Advanced Jitter Analysis with Real-Time Oscilloscopes

Sep 26, 2016

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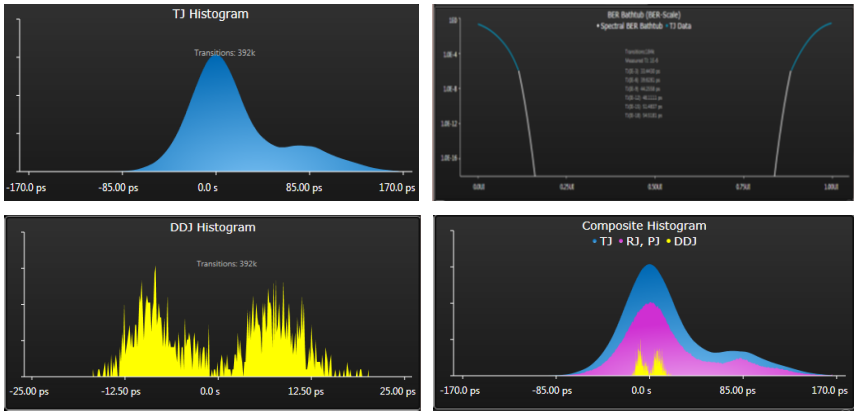
Senior Project Manager



KEYSIGHT TECHNOLOGIES

Agenda

- Review of Jitter Decomposition
- Assumptions and Limitations
- Spectral vs. Tail Fit Method
- Advanced Jitter Analysis with Crosstalk Removal Tool
- Scope Random Jitter Removal from Jitter Analysis
- Other Tools to Consider for Jitter Analysis
- Summary

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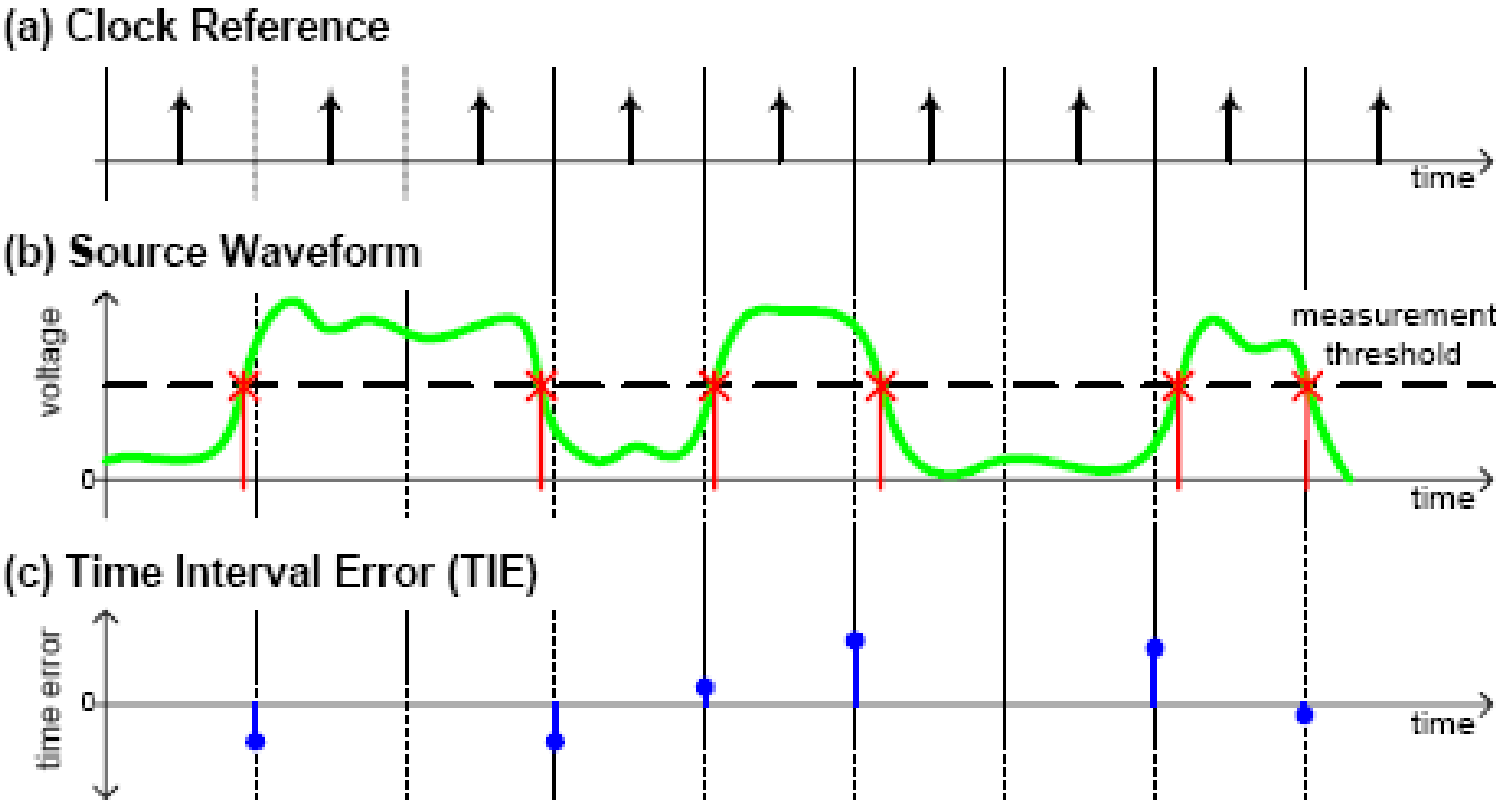
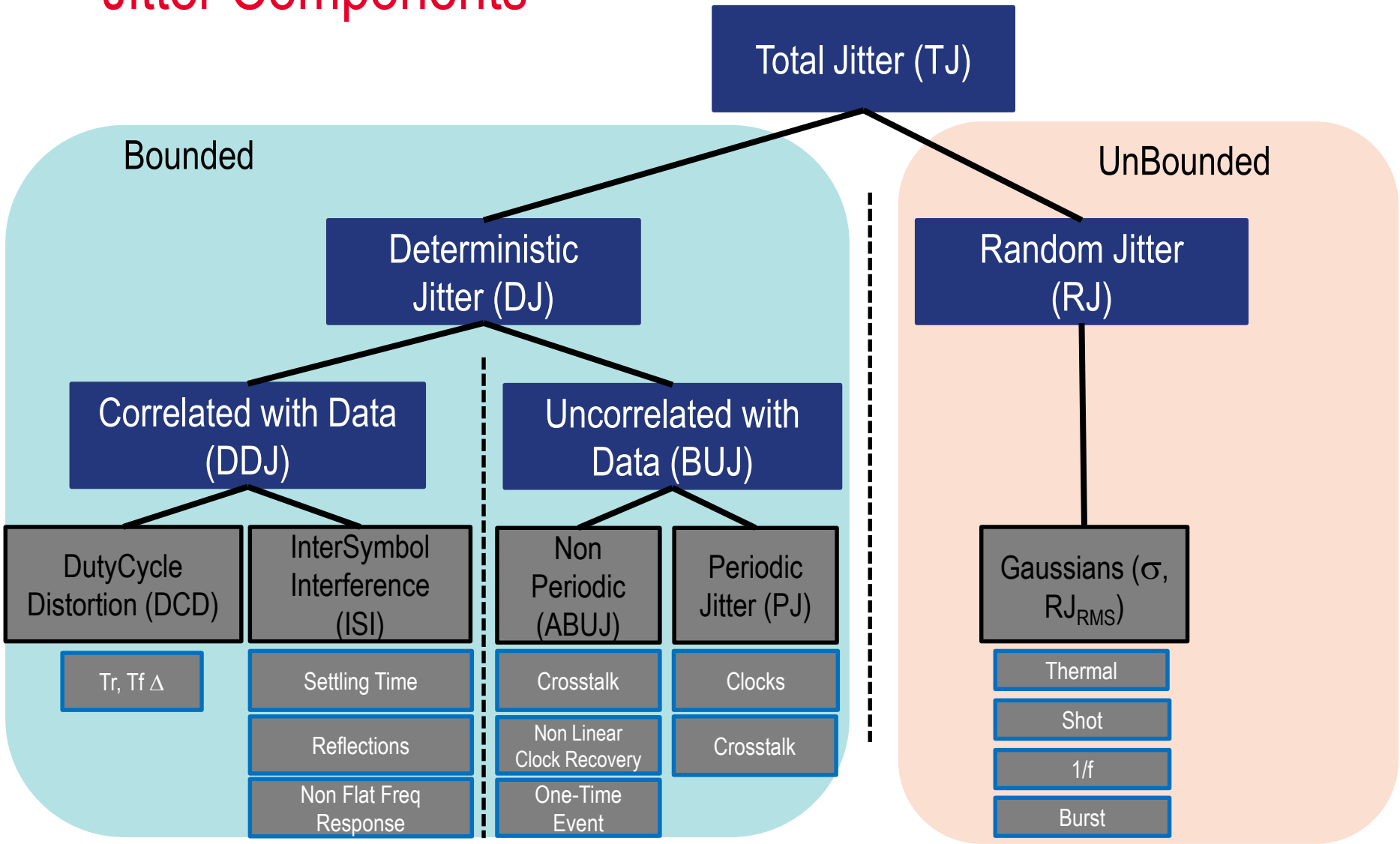
Jitter and Time Interval Error (TIE)



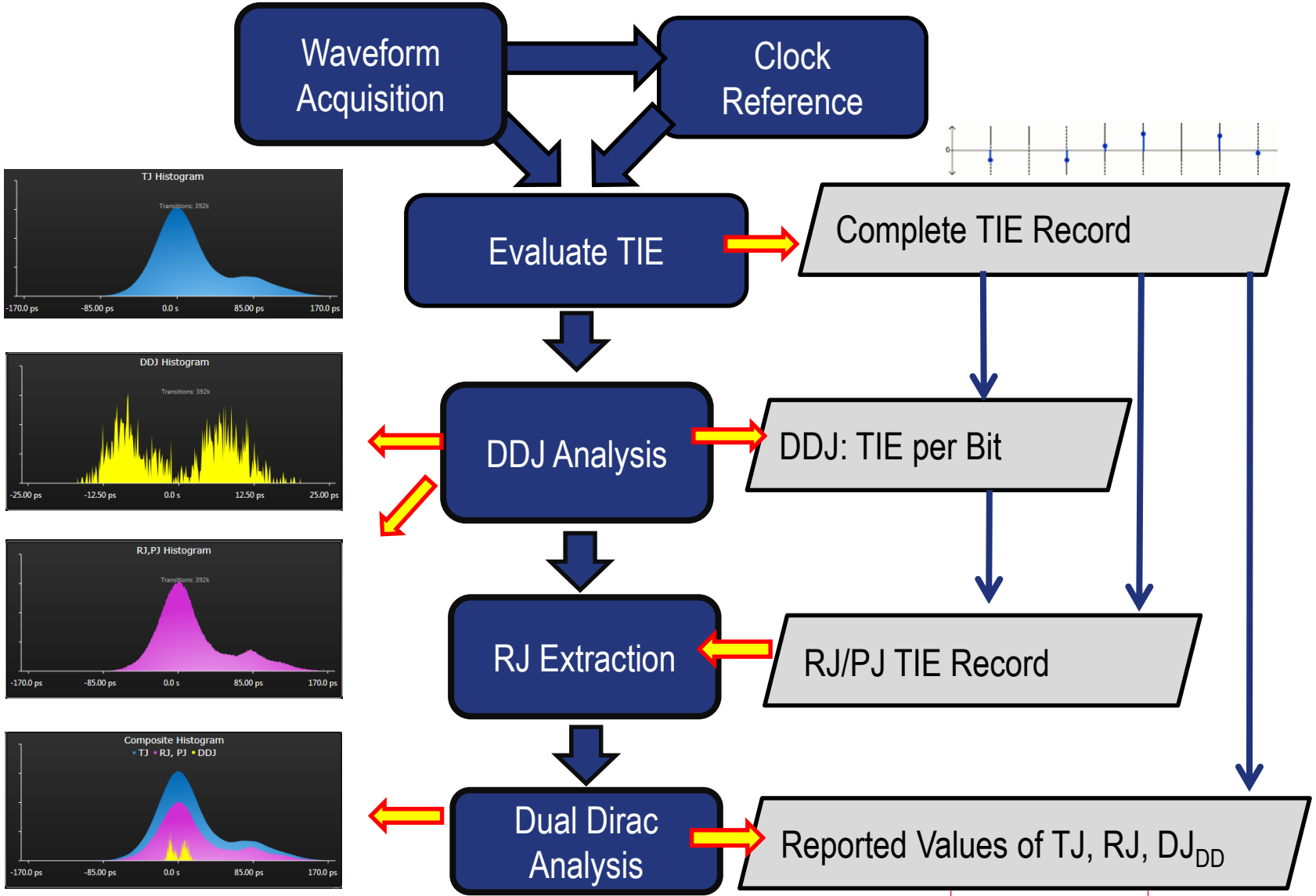
On an oscilloscope we monitor the waveform transitions and note the jitter at each transition point. This is called the Time Interval Error (TIE) record.

