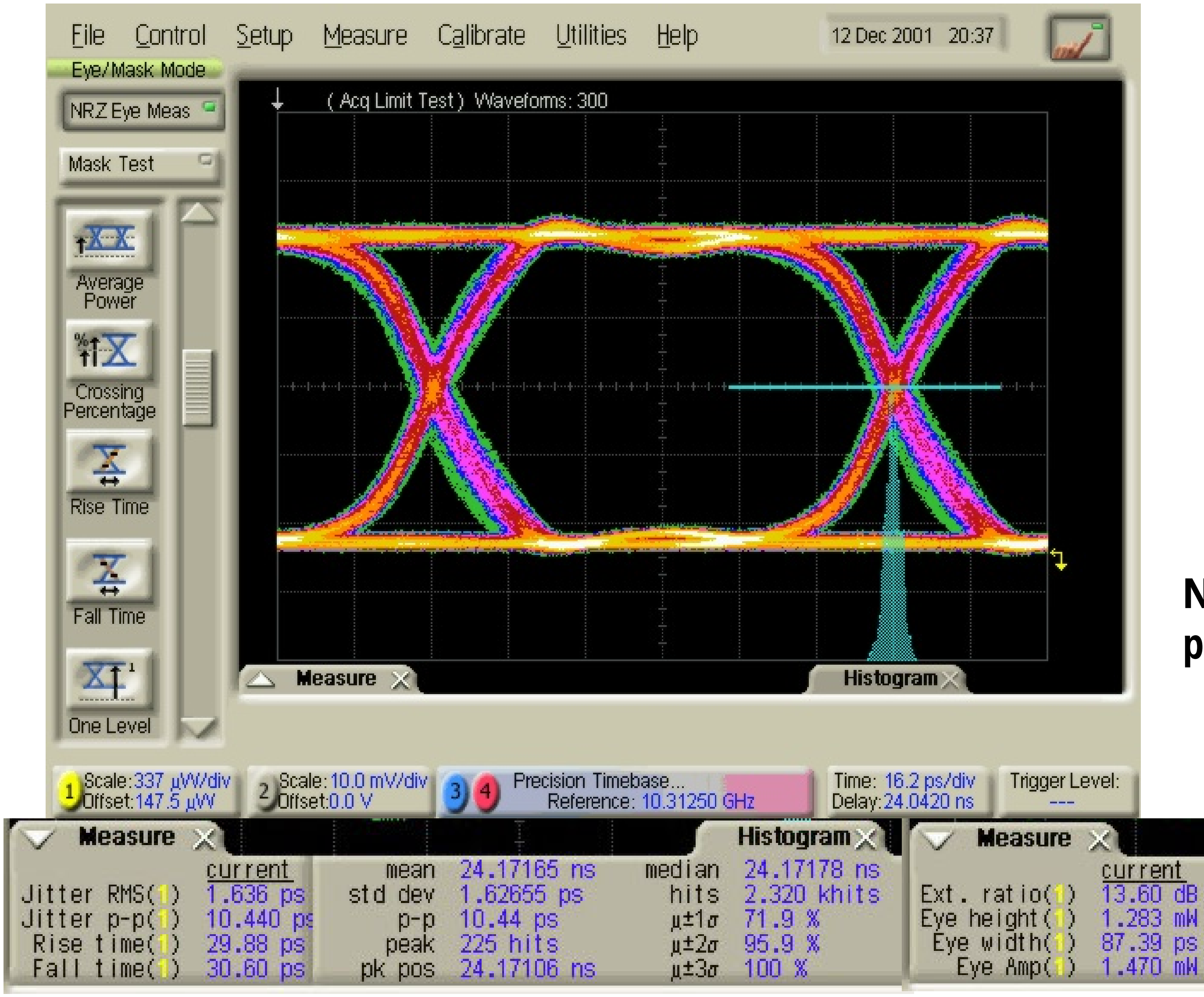
Clean Eye (1010)



