# Introduction to Jitter Techniques for High Speed Serial Technologies


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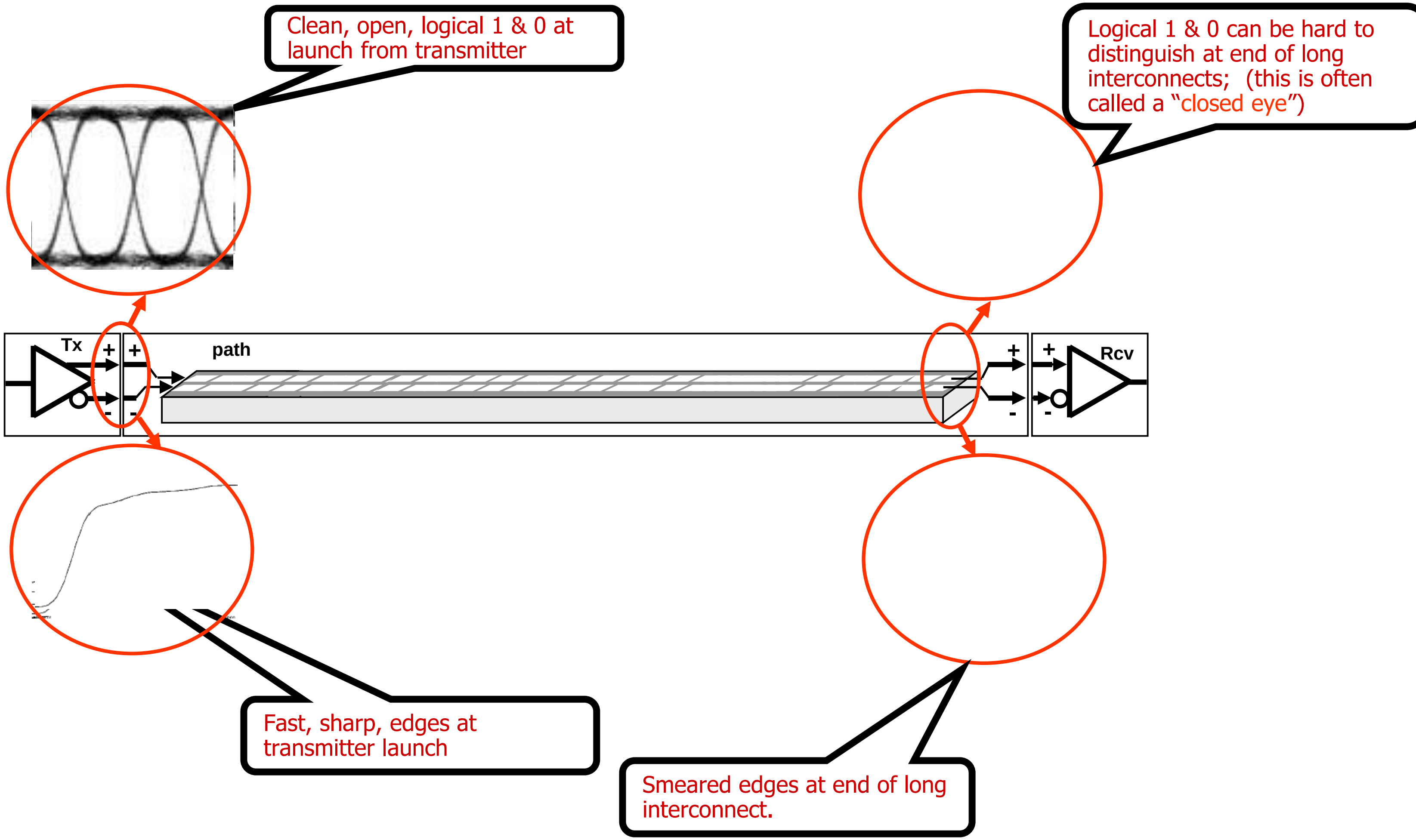
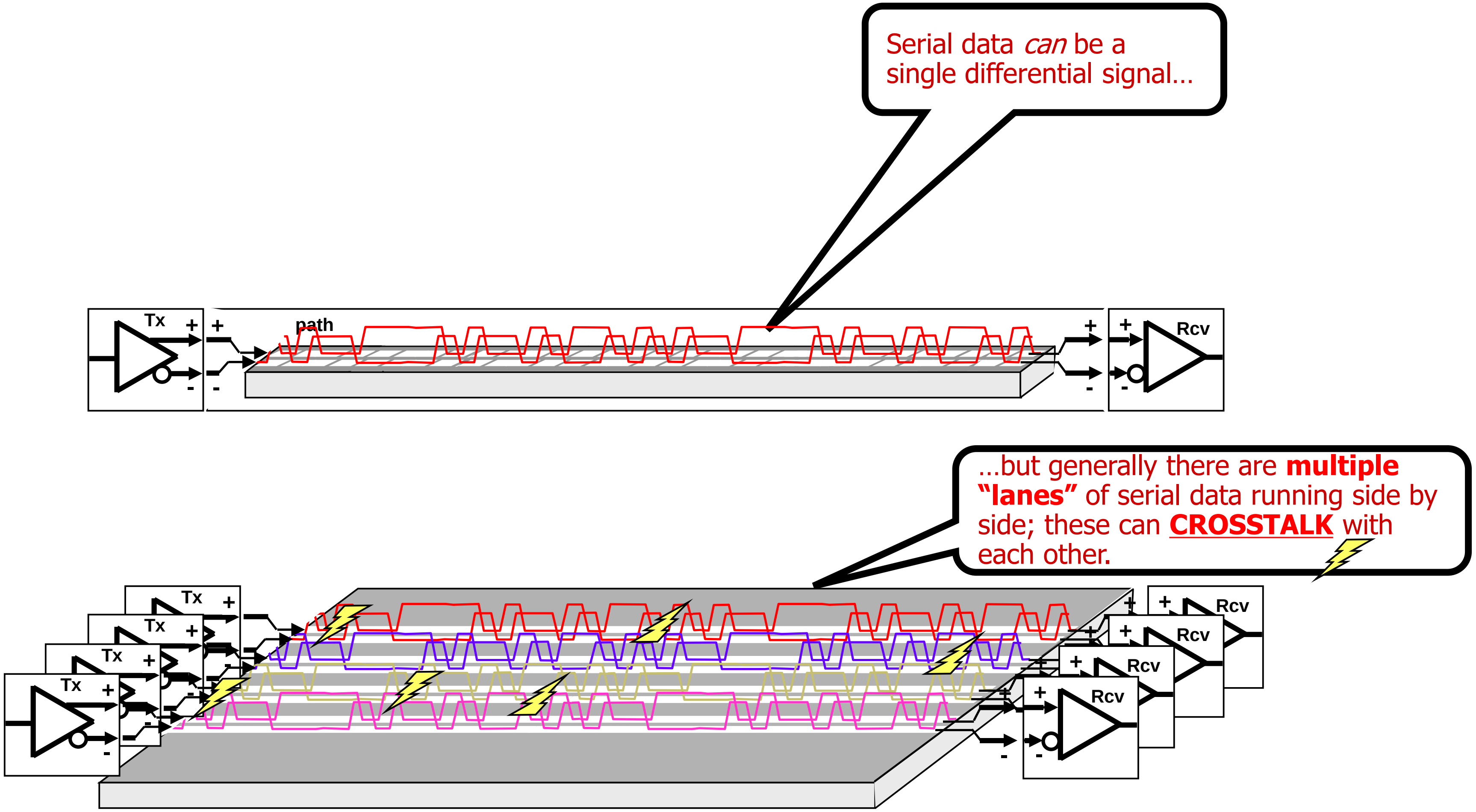
# Fast Data Rates, More HF Loss