Jitter Components



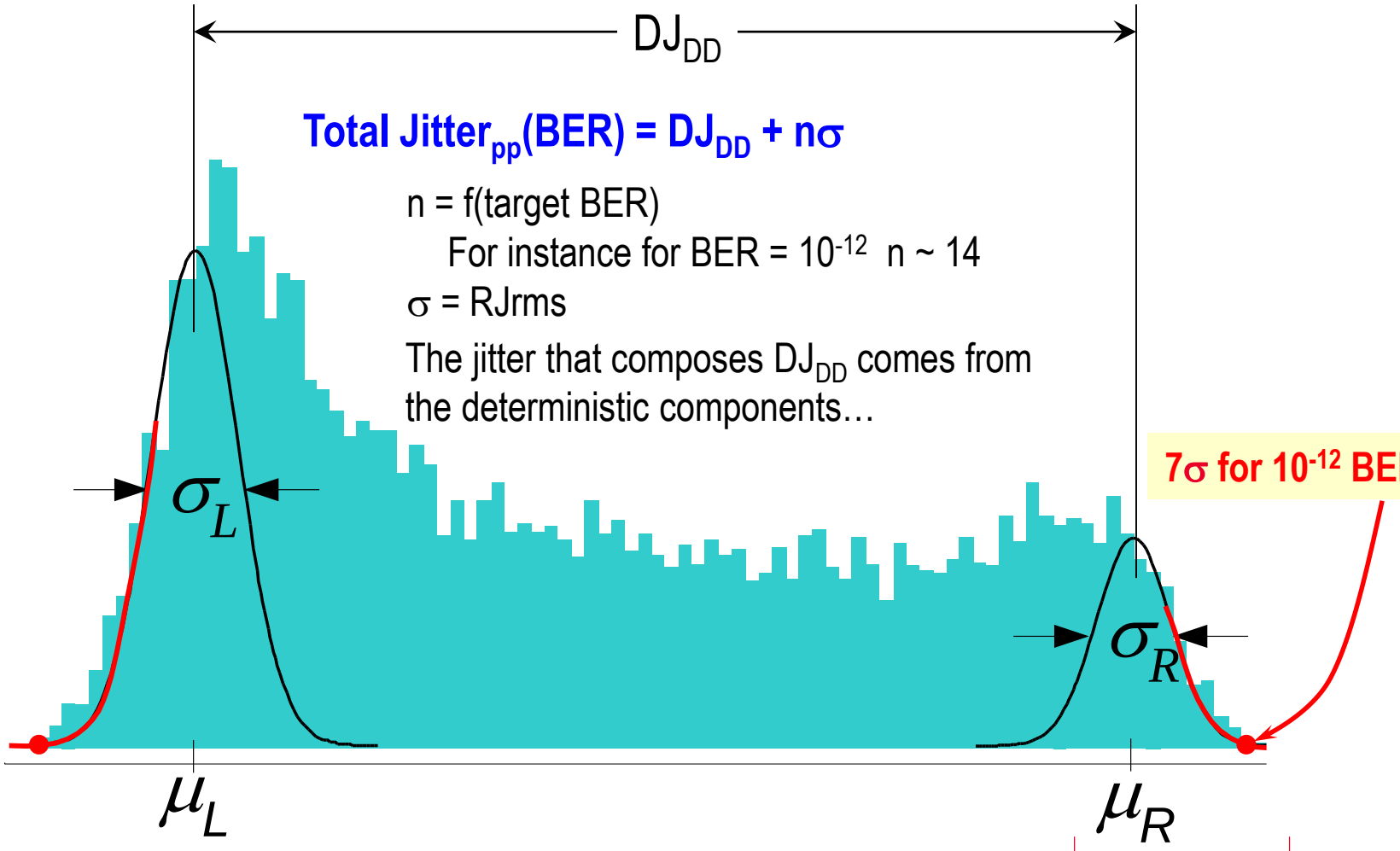
Acronyms:
DDJ: Data Dependent Jitter
BUJ: Bounded Uncorrelated Jitter
ABUJ: Aperiodic Bounded Uncorrected Jitter

Jitter Decomposition Overview



Jitter Decomposition with Dual Dirac Assumption

Fit the RJ Gaussian curve to both tails of the TIE histogram or Jitter Probability Density Function (PDF)



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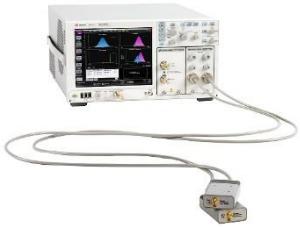
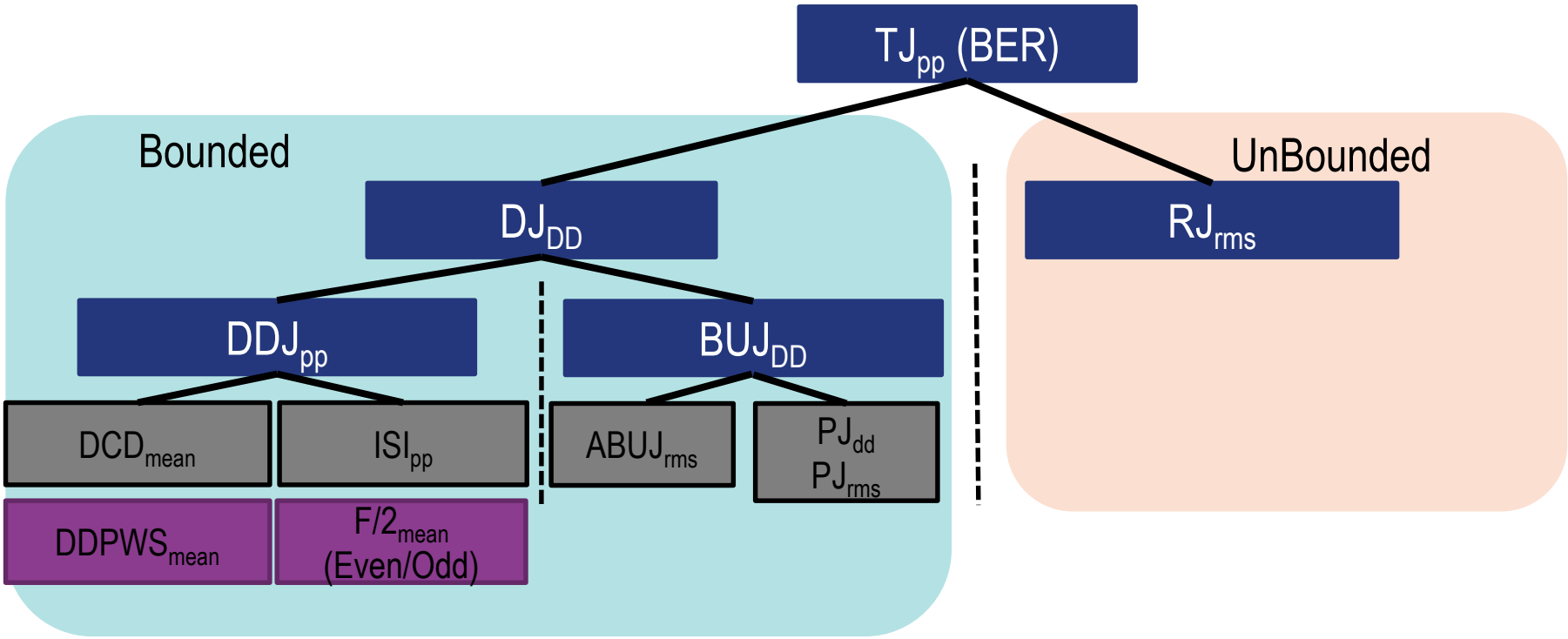
Instruments for Jitter Analysis



Descriptions	Real-Time Scope	Sampling Scope	Bit Error Ratio Tester (BERT)
Measurement	Estimates jitter	Estimates jitter	Measures jitter
Analysis mode	Based on Dual-Dirac Model	Based on Dual-Dirac Model	Accumulate and compare 3 times the BER level bits for 95% confidence level E.g. $3x10^{12}$ bits are received without error to meet the 10^{-12} BER target
Clock reference	Software clock recovery and accepts explicit clock	Hardware clock recovery	Hardware clock recovery
Speed	Fast (Seconds)	Fast (Seconds)	Slow (Minutes or Hours) - depends on time to accumulate the bits
Report jitter components	Yes	Yes	No

Jitter Components Reported by Scope and the Caveats



Caveats of jitter decomposition:

1. Jitter decomposition does not follow a linear bottom-up flow.
2. Algorithm is based on Dual-Dirac model and is an approximation, not the exact value.
3. Each jitter component may have a different unit value (rms, dual-dirac (dd), peak-to-peak (pp), mean, etc.)
4. Not every component has a result. Some are convolved with other components and not separable.
   - E.g. DJ_{pp}, PJ_{pp}, $ABUJ_{dd}$ and $ABUJ_{pp}$ (crosstalk) are not separable and reported.
5. Other jitter components can be calculated separately from the jitter decomposition algorithm (in purple).

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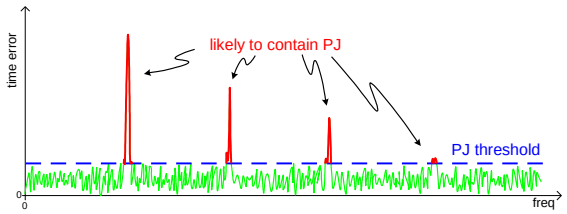
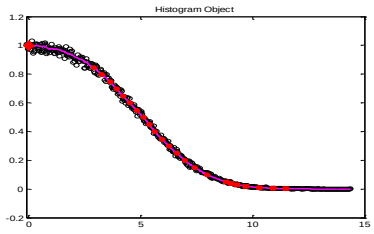
Spectral vs. Tail Fit Jitter Decomposition

Random Jitter (RJ) Extraction Methods

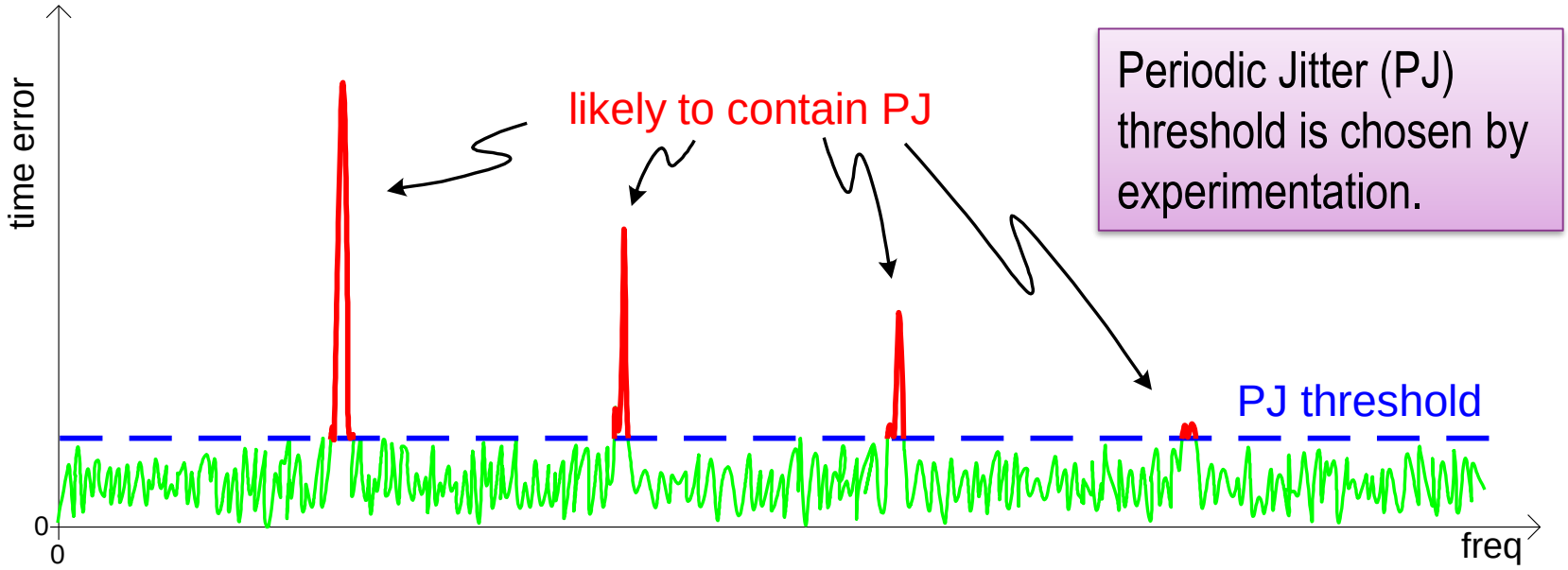
RJ Extraction Methods	Rationale
Spectral	• Speed/Consistency to Past Measurements • Accuracy in low Crosstalk or Aperiodic Bounded Uncorrelated Jitter (ABUJ) conditions
Tail Fit	• General Purpose • Accuracy in high Crosstalk or ABUJ conditions