Clean eye with pattern trigger

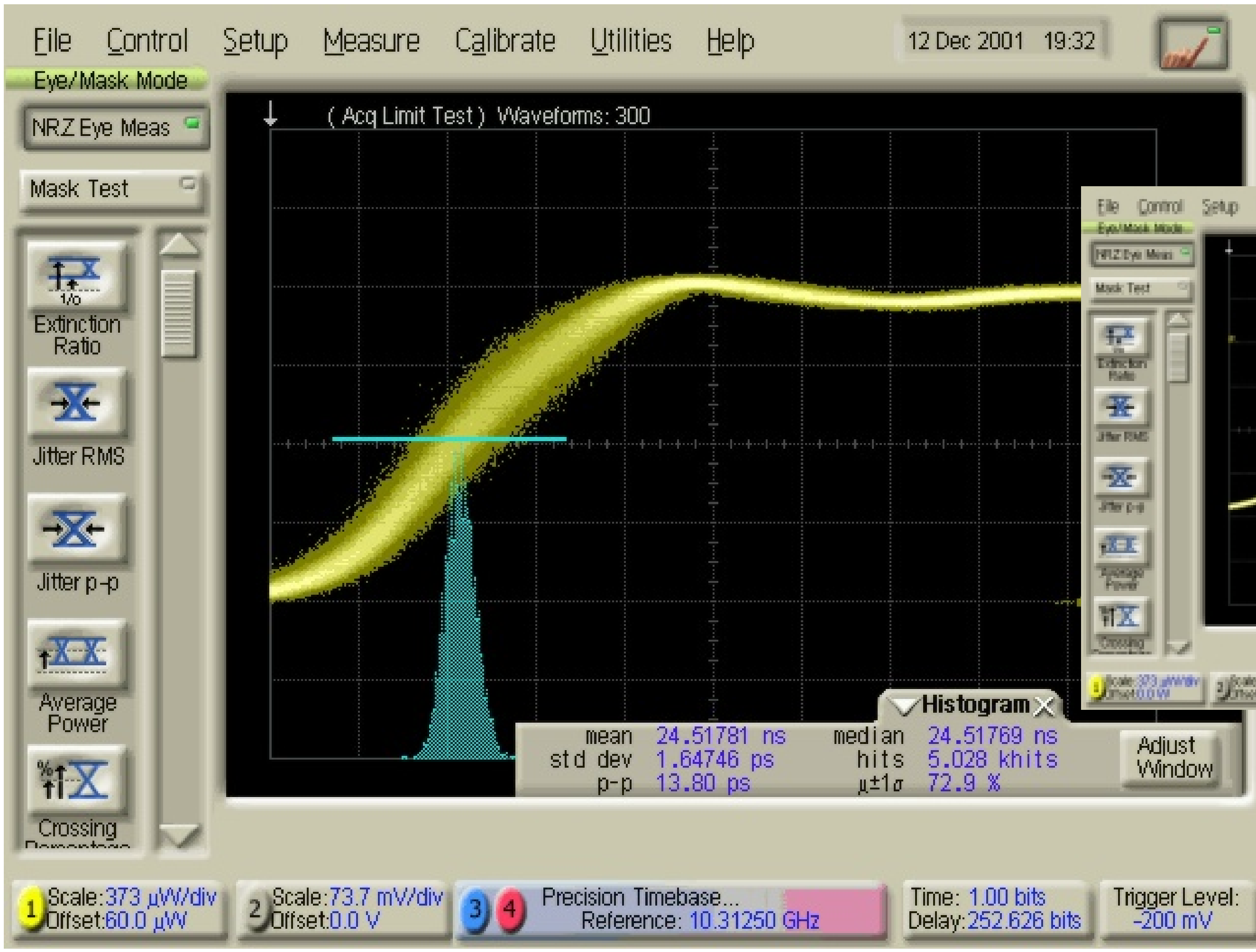


Clean Eye (PRBS7)

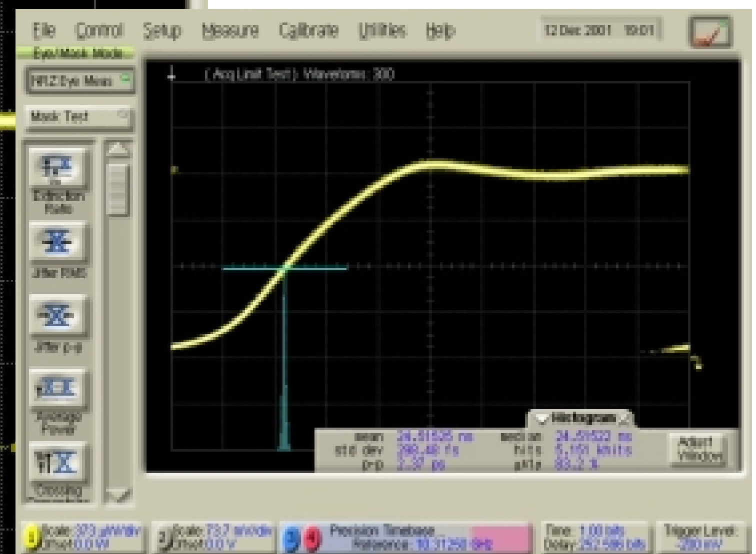


Note DDJ from pattern generator.