Reference Maxim Note HFDN-27.0 (Rev. 0, 09/03)

# Multiple Lanes Result in Crosstalk



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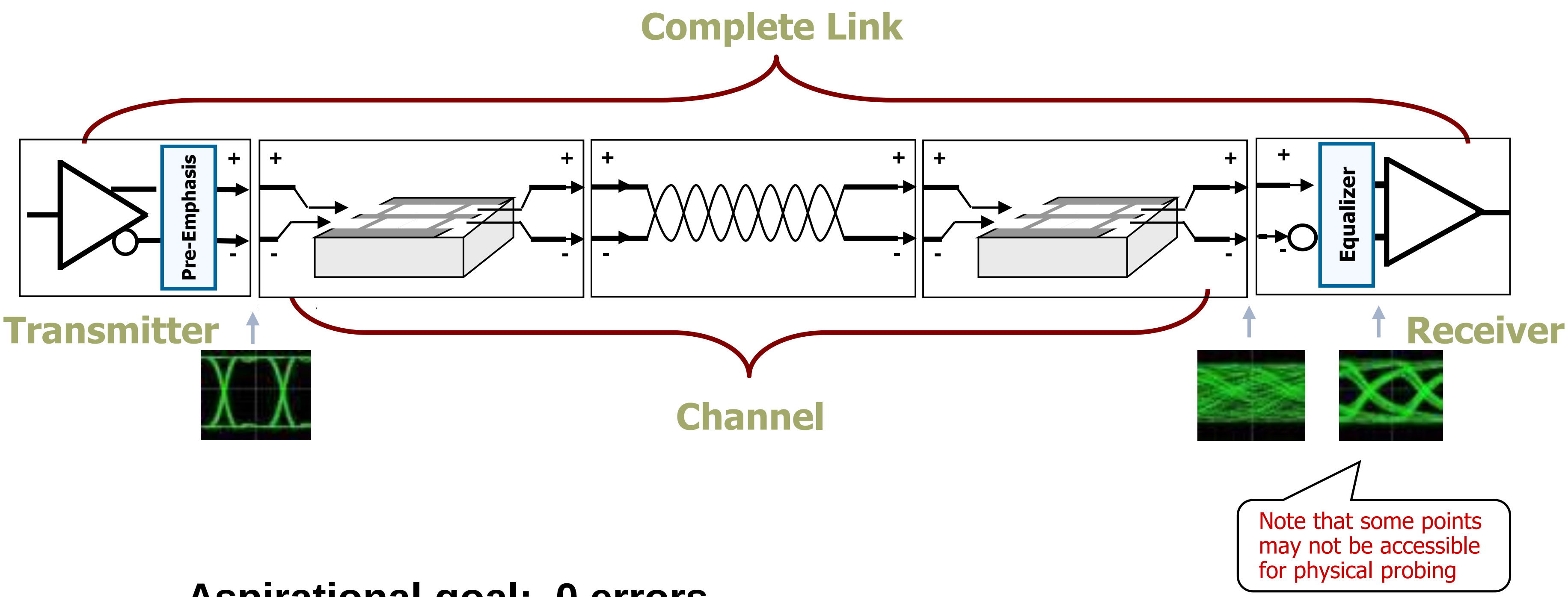
# Anatomy of a Serial Data Link