Spectral Method – PJ Threshold

Measurement Details

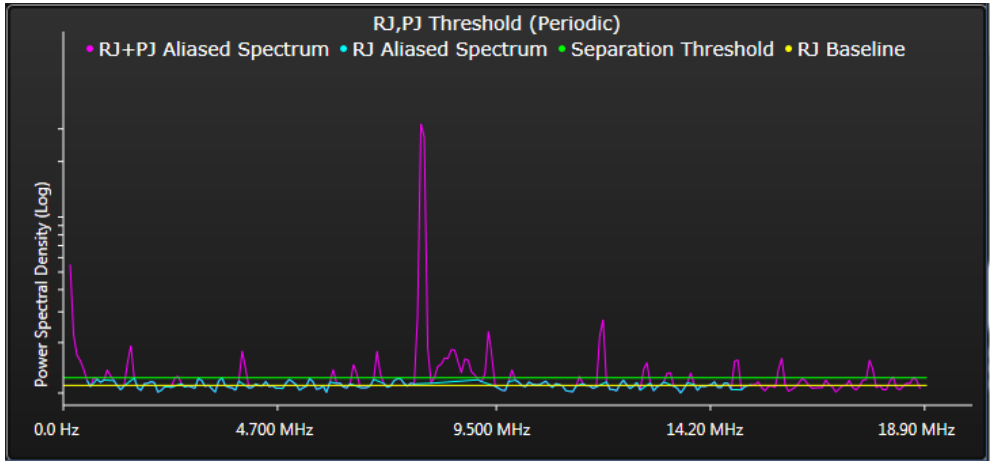


Periodic Jitter (PJ) threshold is chosen by experimentation.

Integrate PSD to derive RJ_{RMS}
Sum the PJ components for PJ_{RMS}

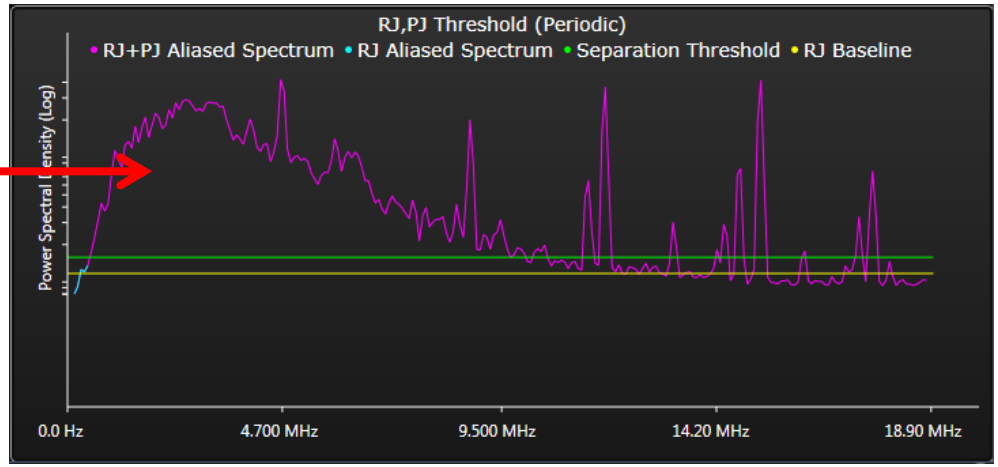
Spectral Method – PJ Threshold

Handling of Different RJ, PJ Spectral Content



Separation occurs as described…

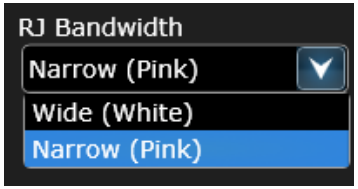
Is it RJ or PJ?



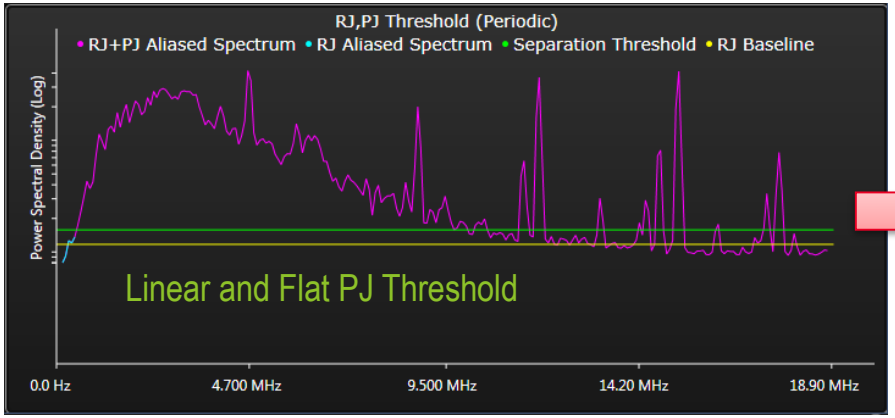
What do you do in this case?

Spectral Method – PJ Threshold

Non-linear Period Jitter (PJ) threshold can help

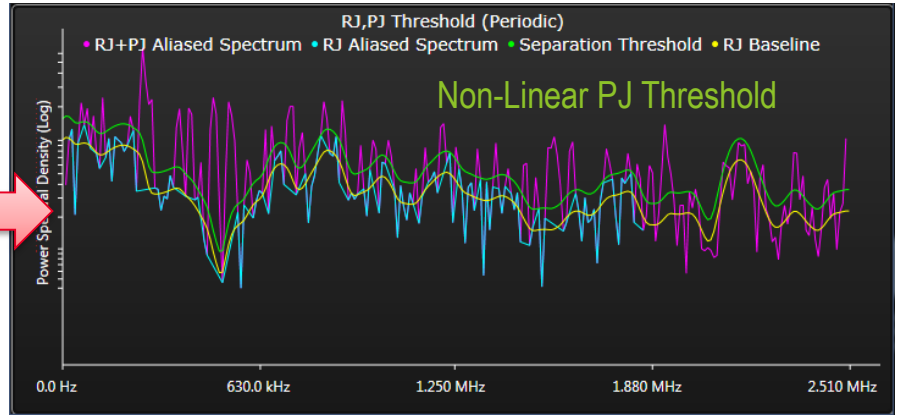


Wide RJ Bandwidth Analysis



RJ_{RMS} = 1.06ps
PJ_{DD} = 93.17ps

Narrow RJ Bandwidth Analysis

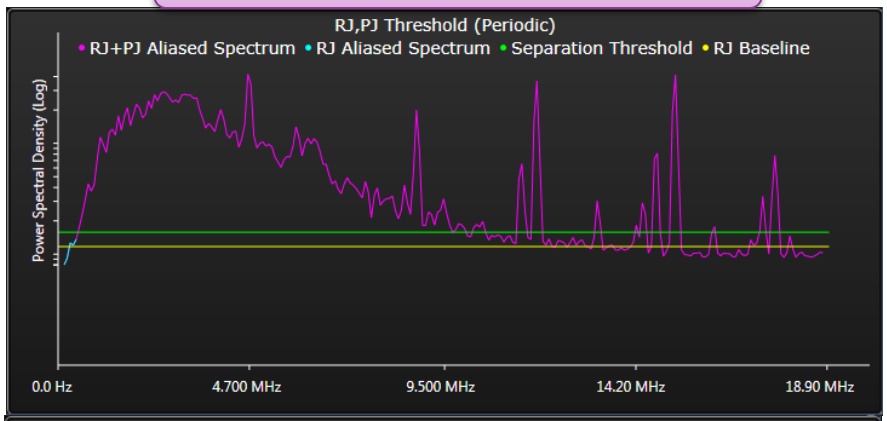


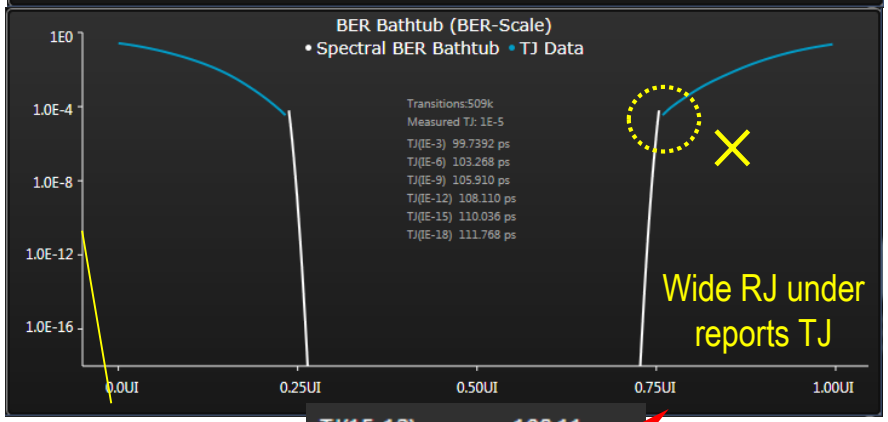
RJ_{RMS} = 9.66ps
PJ_{DD} = 27.18ps

Which PJ Threshold or RJ bandwidth analysis do you choose?

Spectral Method – Wide vs. Narrow

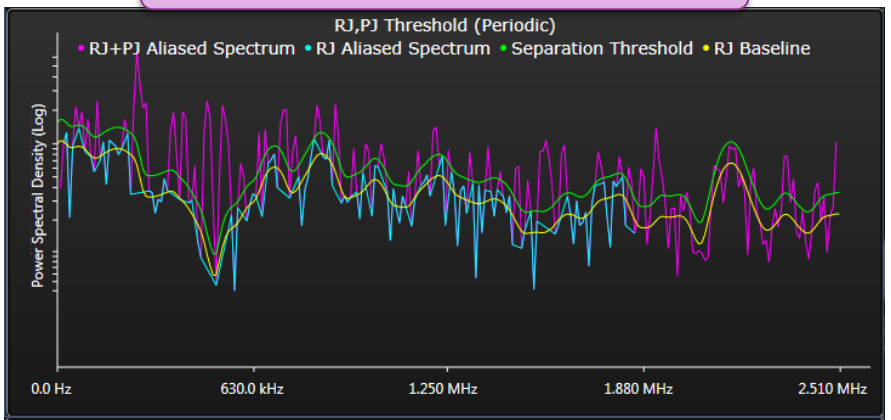
Wide RJ Bandwidth

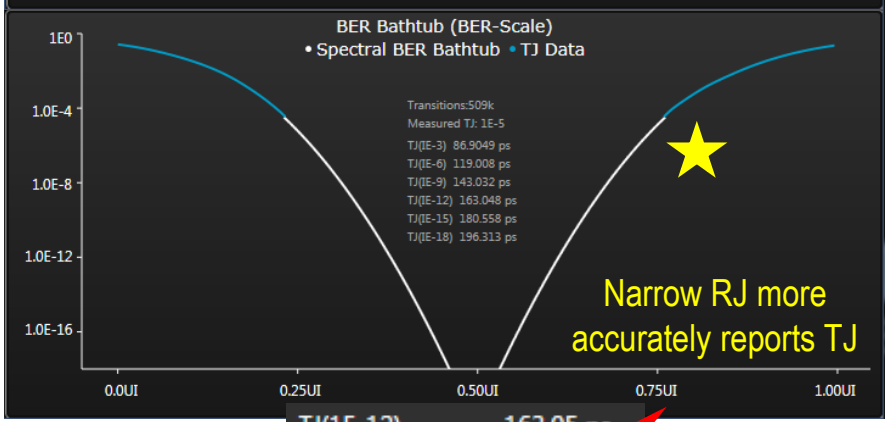




TJ(1E-12)	108.11 ps
RJrms,wide	1.06 ps
DJδδ	93.17 ps

Narrow RJ Bandwidth



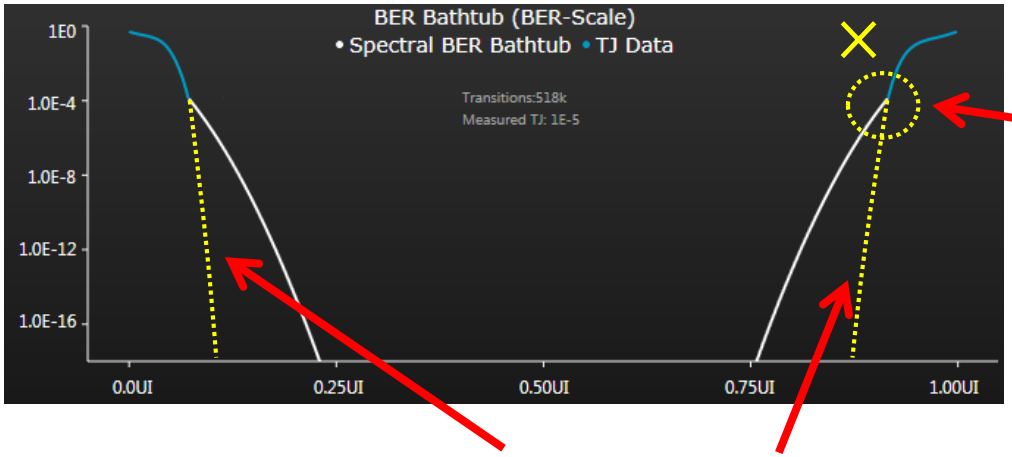


TJ(1E-12)	163.05 ps
RJrms,narrow	9.66 ps
DJδδ	27.18 ps

Smoothness of slope continuity between measured and extrapolated result on the bathtub plot indicates the better PJ threshold (RJ bandwidth) method.