RJ generated by noise source followed by limit amp

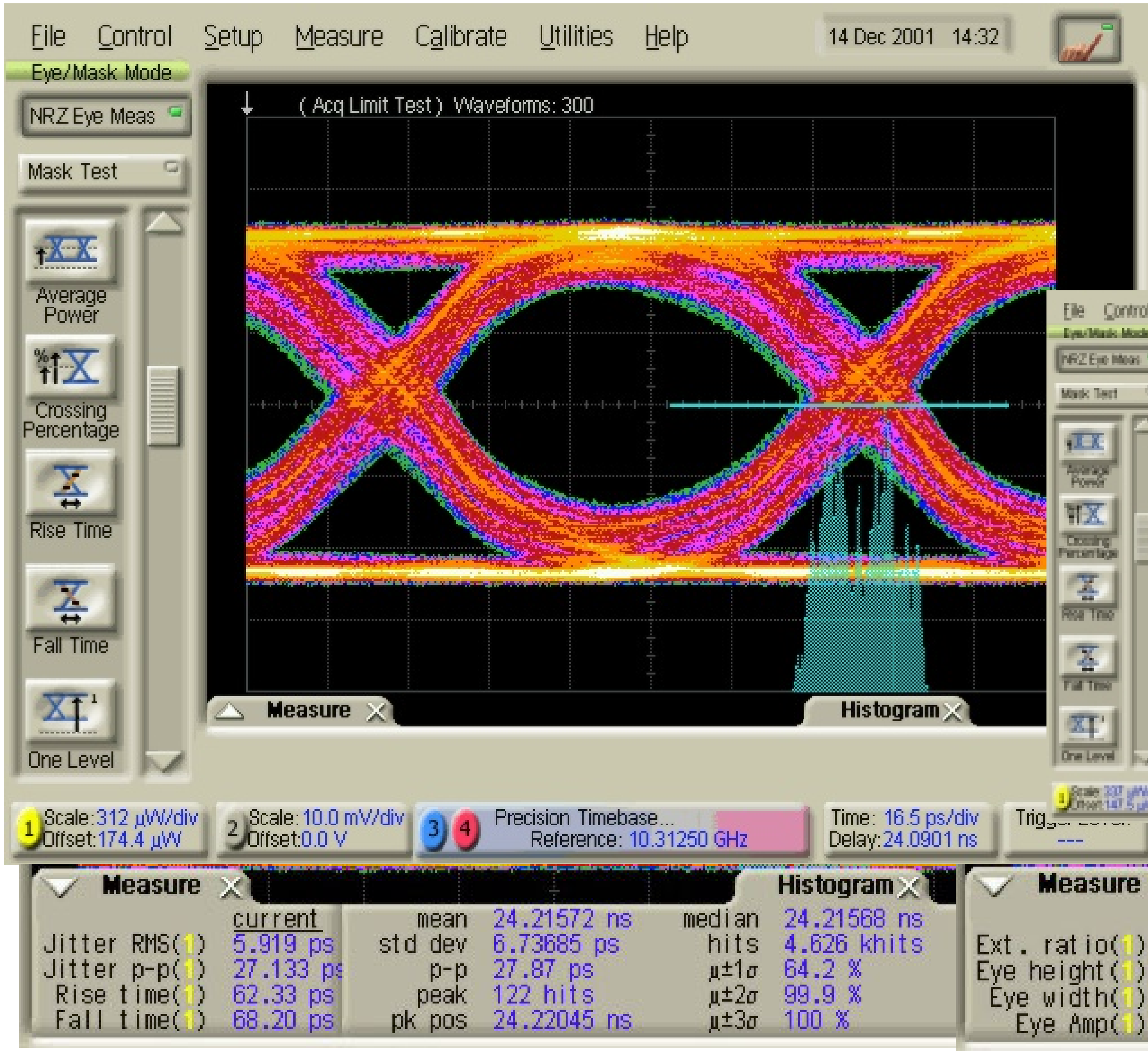


Clean Eye:

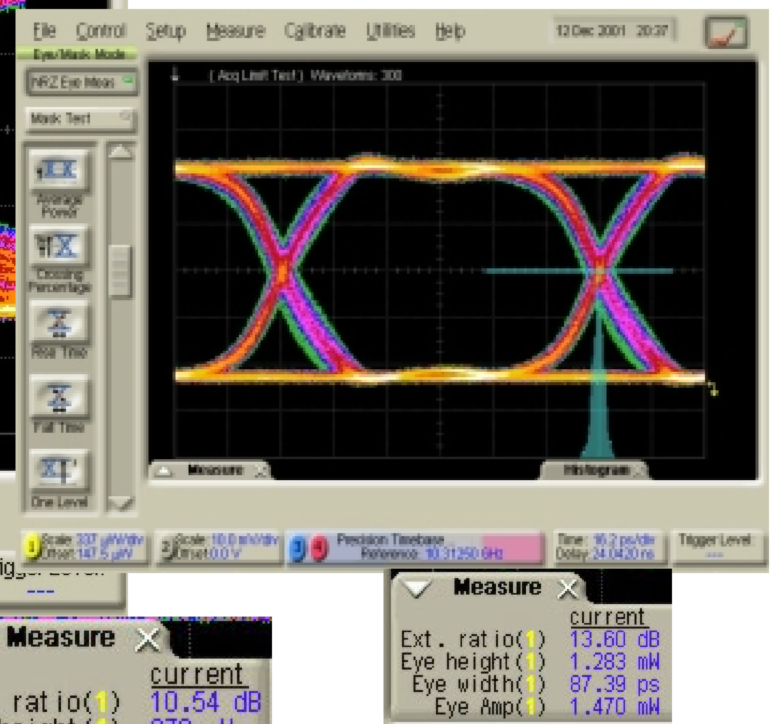


RJ is adjustable.
802.3ae specifies
σ = 1.5ps

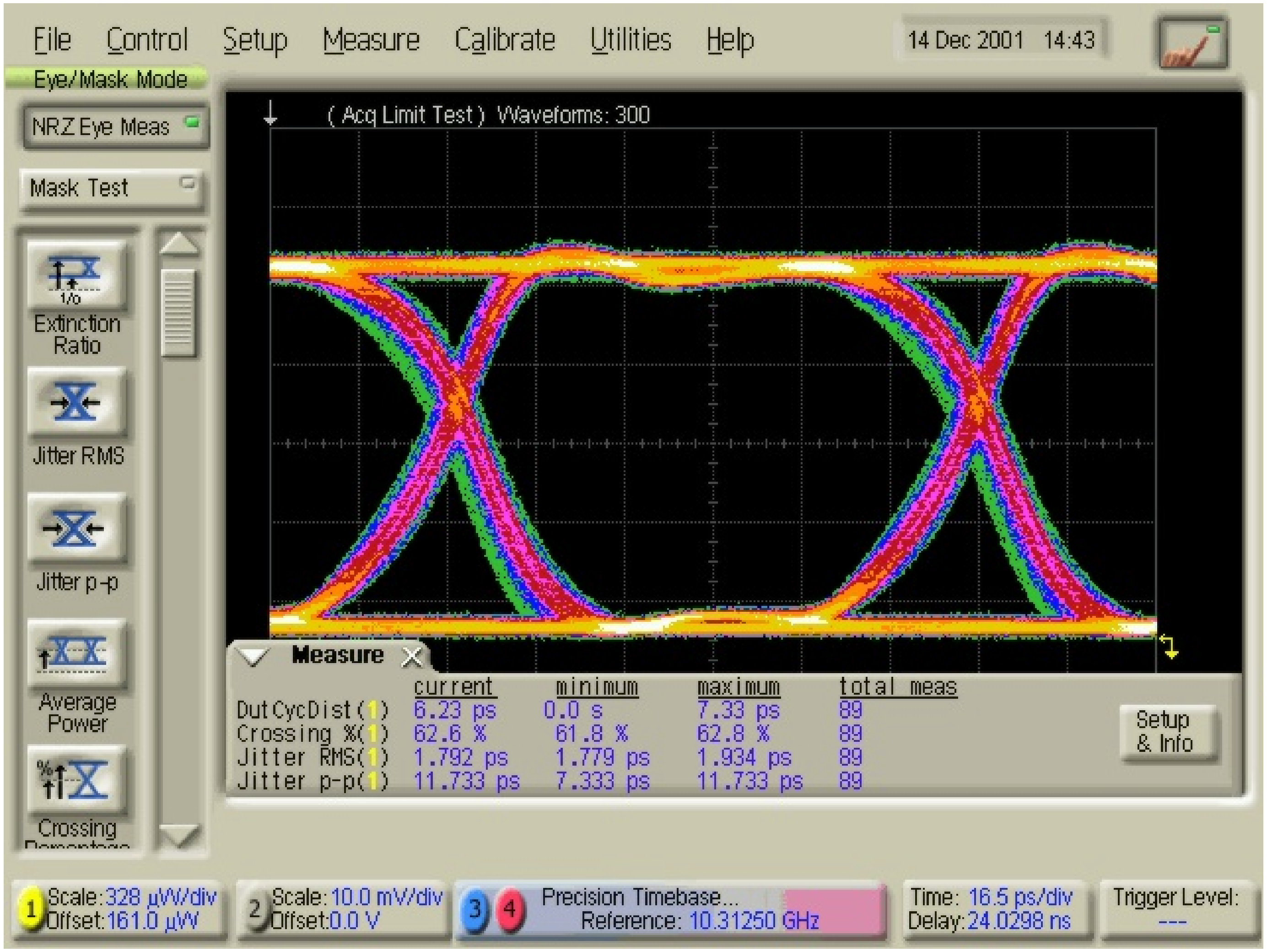
ISI generated by 3 GHz LPF



Clean Eye:

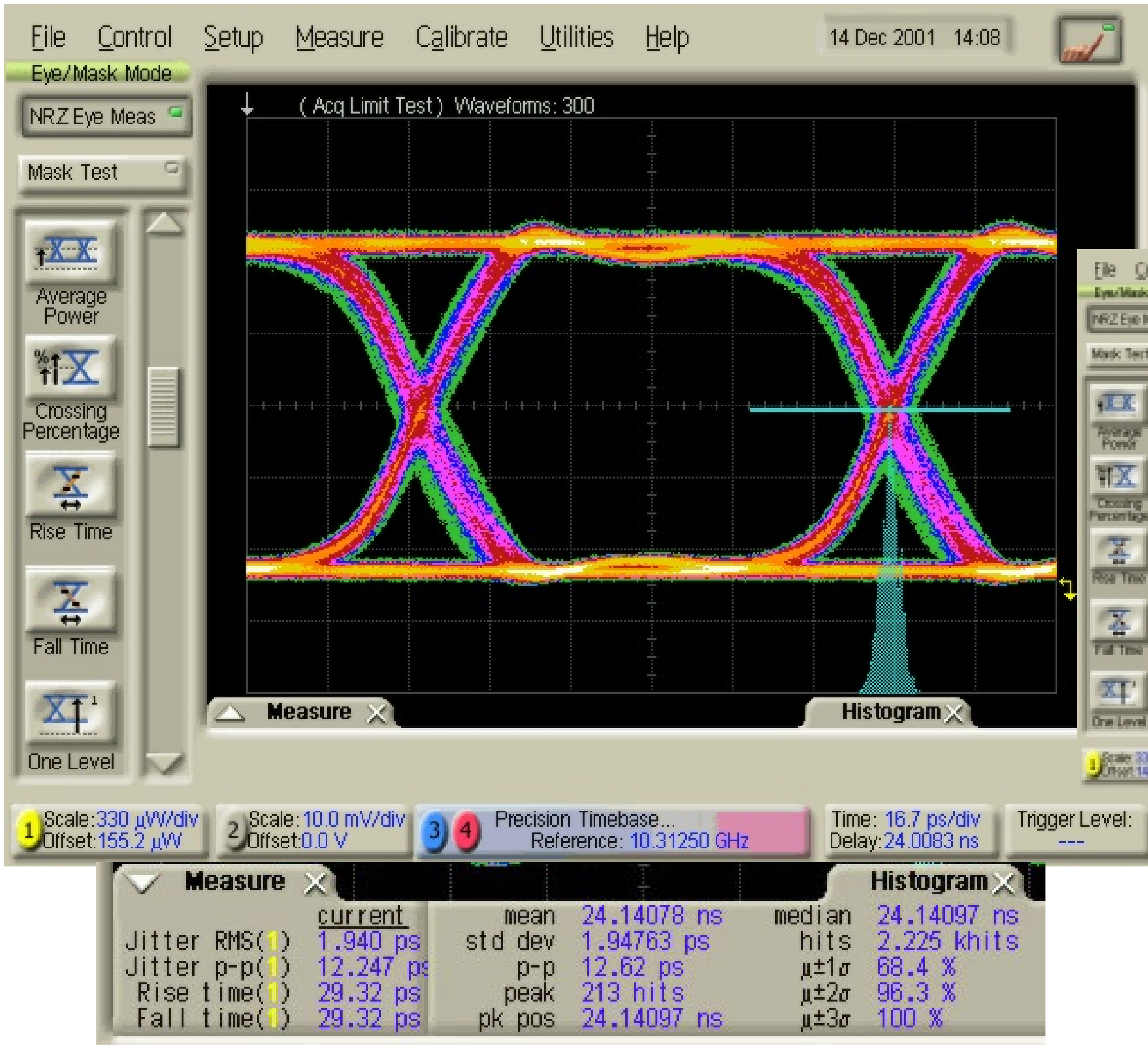


DCD generated by limit amp offset

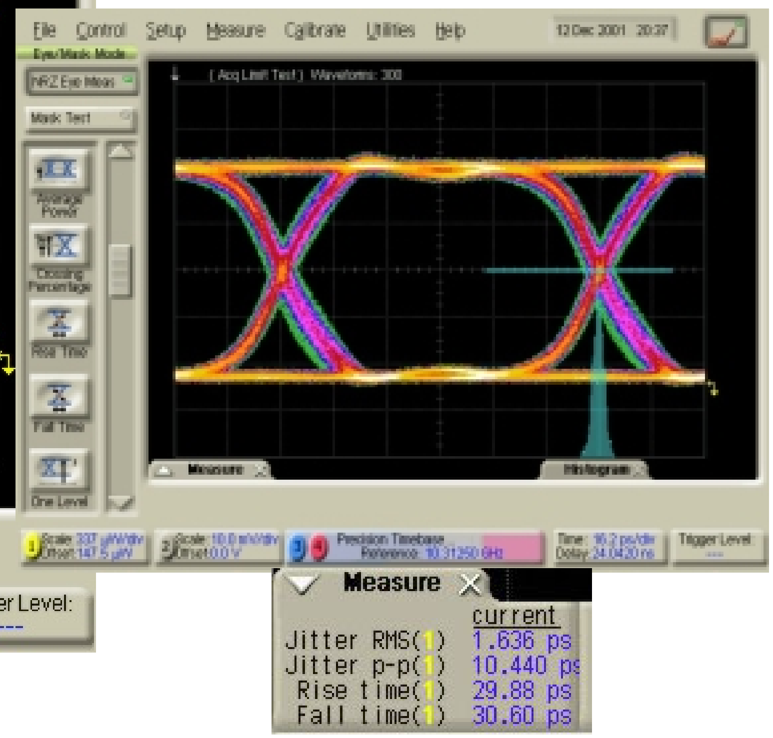


DCD is adjustable.
802.3ae specifies
DCD > 6ps