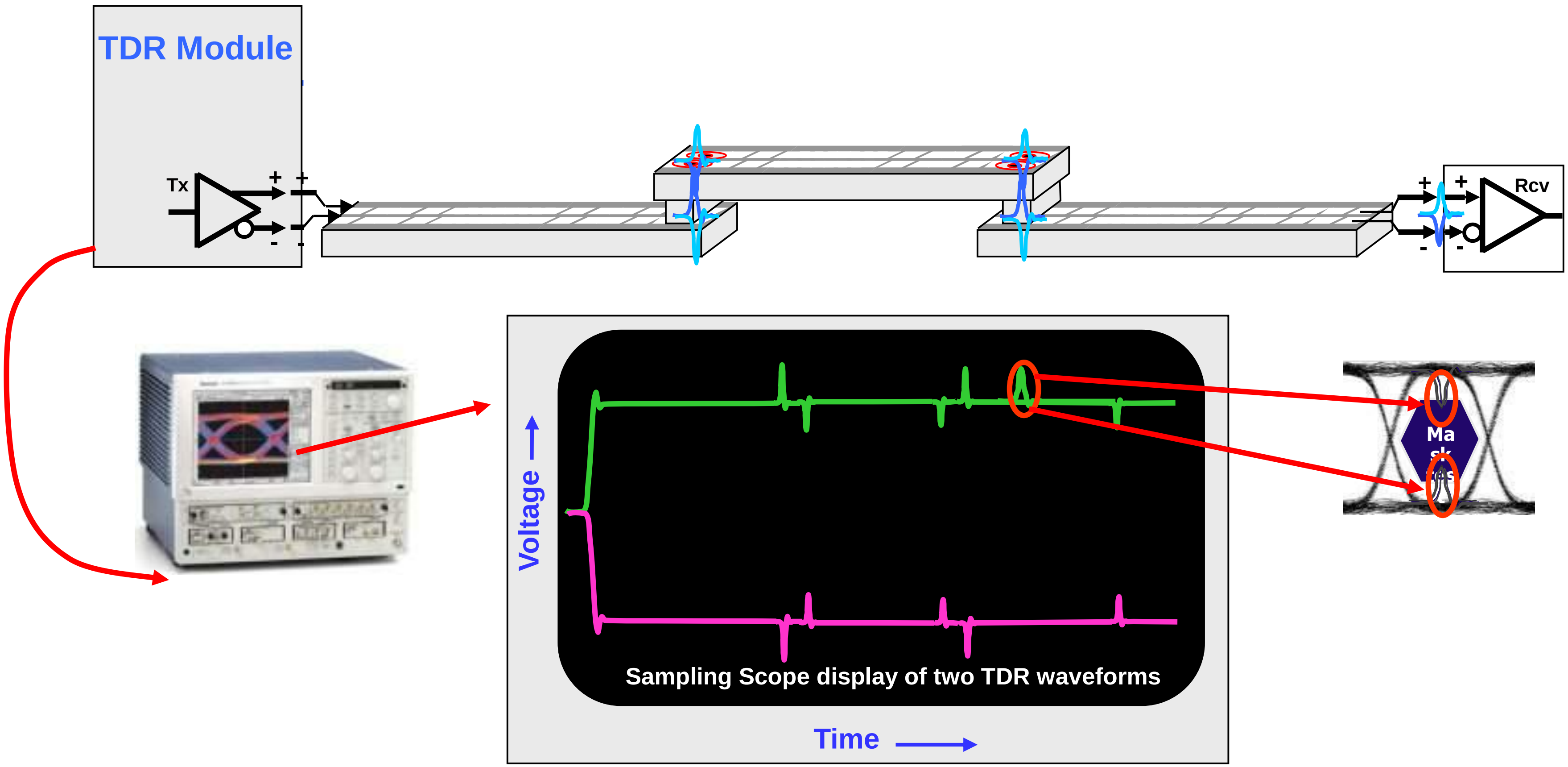



**Aspirational goal: 0 errors**

Practical Goal: Bit Error Rate < Target BER

- Since BER is the ultimate goal, why not measure it directly?

# TDR Basics




*Transition points involve combinations of **solder joints**, **circuit board vias**, and **connectors**:*

*these all can have substantial effect on the total link performance.*

*TDR also is capable of producing **S-parameters***

# Jitter Basics

## Definitions

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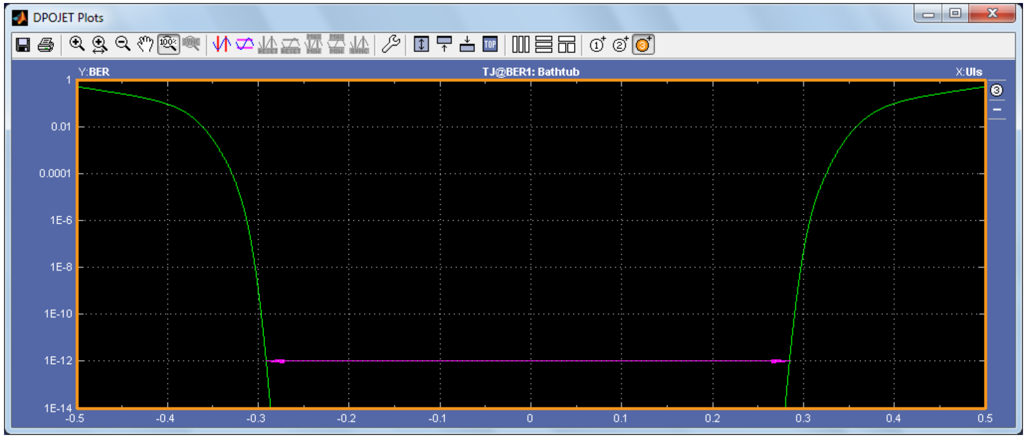
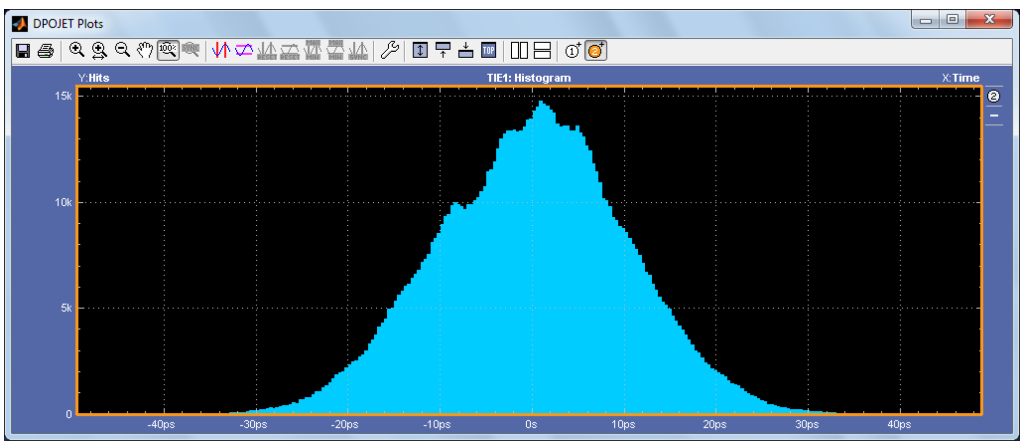
# Jitter Plot?


DPOJET Plots
Y:BER
TJ@BER1: Bathtub
X:UIs
1
0.01
0.0001
1E-6
1E-8
1E-10
1E-12
1E-14
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5