Spectral Method with Presence of Crosstalk or ABUJ

(ABUJ = Aperiodic Bounded Uncorrelated Jitter)



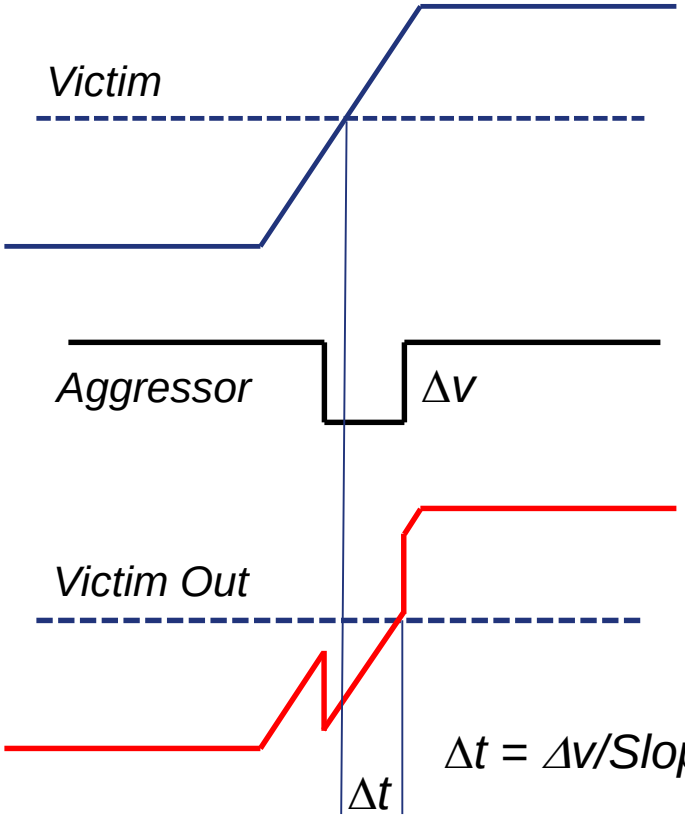
Something is wrong here...

Using the slope continuity concept we expect the extrapolated curve to look like this.

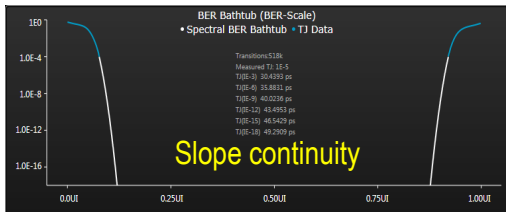
The RJ/PJ spectral extraction does not deal with Crosstalk or ABUJ well. The RJ is overestimated severely.

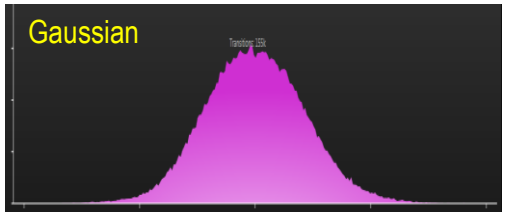
ABUJ: Crosstalk or Ground Bounce

Amplitude interference uncorrelated with data and not periodic in nature.

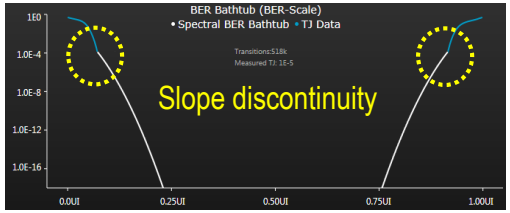


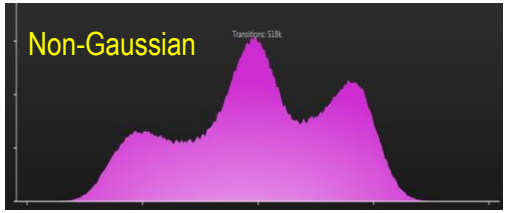
$$\Delta t = \Delta v / Slope_{victim}$$





No crosstalk
Bathtub and RJ,PJ Histogram

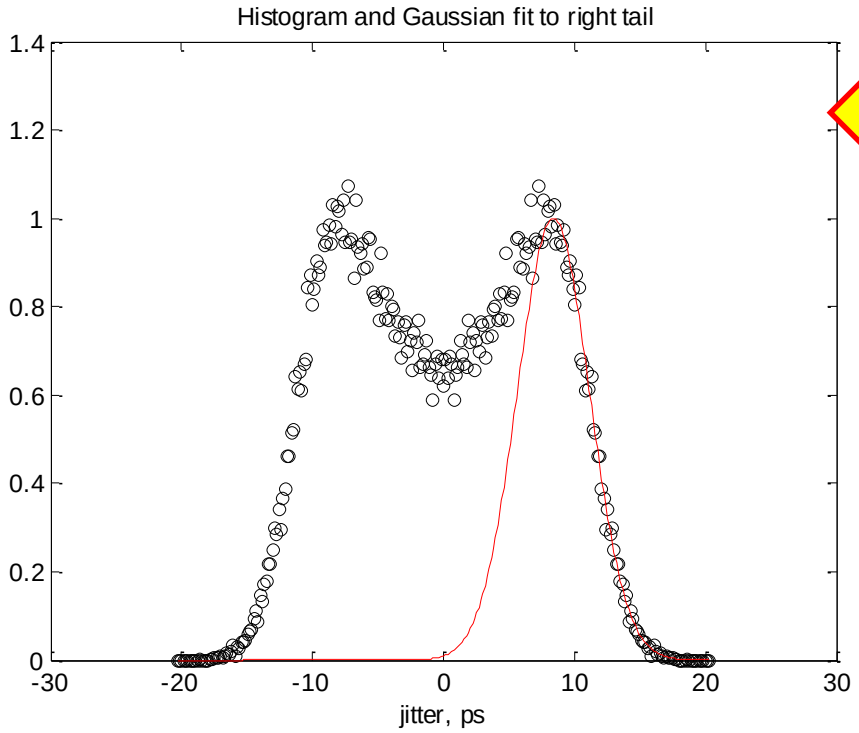




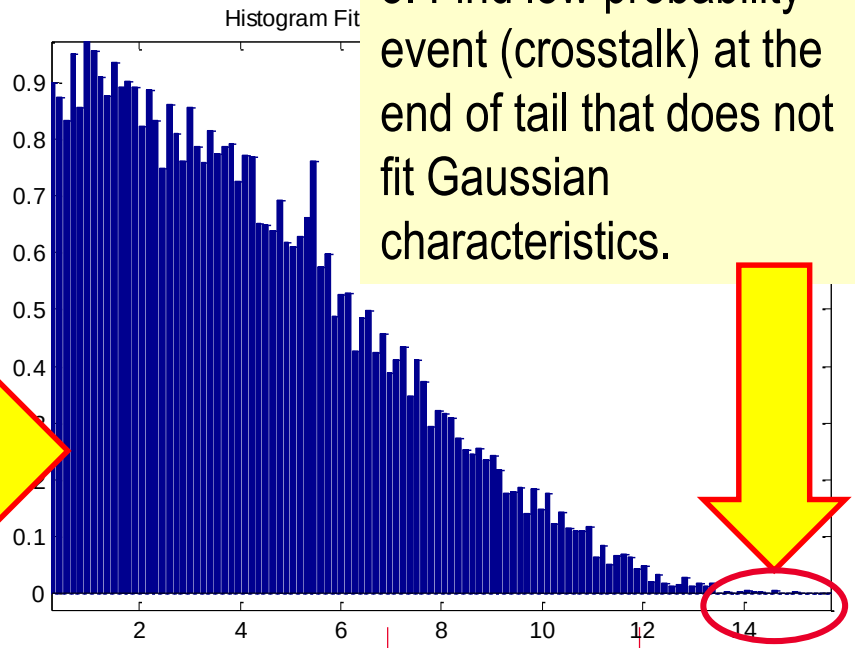
With crosstalk
Bathtub and RJ,PJ Histogram