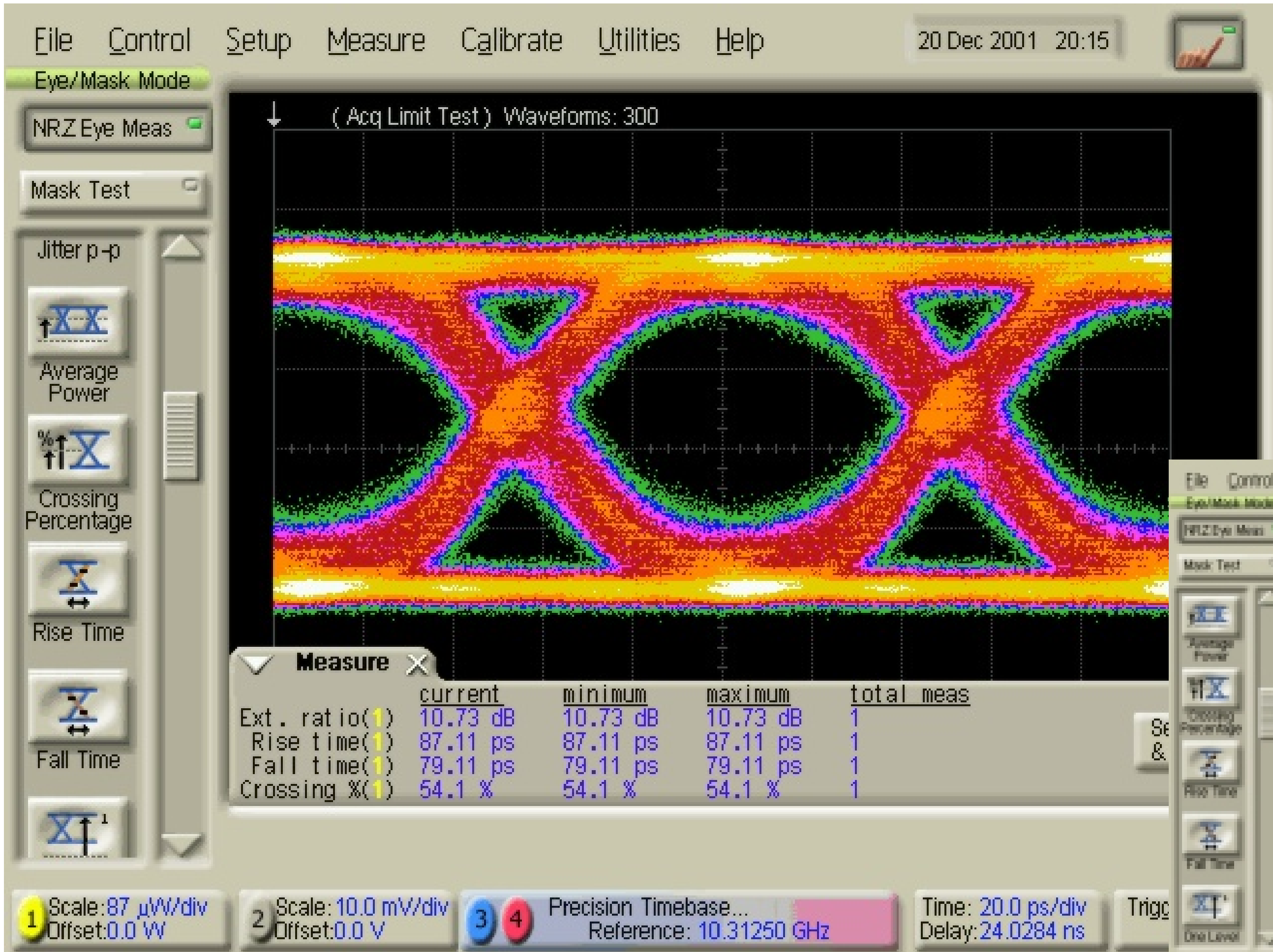
DDJ generated by 11’ coax



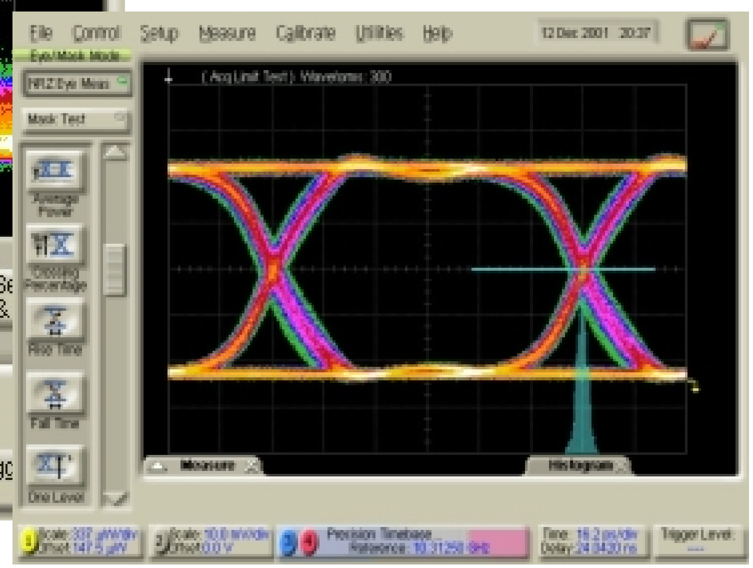
Clean Eye:



Combined DDJ, RJ, ISI, DCD and 6dB opt attenuation



Clean Eye:



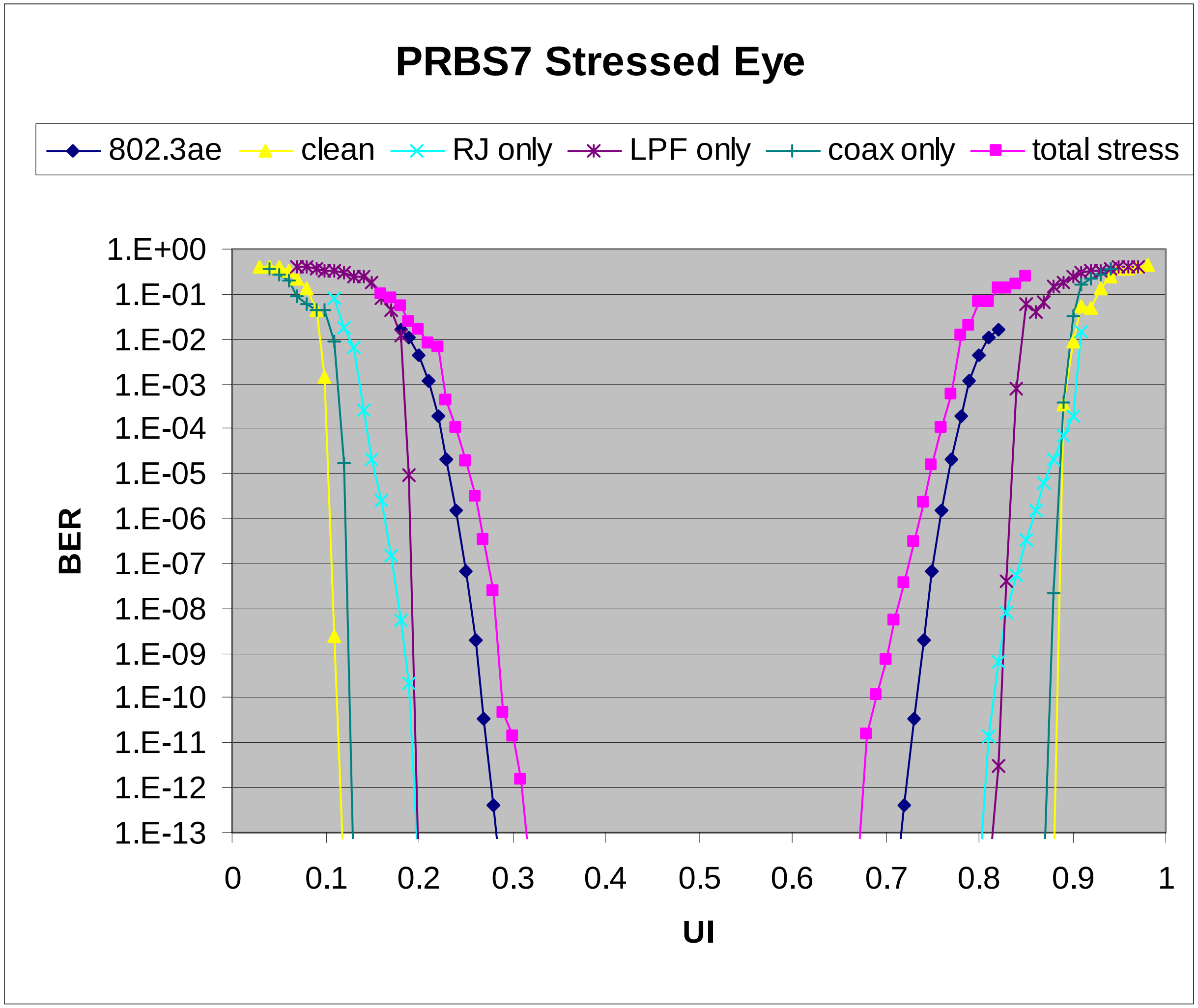
DDJ and RJ measurements

	clean 1010	“clean” PRBS	11 ft coax	LPF	11 ft coax and LPF	White noise	Coax, white, LPF	Coax, white, LPF, –11.6dB atten
Rising edge DDJ	0.785 ps	5.90 ps	7.71 ps	17.3 ps	19.6 ps	5.23 ps	19.1 ps	18.9 ps
Falling edge DDJ	0.414 ps	9.54 ps	10.9 ps	16.7 ps	18.8 ps	9.85 ps	18.5 ps	19.6 ps
RJ (RMS)	0.298 ps	0.298 ps	0.254 ps	0.425 ps	0.463 ps	1.65 ps	1.87 ps	4.55 ps **
RJ (p-p)	2.16 ps	2.37 ps	1.72 ps	3.23 ps	3.45 ps	13.8 ps	14.9 ps	33.4 ps **

** degraded by scope vertical noise

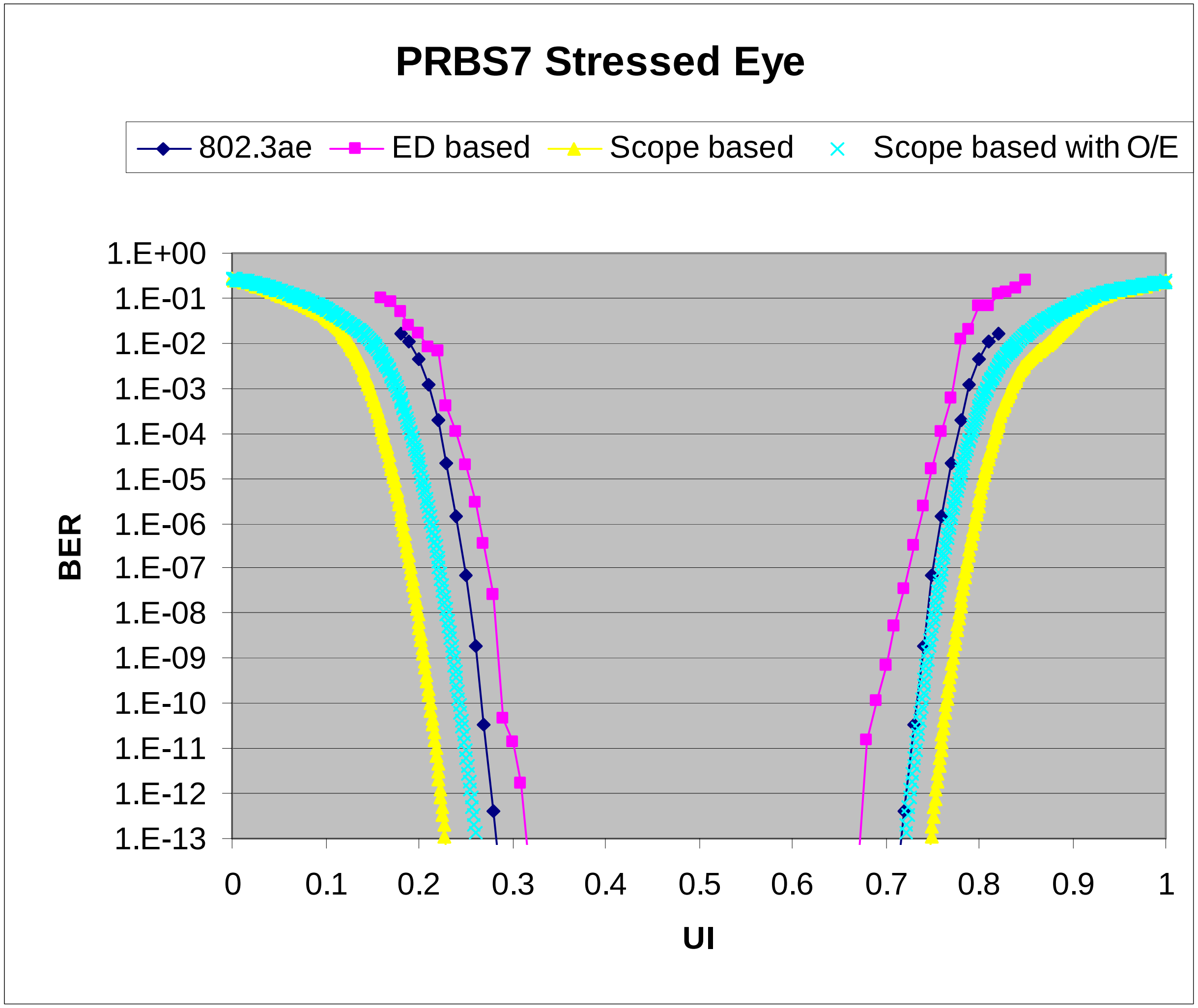
DDJ values based on measurements of the deviation of individual edges from a nominal crossing point. RJ values based on histogram measurements of a single edge.