DPOJET Plots
Y:Hits
TIE1: Histogram
X:Time
15k
10k
5k
0
-40ps
-30ps
-20ps
-10ps
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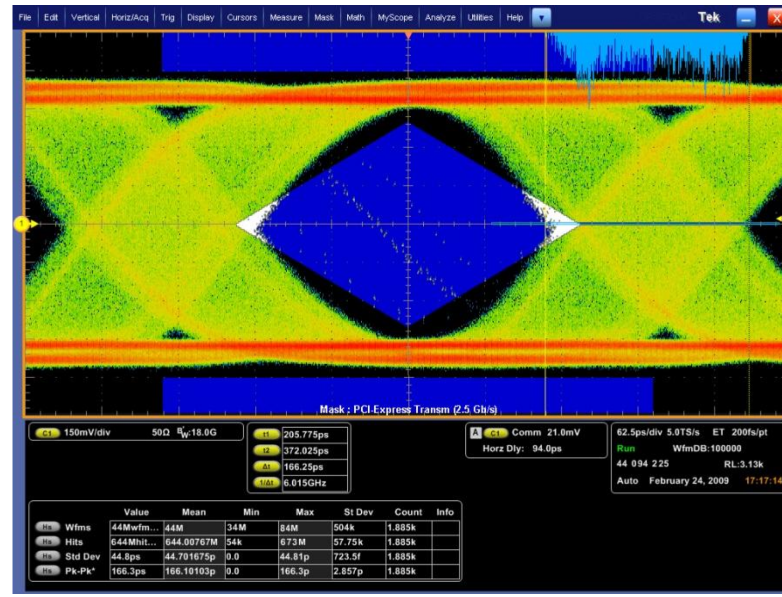
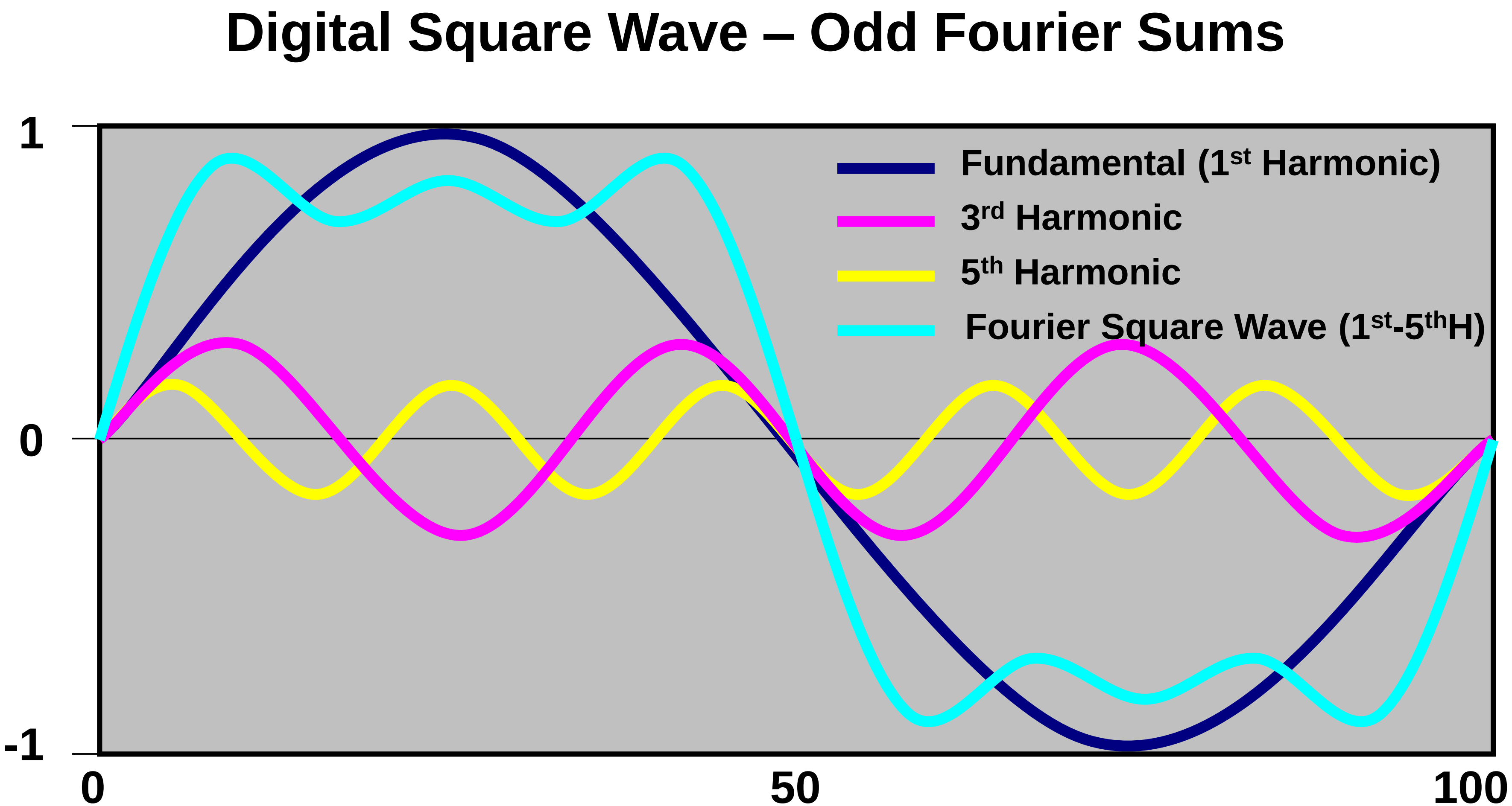
10ps
20ps
30ps
40ps