Tail Fit Method – Gaussian Extraction

Measurement Detail



1. Fit a Gaussian characteristic to the right and left extremes of the RJ/PJ histogram distribution.

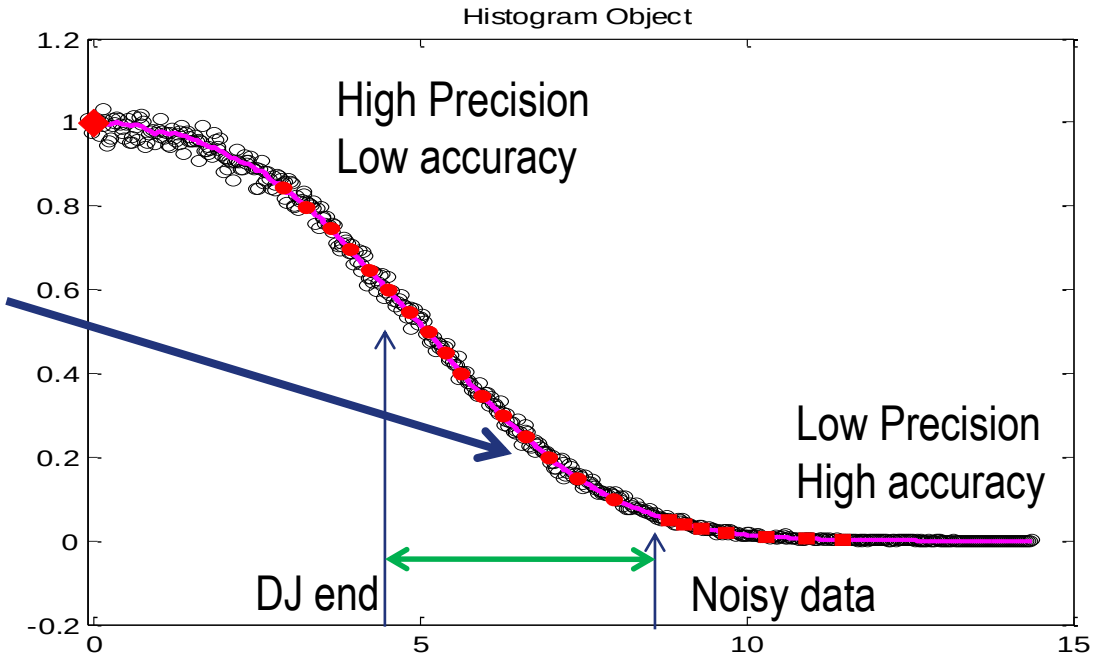


3. Find low probability event (crosstalk) at the end of tail that does not fit Gaussian characteristics.

2. Actual data is never smooth

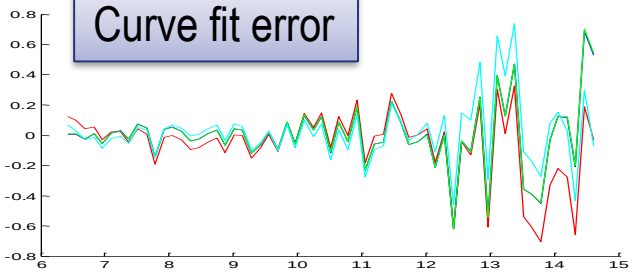
What Makes Tail Fit Hard

Measurement Detail



Fit Window

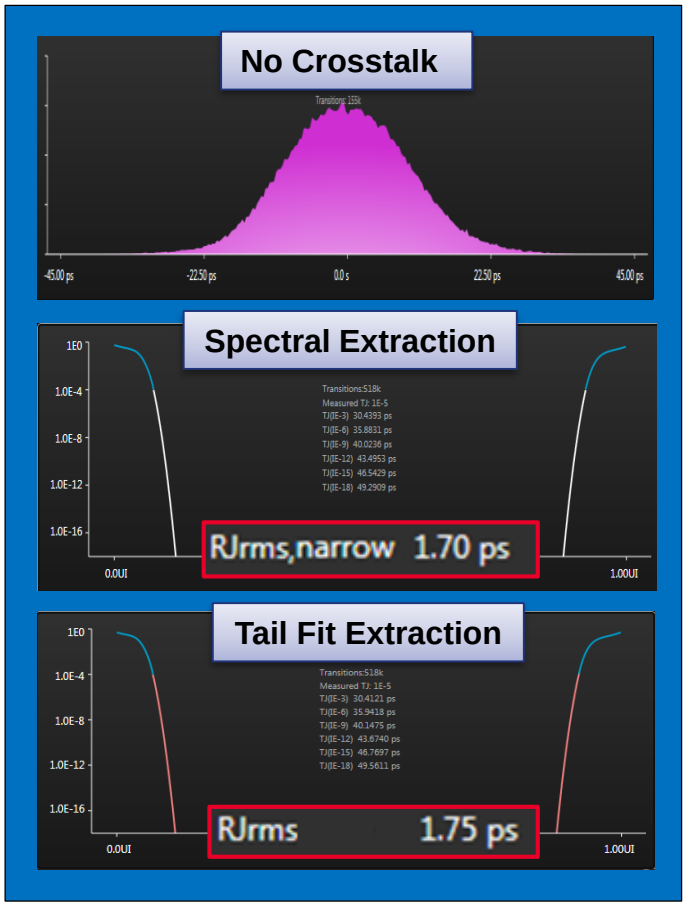
Curve fit error

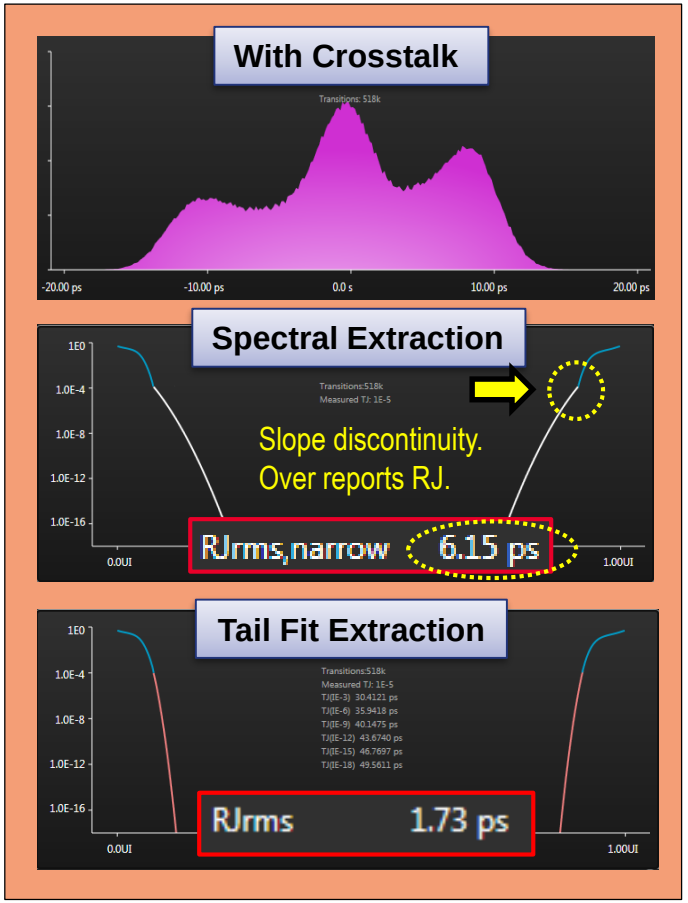


Hard to detect Crosstalk events out in the tail. Might take longer time for Tail Fit results to converge.

RJ Extraction with Presence of Crosstalk (ABUJ)

Spectral vs. Tail Fit Extraction





Analyze the bathtub plot with both RJ extraction modes to explore the presence of crosstalk or ground bounce.

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Jitter Analysis with Crosstalk Removal Tool

Crosstalk Identification

- Which signals are coupling onto your victim?

Crosstalk Quantification

- How much error and jitter do each aggressor add to your victim?

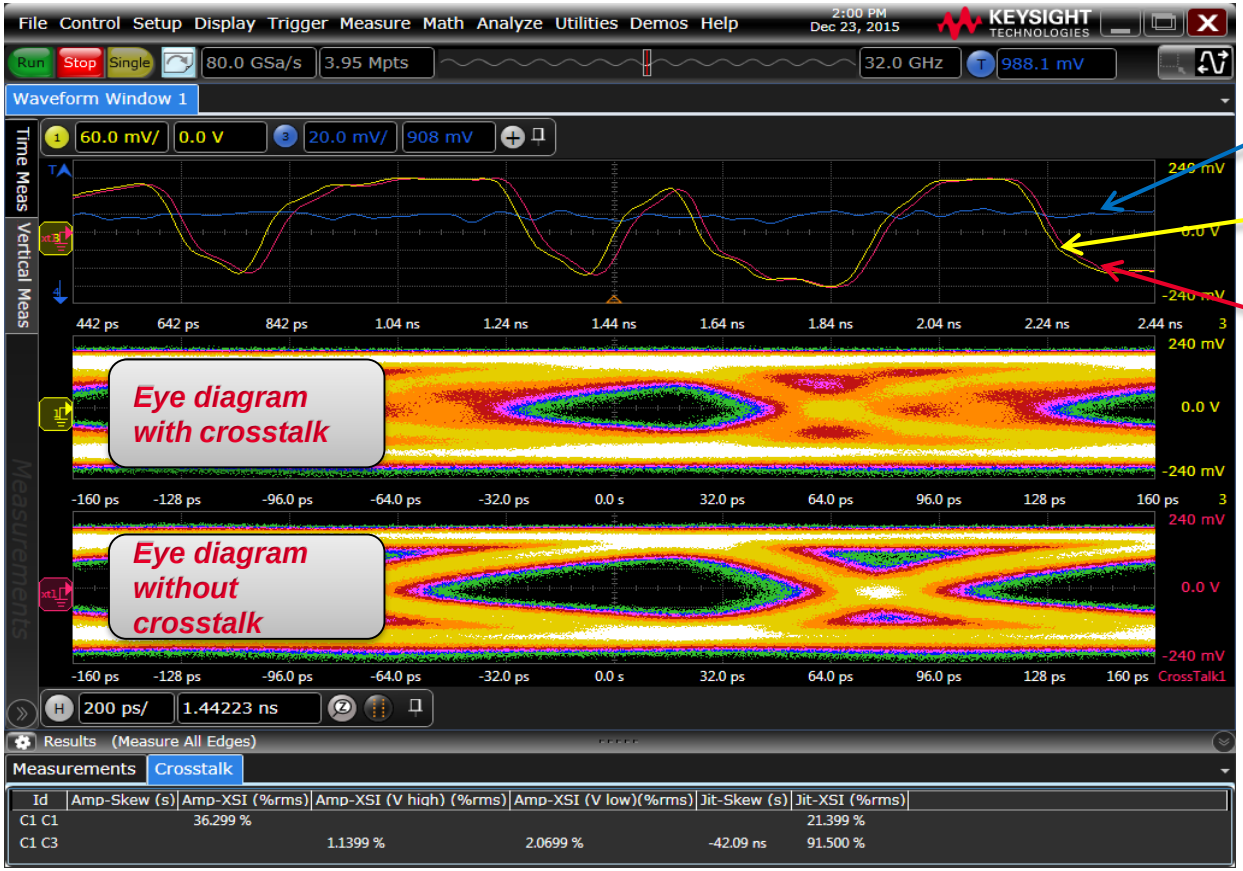
Crosstalk Removal for Jitter Analysis

- What would your signal look without crosstalk present on victim?
- How much jitter margin can be recovered without crosstalk?
- If the signal was failing the jitter spec, can it pass without crosstalk?

Assist in making important design decisions:

- ***Is it worth reducing crosstalk impact in design?***
- ***Where to improve?***

Remove Crosstalk from Victim Signal



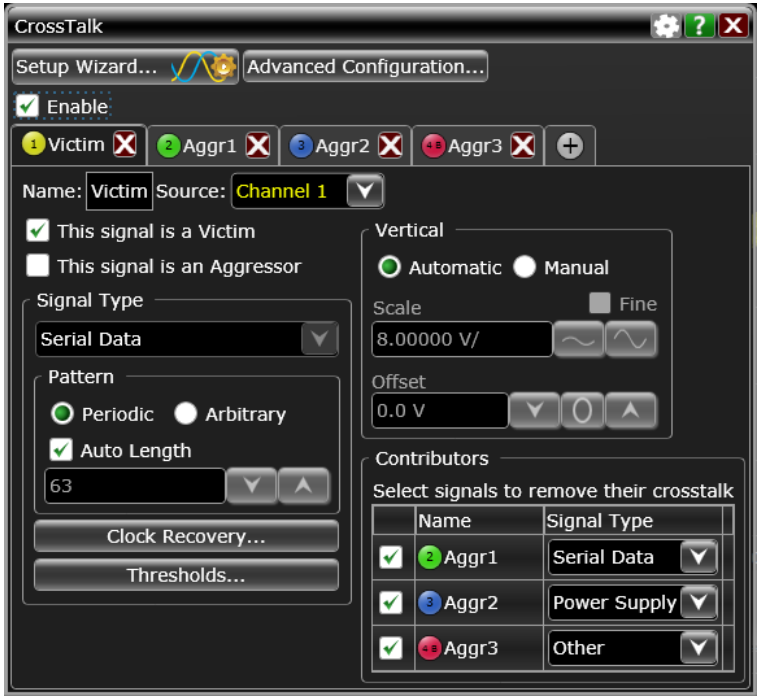
Power supply aggressor signal

Original serial data victim signal

Serial data victim signal with crosstalk removed

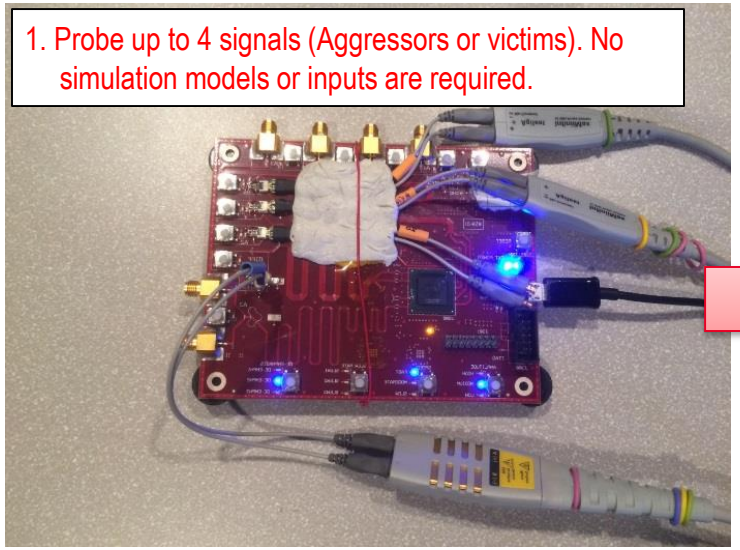
Features of the N8833A Crosstalk Analysis Application

1. Analyze up to four signals (victim or aggressor) at once.
2. Remove Near-End Crosstalk (NEXT), Far-End Crosstalk (FEXT) and Power Supply Crosstalk from Victim signal.
3. Plot waveform without crosstalk on the scope which can be:
   - Used for eye diagram, ***jitter decomposition***, de-embedding, equalization and mask test
   - Saved as a waveform file