PRBS7 ED based Bathtub measurement



Vertical Eye Closure penalty = -1.6dB

ED versus Scope-Based bathtub measurements

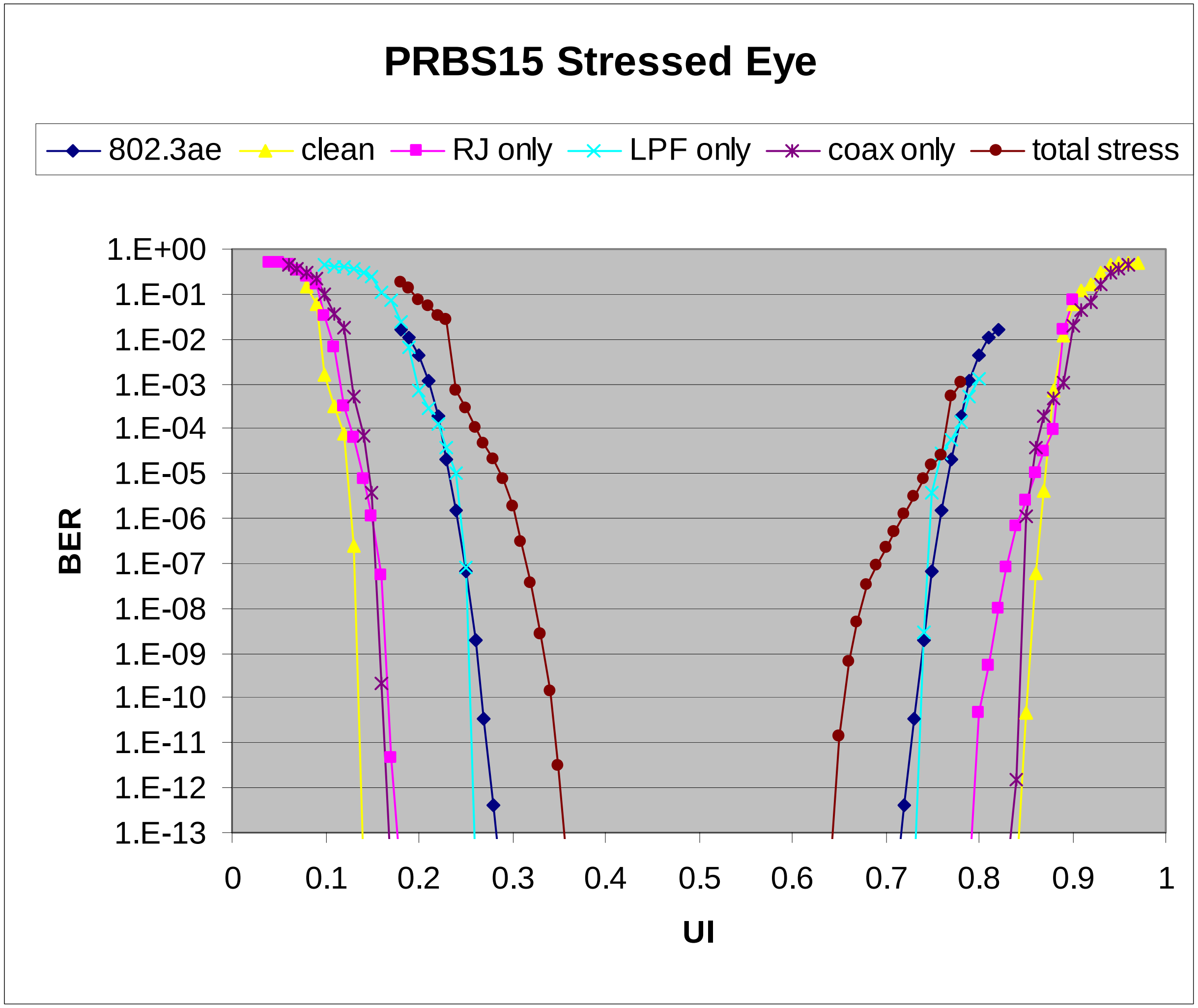


Note: ED measurement made with "golden receiver"

PRBS7 Power Penalty

Optical Attenuation	Un-Stressed BER	Stressed BER (Vert Eye closure penalty = -1.6dB)	Stressed BER (Vert Eye closure penalty = -2.2dB)
-11 dB			$< 10^{-12}$
-12 dB		$< 10^{-12}$	2.7×10^{-11}
-13 dB	$< 10^{-12}$	3.1×10^{-11}	1.8×10^{-9}
-14 dB	2.0×10^{-11}	1.8×10^{-8}	2.2×10^{-7}
-15 dB	7.9×10^{-8}	3.8×10^{-6}	1.8×10^{-5}
-16 dB	1.5×10^{-5}	1.8×10^{-4}	

ED based bathtub measurement with PRBS15



PRBS15 Power Penalty

Optical Attenuation	Un-Stressed BER	Stressed BER (Vert Eye closure penalty = -2.75dB)
-11 dB		$< 10^{-12}$
-12 dB		3.6×10^{-10}
-13 dB	$< 10^{-12}$	7.1×10^{-8}
-14 dB	1.7×10^{-10}	3.7×10^{-6}
-15 dB	1.6×10^{-7}	6.2×10^{-5}
-16 dB	1.8×10^{-5}	

Some caveats

- We only have access to “instrumentation” grade receivers and transmitters
- Need to verify bathtub curves on “real” 10 GbEn transmitter components
- Need to verify stressed eye performance on “real” 10 GbEn receiver components