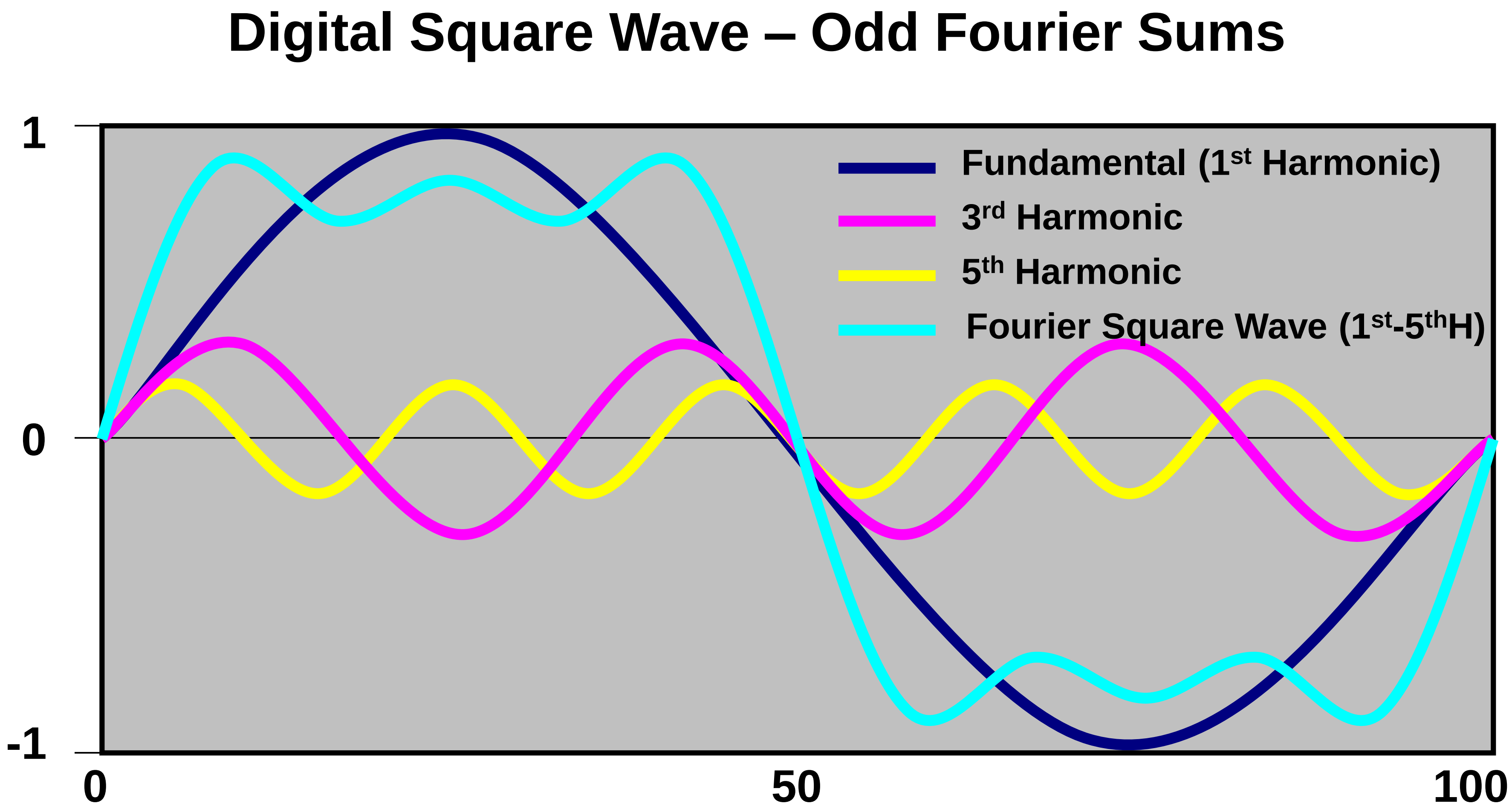

File Edit Vertical Horiz/Acq Trig Display Cursors Measure Mask Math MyScope Analyze Utilities Help
Tek
Mask : PCI-Express Transm (2.5 Gb/s)

# Bandwidth & Harmonics




ROT: Specify the Oscilloscope + Probe with System BW to be 3 - 5 times greater than the Signal Frequency to be measured.

# Bandwidth & Harmonics




ROT: Specify the Oscilloscope + Probe with System BW to be 3 - 5 times greater than the Signal Frequency to be measured.



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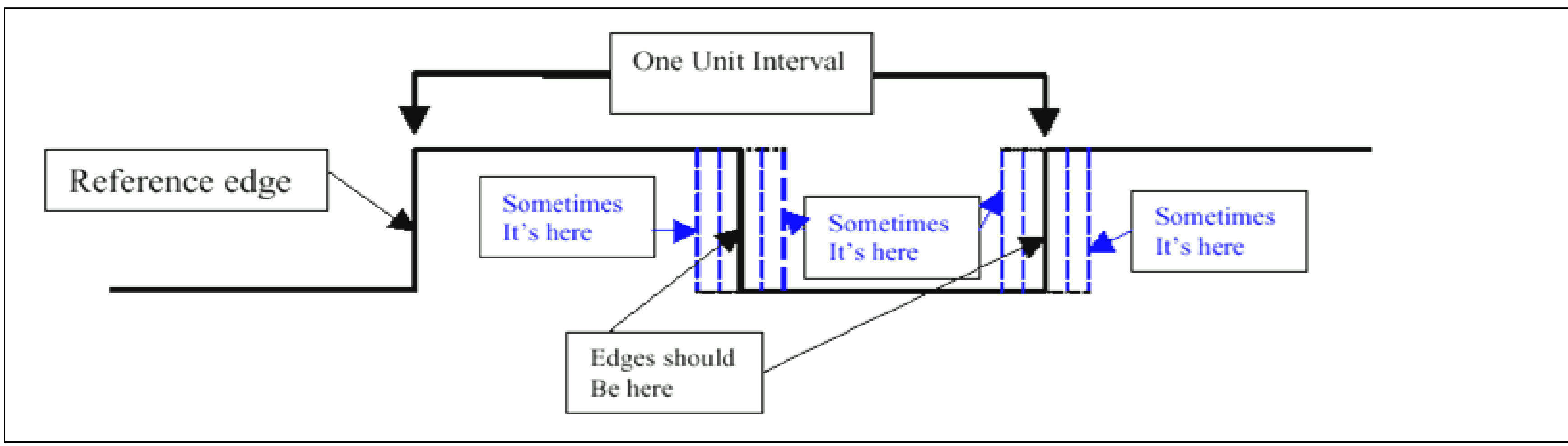
# What is Jitter?

- Definitions
  - "The deviation of an edge from where it should be"
  - ITU Definition of Jitter: "Short-term variations of the significant instants of a digital signal from their ideal positions in time"



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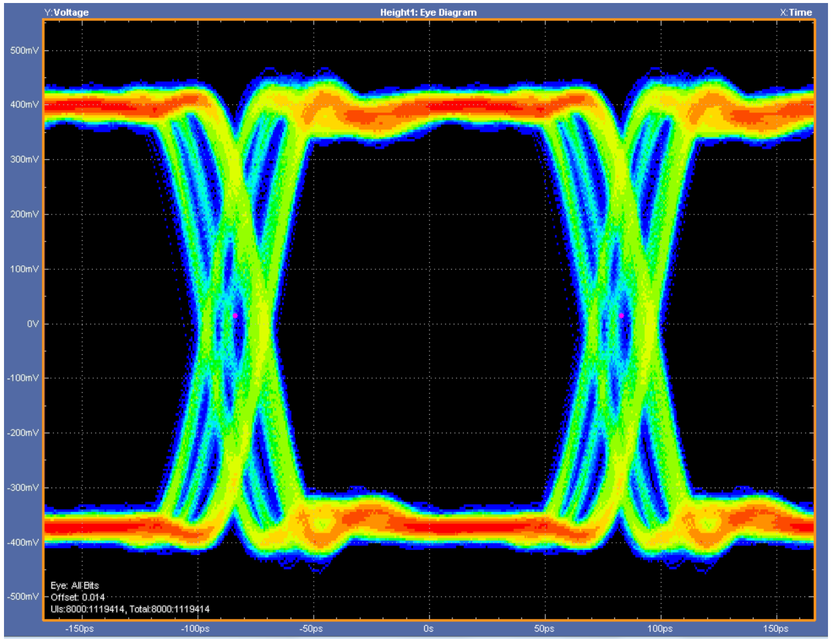
# Jitter is caused by many things…