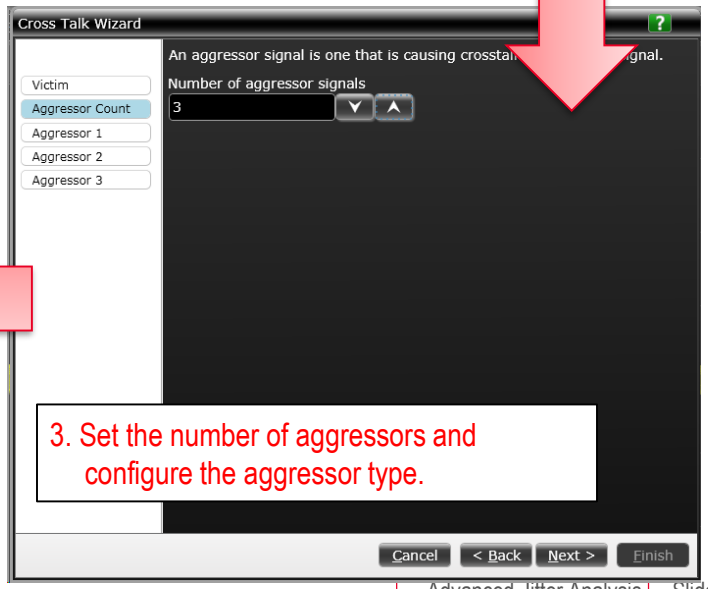


Crosstalk Analysis Setup

1. Probe up to 4 signals (Aggressors or victims). No simulation models or inputs are required.

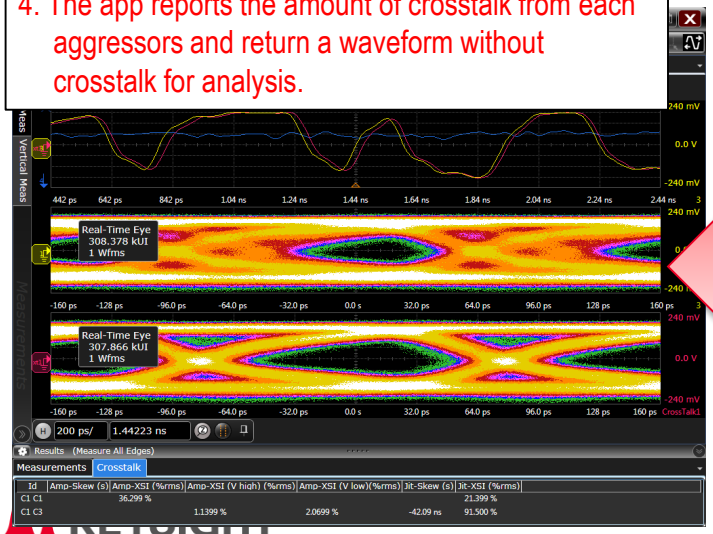


2. Setup the victim signal.



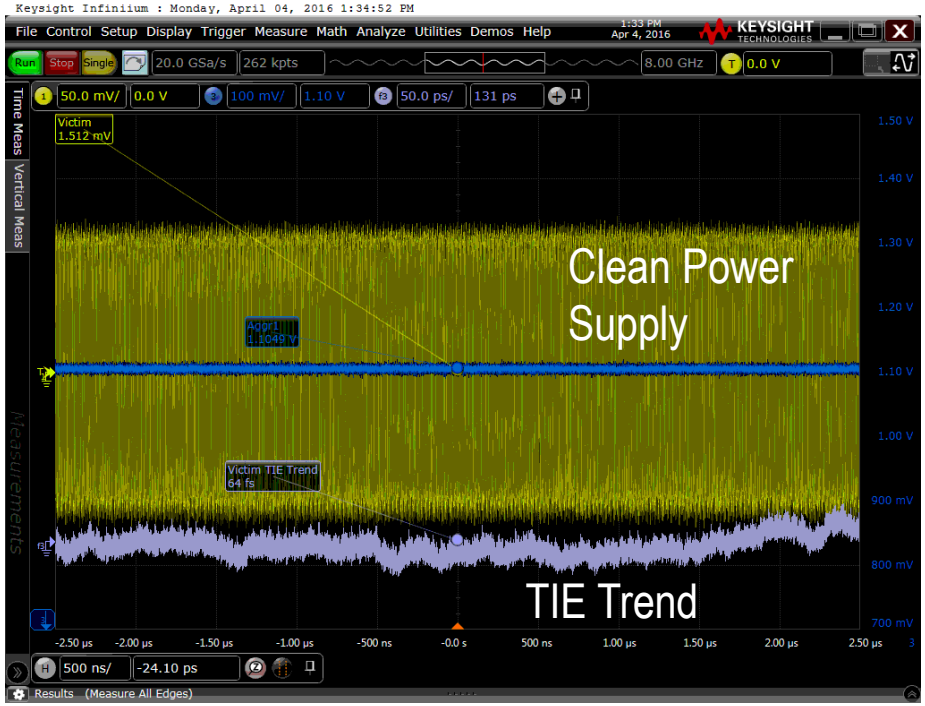
3. Set the number of aggressors and configure the aggressor type.

4. The app reports the amount of crosstalk from each aggressors and return a waveform without crosstalk for analysis.

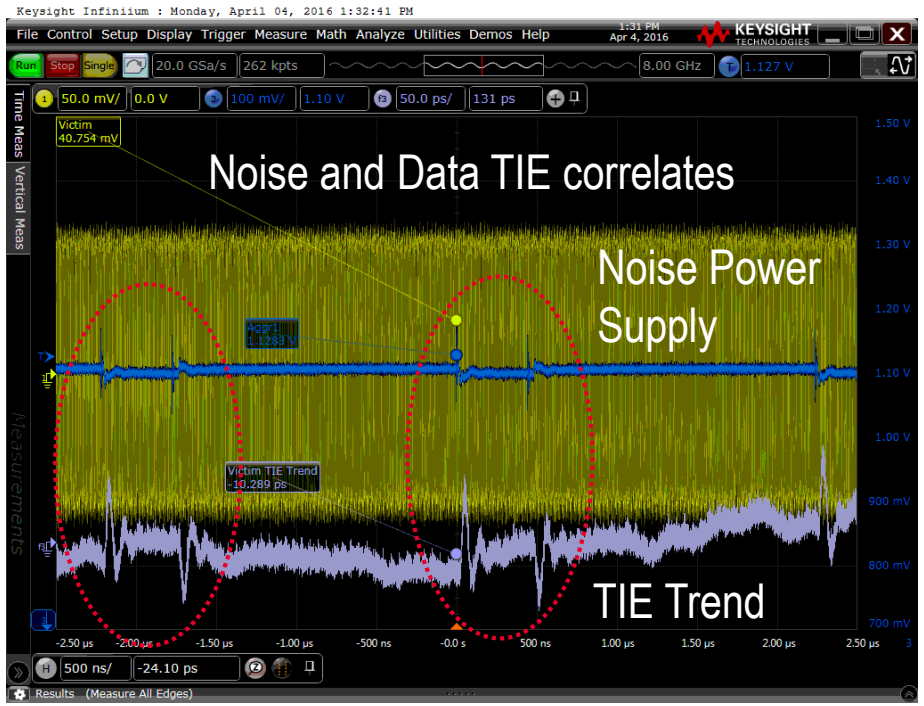


Power Supply Crosstalk on Victim

No Power Supply Aggressor

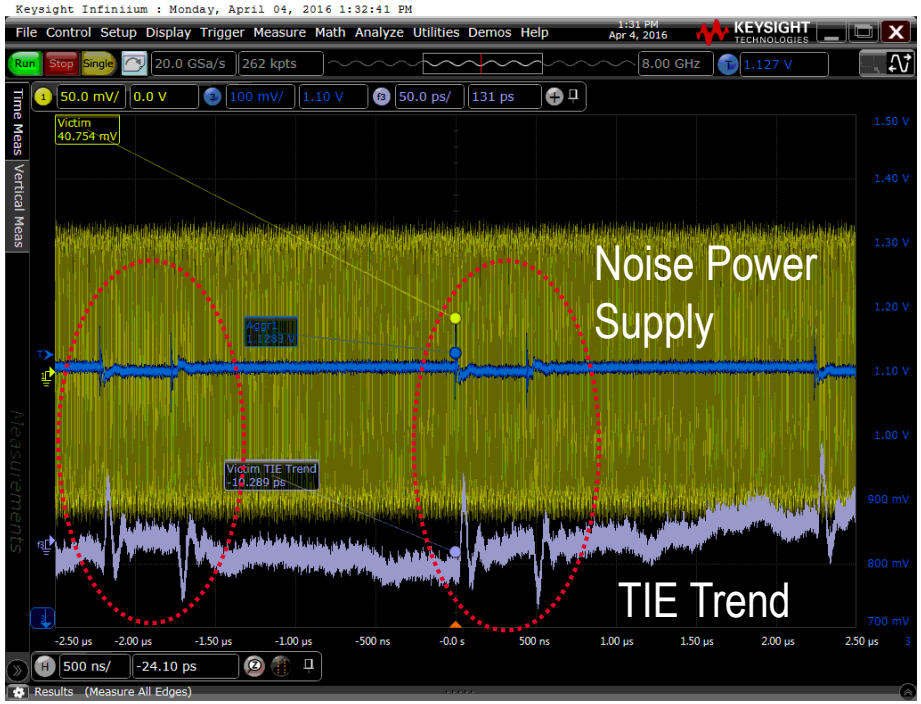


With Power Supply Aggressor on the Transmitter PLL

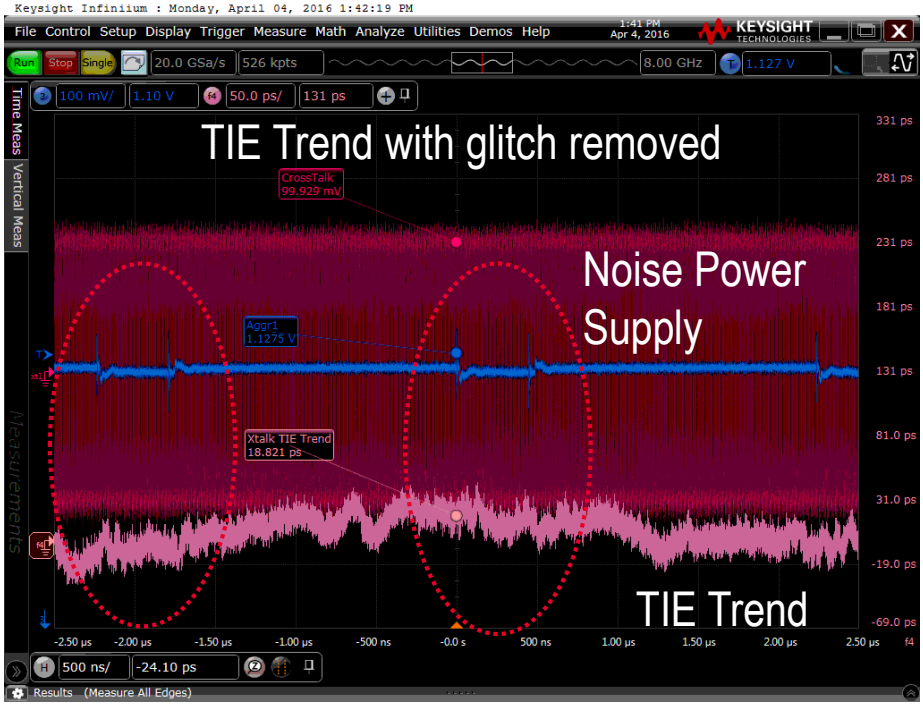


Removing Power Supply Crosstalk from Victim

With Power Supply Crosstalk on the Transmitter PLL

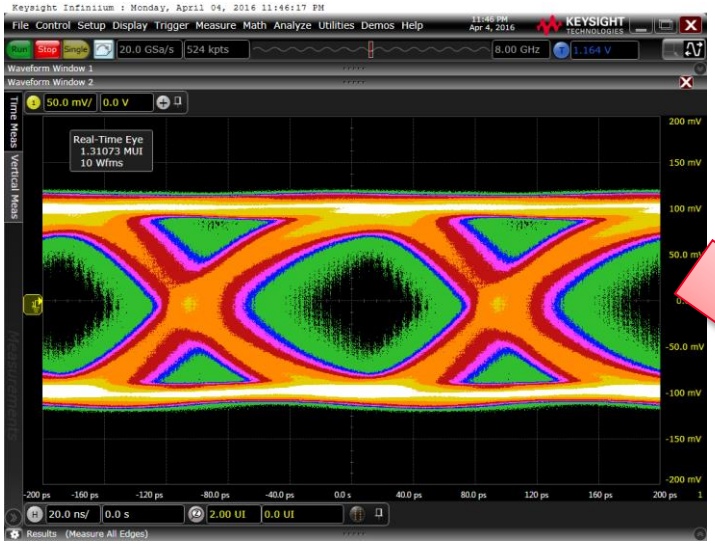


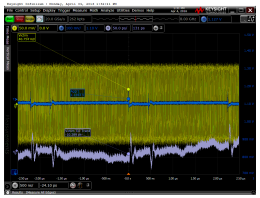
Power Supply Crosstalk Removed with Improvement on Data TIE Trend

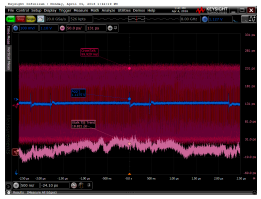


Removing Power Supply Crosstalk from Victim

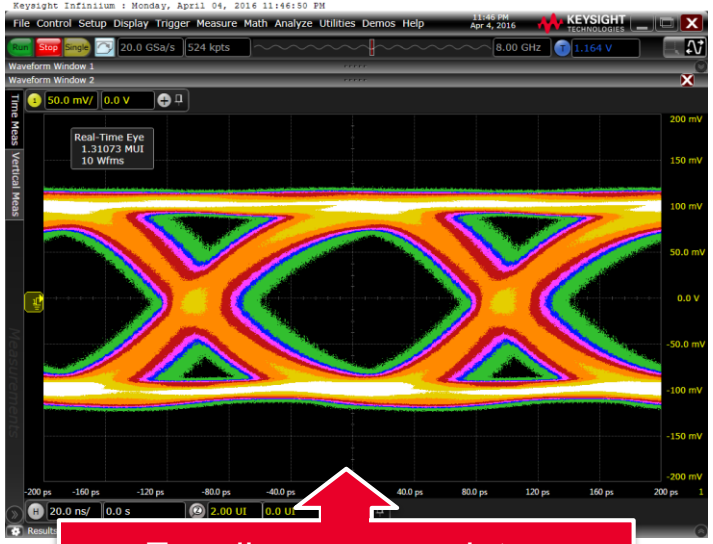
Measured Victim with Power Supply Crosstalk



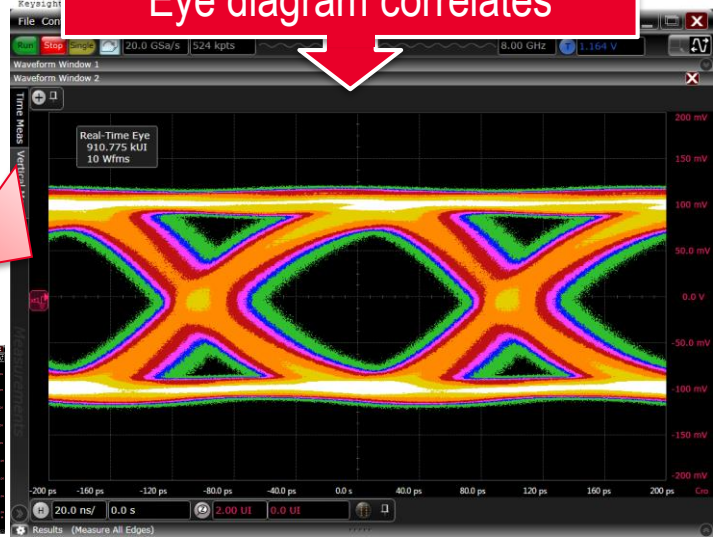




Measured Victim Without Crosstalk



Eye diagram correlates



Victim after Power Supply Crosstalk removed

Jitter Improvement Without Power Supply Crosstalk

Compare jitter results before and after crosstalk removal.

TJ = 158ps
PJdd = 58ps
DJdd = 68ps

An Improvement of 20% to Total Jitter without Crosstalk.

TJ = 124ps
PJdd = 27ps
DJdd = 33ps

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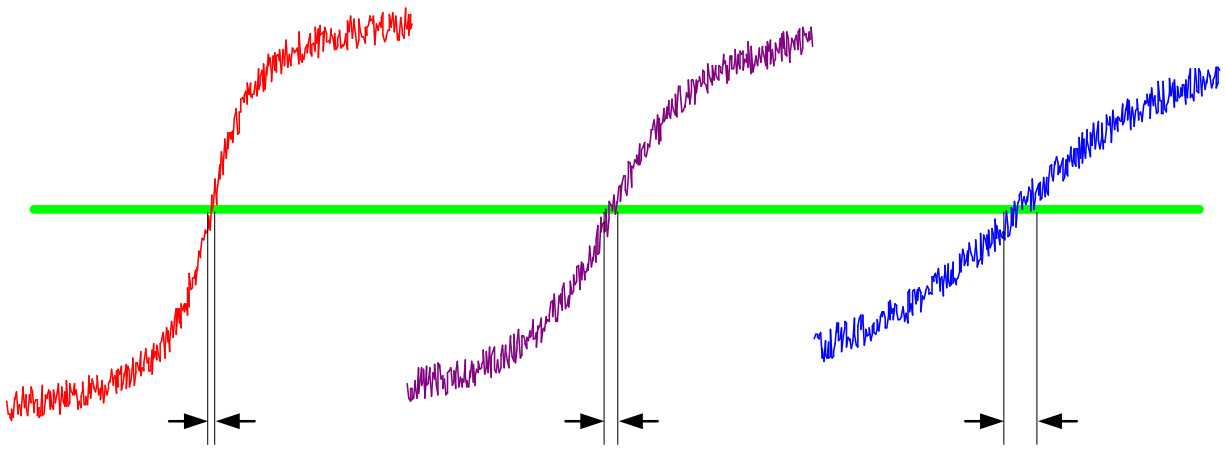
- Summary

Influence of Scope Noise to Jitter Performance

Random jitter will vary with slew rates.



TIE:

$$\sqrt{\left(\frac{Noise}{SlewRate}\right)^2 + SampleClockJitter^2} \quad \text{sec rms}$$

Periodic Jitter:

$$\sqrt{2}\cdot\sqrt{\left(\frac{Noise}{SlewRate}\right)^2 + SampleClockJitter^2} \quad \text{sec rms}$$

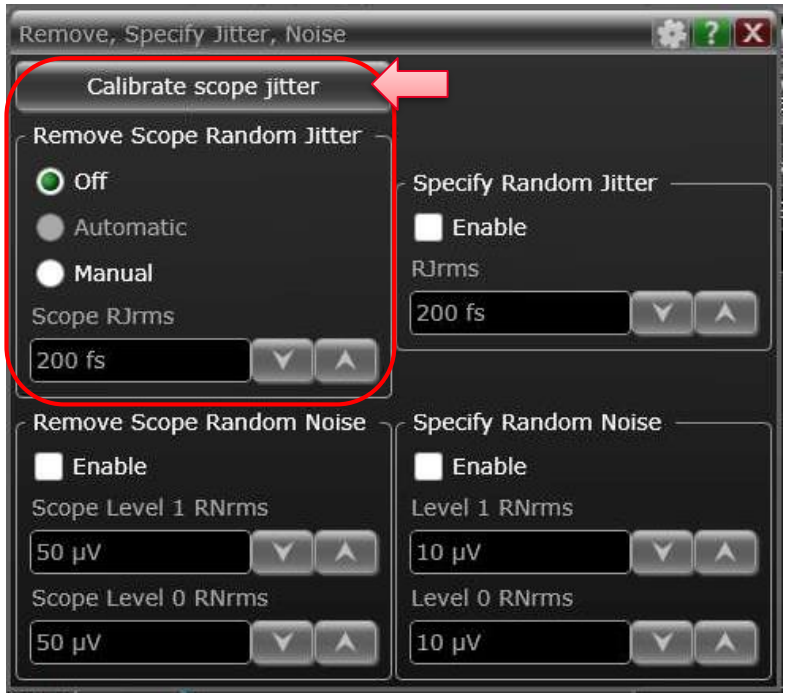
Cycle-Cycle:

$$\sqrt{3}\cdot\sqrt{\left(\frac{Noise}{SlewRate}\right)^2 + SampleClockJitter^2} \quad \text{sec rms}$$

1. Every scope has intrinsic vertical noise floor. This vertical noise can translate into horizontal jitter.
2. As signal slew rate decreases, vertical noise increases the random jitter.
3. Measured random jitter is a function of signal slew rate, scope noise and scope sample clock jitter.

Scope Random Jitter Removal

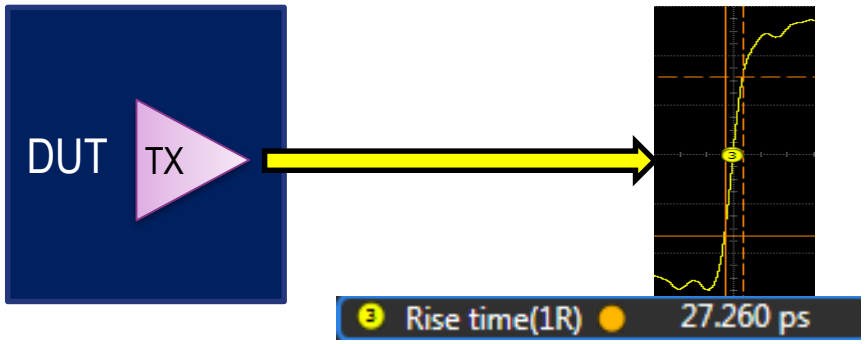
Calibrate and remove scope random jitter contribution



- Scope RJ calibration is available to remove the contribution of scope noise to measured RJ.
- User is asked to disconnect the signal from Channel to measure the ACV_{rms} noise for the current Vertical setting.

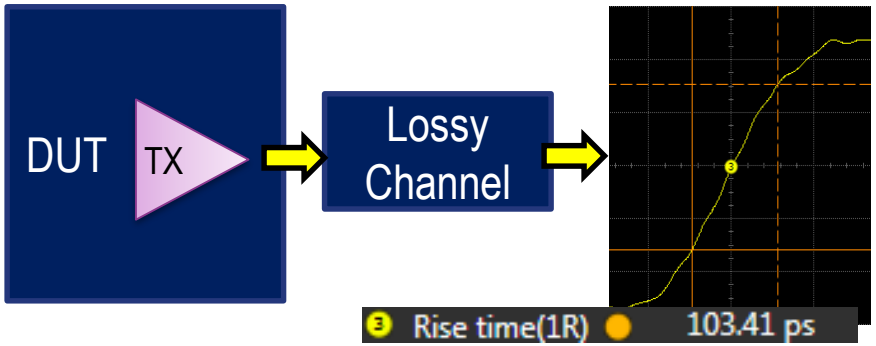
Other Jitter Measurement Considerations

Gain Margin by removal of Scope contribution to RJ



Signal with Fast Rise Time

TJ(1E-12)	7.115 ps
RJrms,narrow	347 fs
DJδδ	2.236 ps



With no Scope RJ removal

TJ(1E-12)	26.96 ps
RJrms,narrow	1.28 ps
DJδδ	8.99 ps

After Scope RJ removal

TJ(1E-12)	14.43 ps
RJrms,narrow	340 fs
DJδδ	9.70 ps

Gain margin through scope RJ removal.

Agenda

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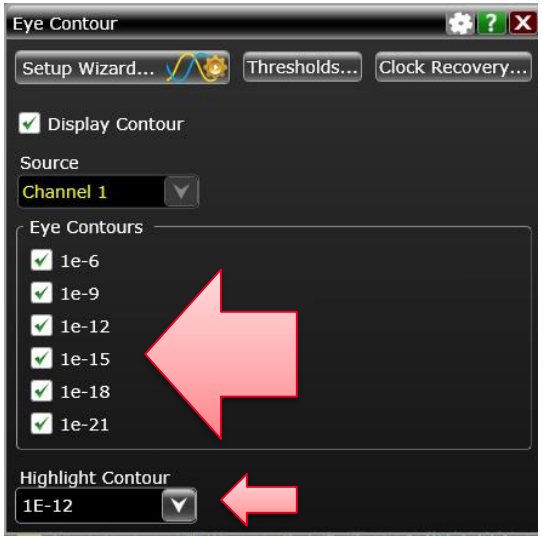
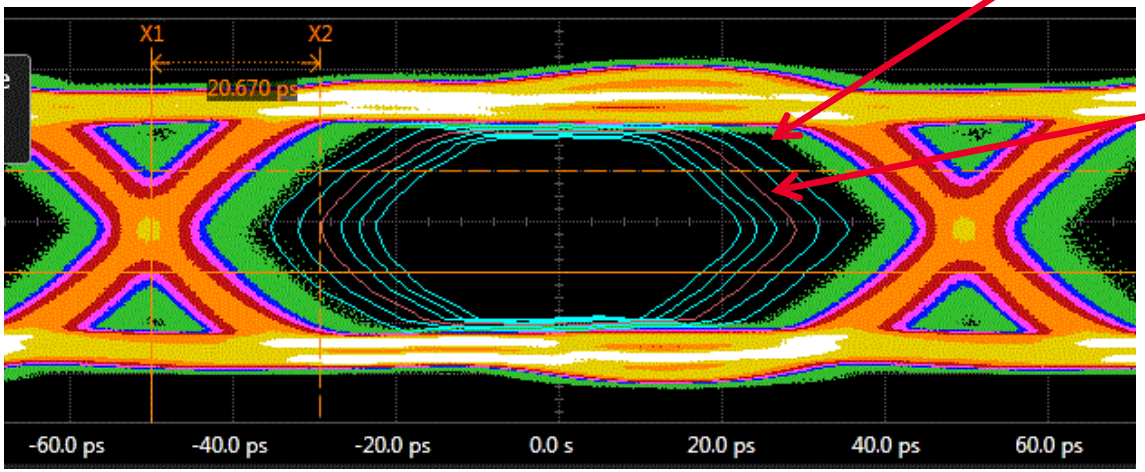
Jitter Analysis with BER Eye Contour

Estimate Jitter and Eye Opening to various BER level



- Specify the BER eye contours you want the scope to plot.
- Specify which BER contour to highlight in red.