- Causes of Random Jitter
  - Thermal noise
    - Generally Gaussian
    - External radiation sources
    - Like background conversations…random and ever changing
- Causes of Periodic Jitter
  - Injected noise (EMI/RFI) & Circuit instabilities
    - Usually a fixed and identifiable source like power supply and oscillators
    - Will often have harmonic content
    - Transients on adjacent traces
    - Cabling or wiring (crosstalk)
  - PLL’s problems
    - Loop bandwidth (tracking & overshoot)
    - Deadband (oscillation / hunting)
- Causes of Data Dependent Jitter
  - Transmission Losses
    - There is no such thing as a perfect conductor
    - Circuit Bandwidth
    - Skin Effect Losses
    - Dielectric Absorption
    - Dispersion – *esp. Optical Fiber*
    - Reflections, Impedance mismatch, Path discontinuities (connectors)



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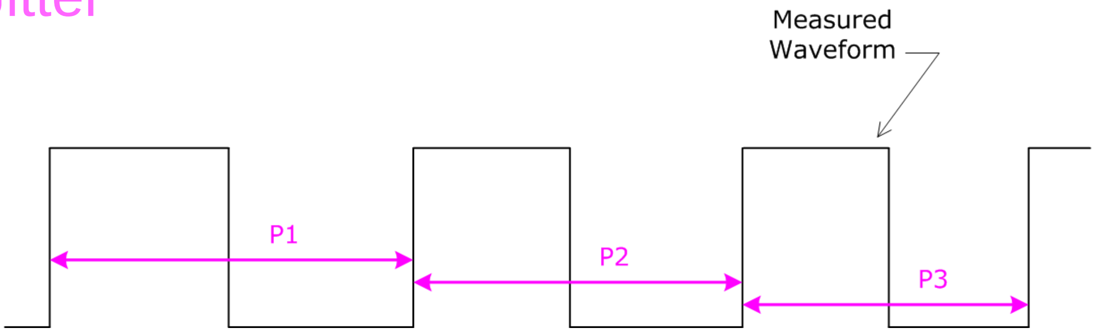
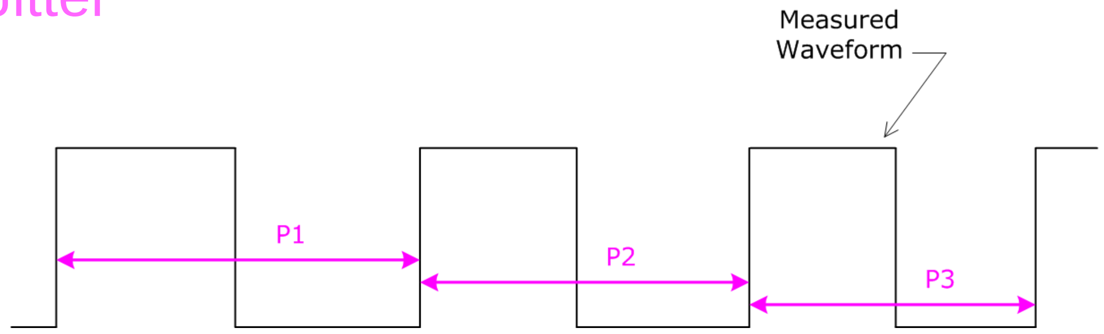
# Types of Jitter