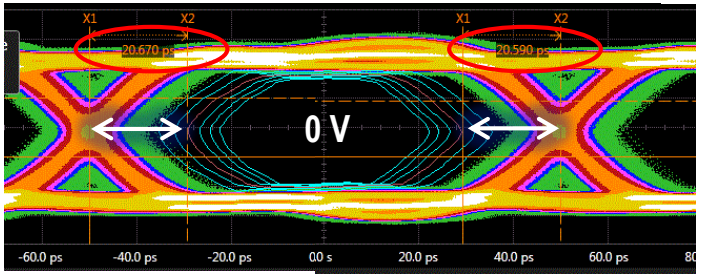


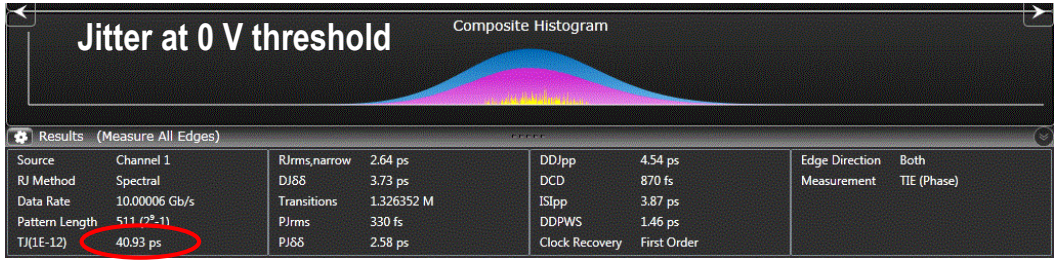
BER Eye Contours

Eye Contour at BER 10^{-12}

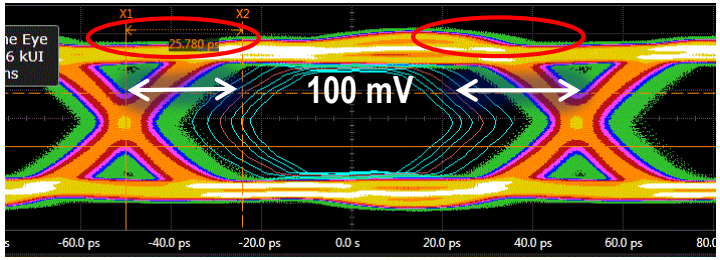
BER Eye Contour matches Jitter Decomposition

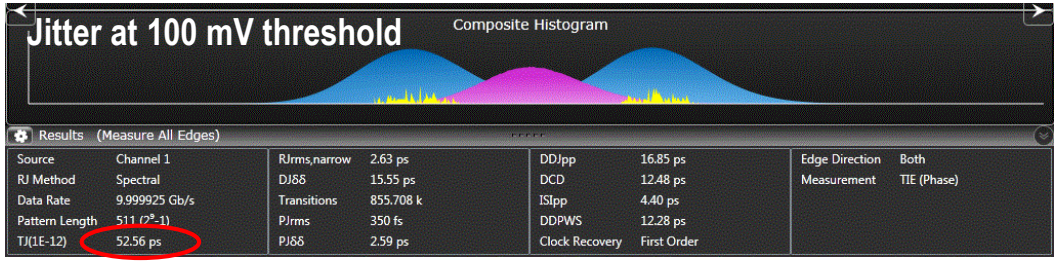
Results matches at various threshold settings





The 10^{-12} BER eye contour width agrees with TJ 10^{-12} BER result at ~41ps at 0V threshold.

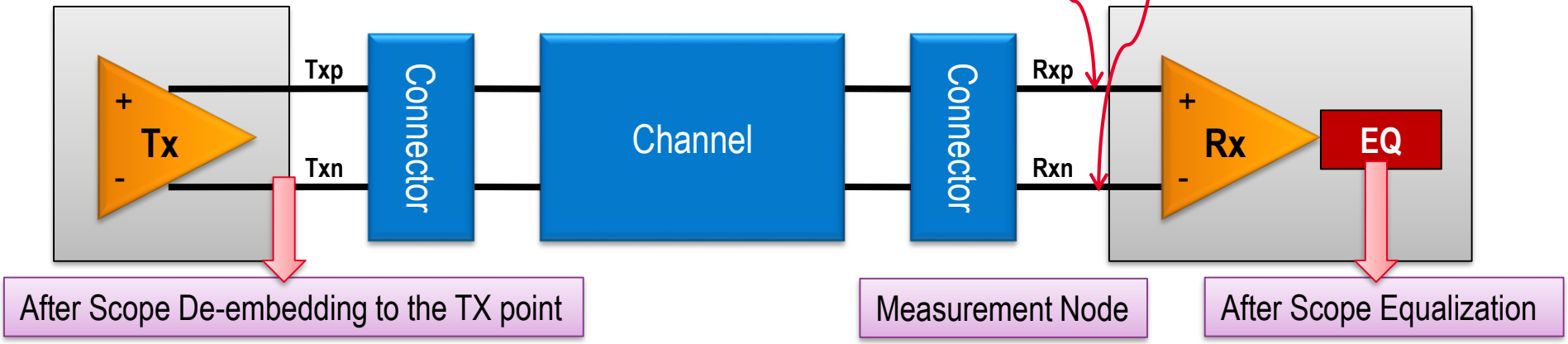




The 10^{-12} BER eye contour width agrees with TJ 10^{-12} BER result at ~53ps at 100mV threshold.

Analyze Jitter at Various Test Points

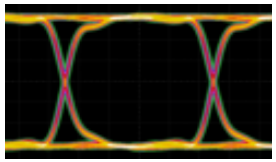
Jitter Analysis with De-embedding and Equalization

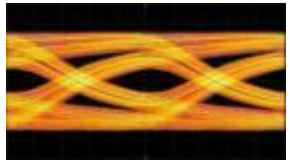


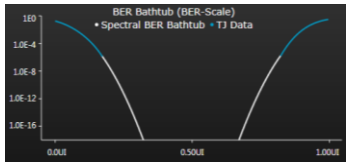
After Scope De-embedding to the TX point

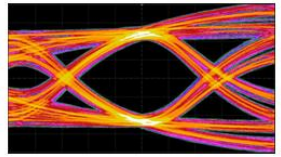
Measurement Node

After Scope Equalization









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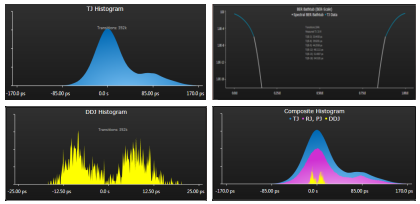
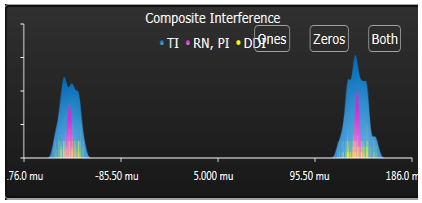
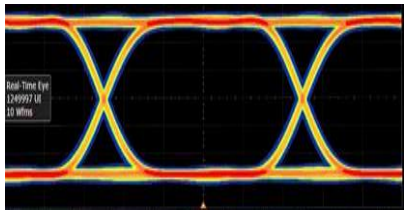
Keysight Real-Time Scope Jitter Analysis Tools



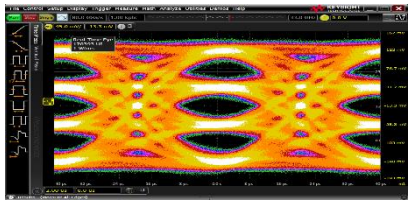
N5400A EZJIT Plus for Jitter Analysis and RJ Scope Removal Calibration



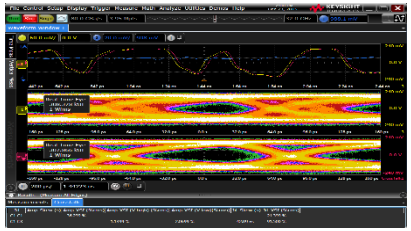
N8823A EZJIT Complete for Vertical Noise Analysis



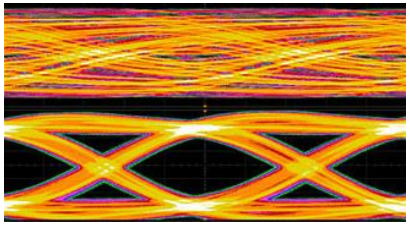
E2688A High-Speed SDA for Reference Clock Recovery and Eye Analysis



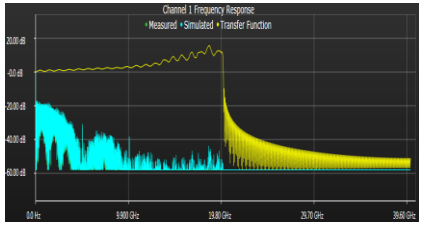
N8827A PAM-4 Clock Recovery



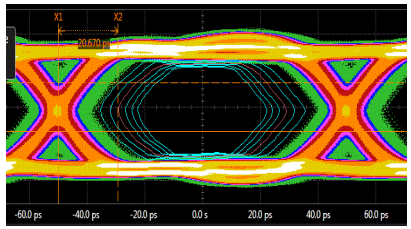
N8833A Crosstalk Analysis and Removal Application



N5461A Serial Data Equalization Software



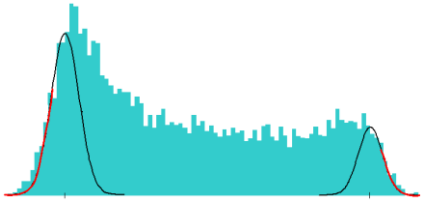
N5465A InfiniiSim De-embedding Software



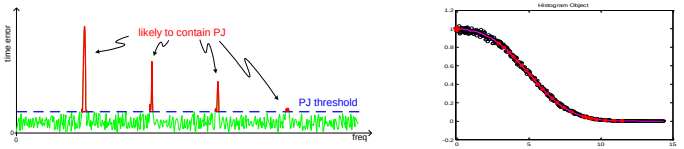
BER Eye Contour Comes standard with E2688A and N8823A

BER Eye Contour : 误码率的眼图轮廓

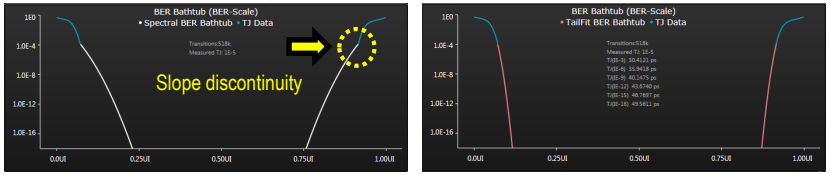
Jitter Analysis Summary



Dual Dirac Model for Jitter Decomposition

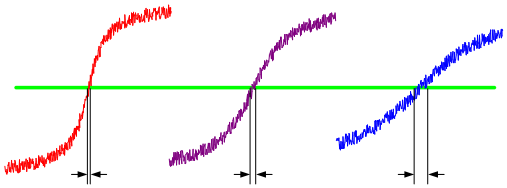


Spectral vs. Tail Fit for ABUJ (Crosstalk) Jitter Analysis

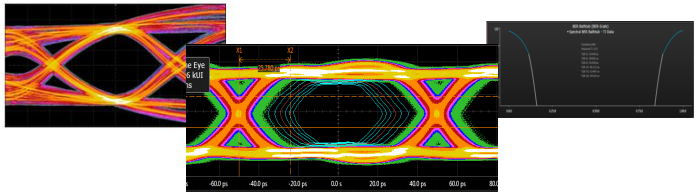


Use Smoothness of Slop Continuity on the Bathtub Curve

Use Crosstalk Removal Tool to Recover Jitter Margins



Scope Random Jitter Removal



BER Eye Contour, De-embedding and Equalization for Jitter Analysis

BER Eye Contour : 误码率的眼图轮廓

Thanks for joining us!

Question ?