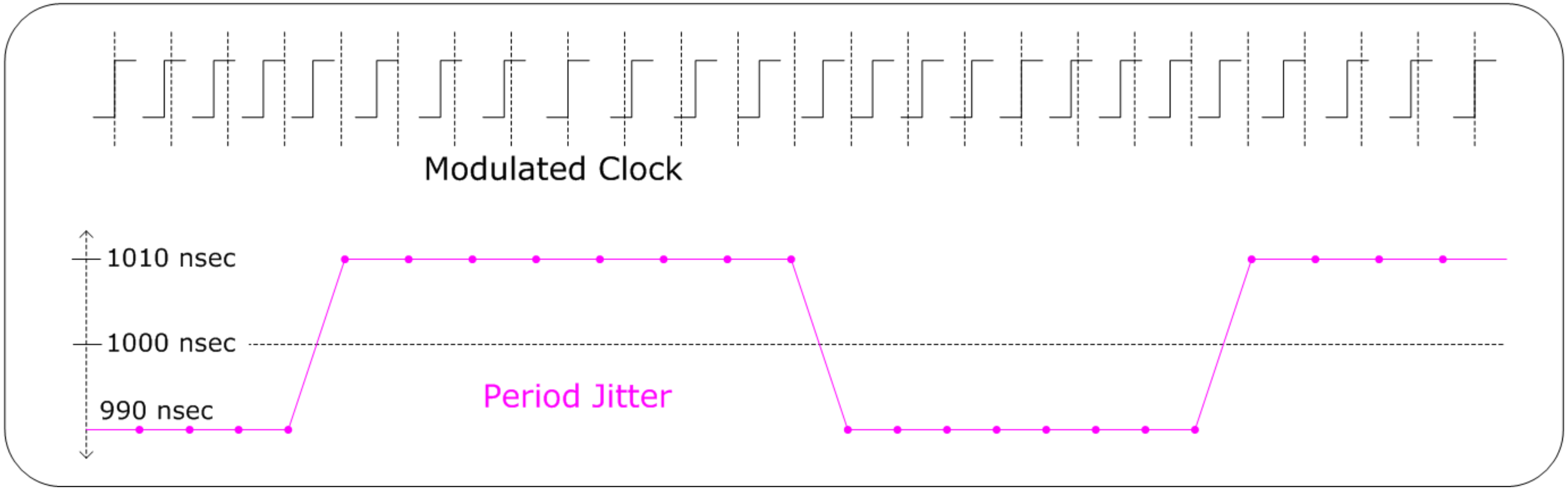
- Period Jitter



# Types of Jitter

- Period Jitter



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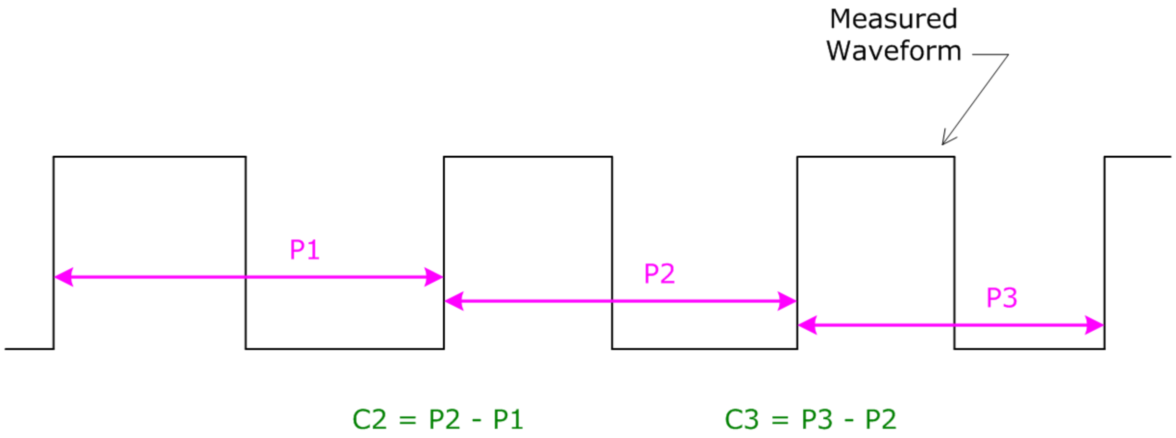
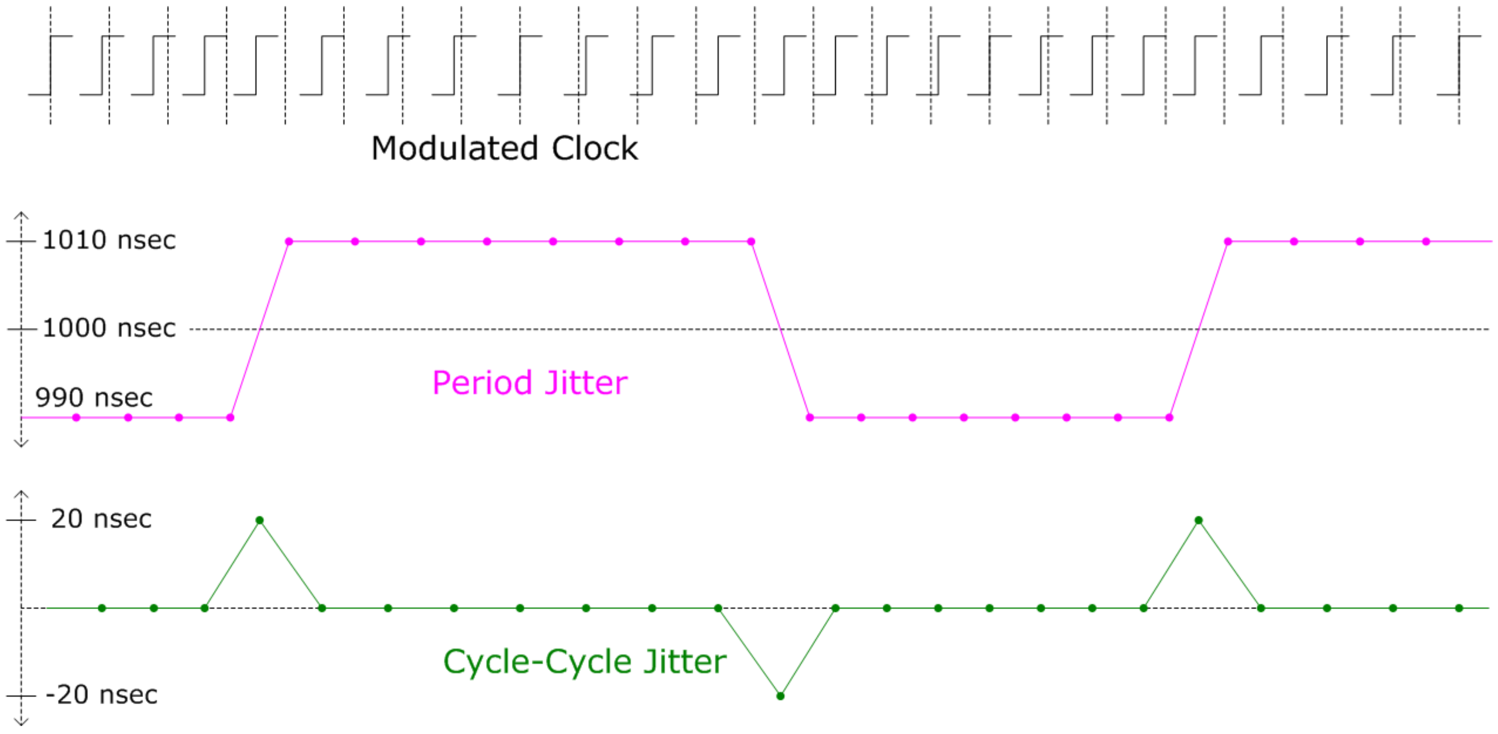
# Types of Jitter

- Period Jitter
- Cycle-to-Cycle Jitter




– **Cycle-to-Cycle Jitter** is the first-order difference of the Period Jitter

# Types of Jitter (Visualization)



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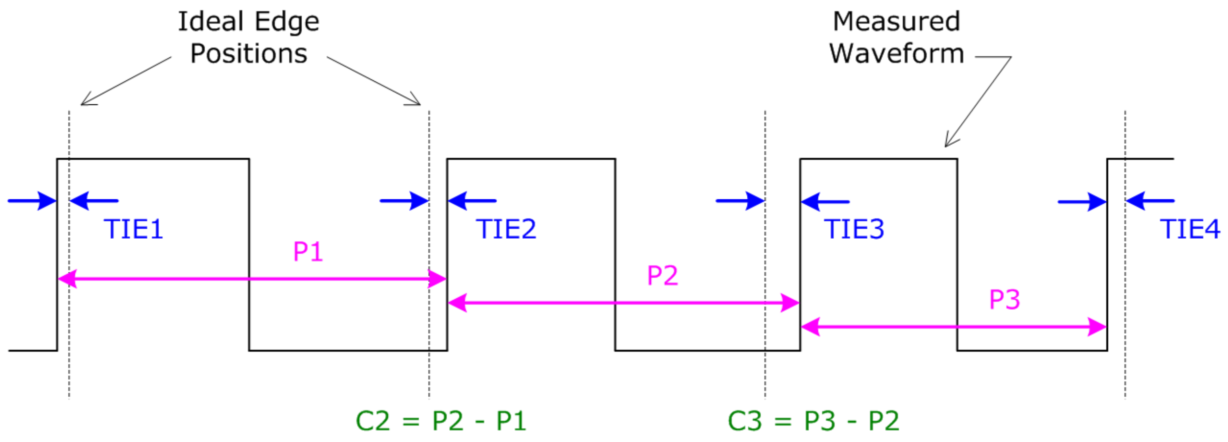
# Types of Jitter

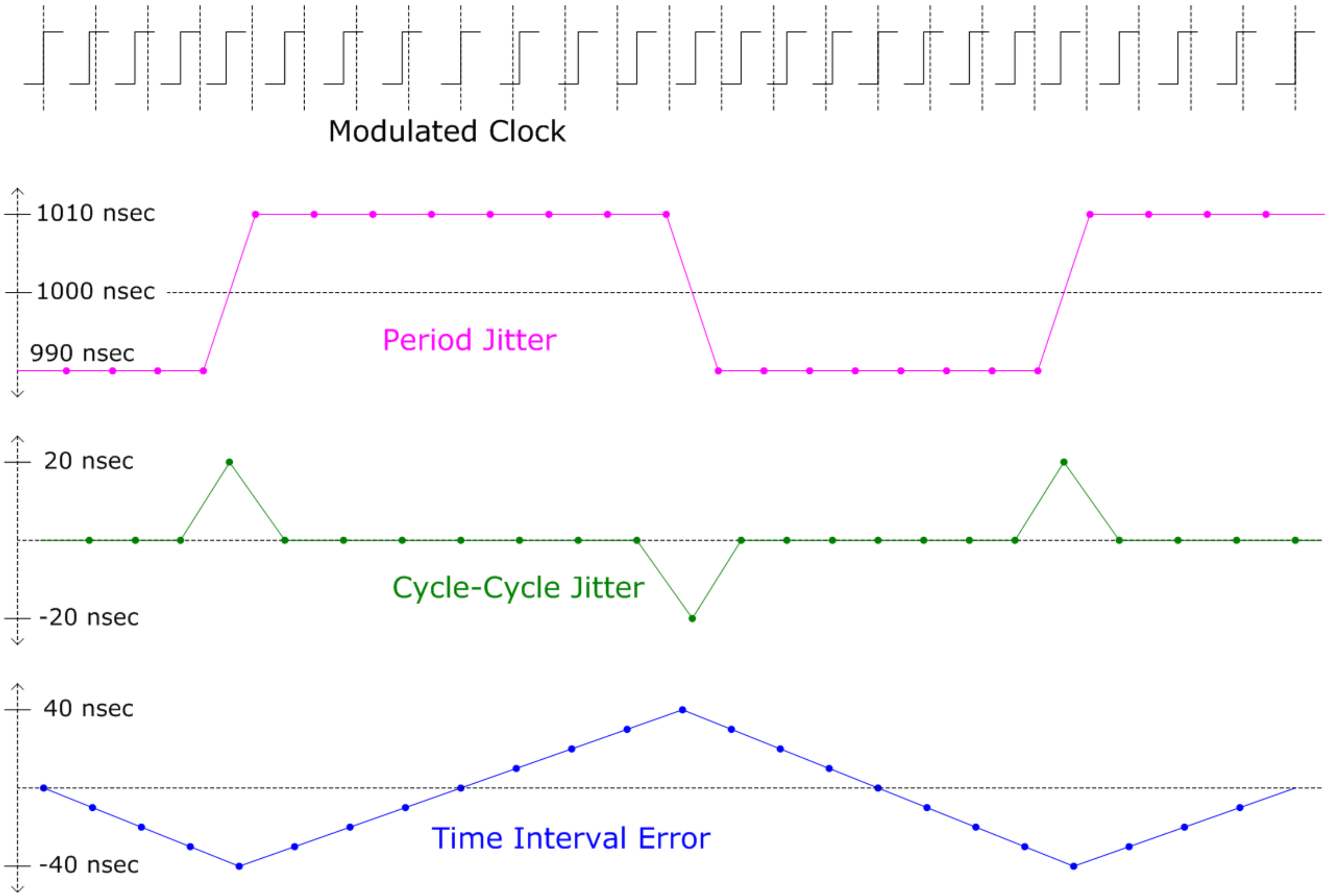
- Period Jitter
- Cycle-to-Cycle Jitter
- TIE (Time Interval Error)




– **Period Jitter** is the first-order difference of the **TIE Jitter** (plus a constant)

$$P_n = TIE_n - TIE_{n-1} + K$$

# Types of Jitter (Visualization)



# Advanced Jitter - Decomposition

## Rj / Dj Separation

# Motivations for Jitter Decomposition

- **Speed**: Directly measuring error performance at 1e-12 requires directly observing MANY bits (1e14 or more). This is time consuming! Extrapolation from a smaller population can be done in seconds instead of hours.

- **Knowledge**: Jitter decomposition gives great insight into the root causes of eye closure and bit errors, and is therefore invaluable for analysis and debug.

- **Flexibility**: Already have a scope on your bench? You can do Jitter@BER measurements without acquiring more, perhaps somewhat specialized equipment.

# Common Terms

- Random Jitter (RJ)
- Deterministic Jitter (DJ)
  - Periodic Jitter (PJ)
  - Sinusoidal Jitter (SJ)
  - Duty Cycle Distortion (DCD)
  - Data-Dependent Jitter (DDJ)
  - Inter-Symbol Interference (ISI)
- Bit Error Rate (BER)
- Total Jitter ~ (TJ or TJ@BER)
- Eye Width @BER
  - versus Actual or Observed Eye Width

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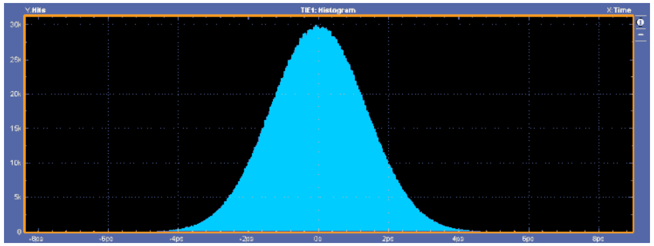
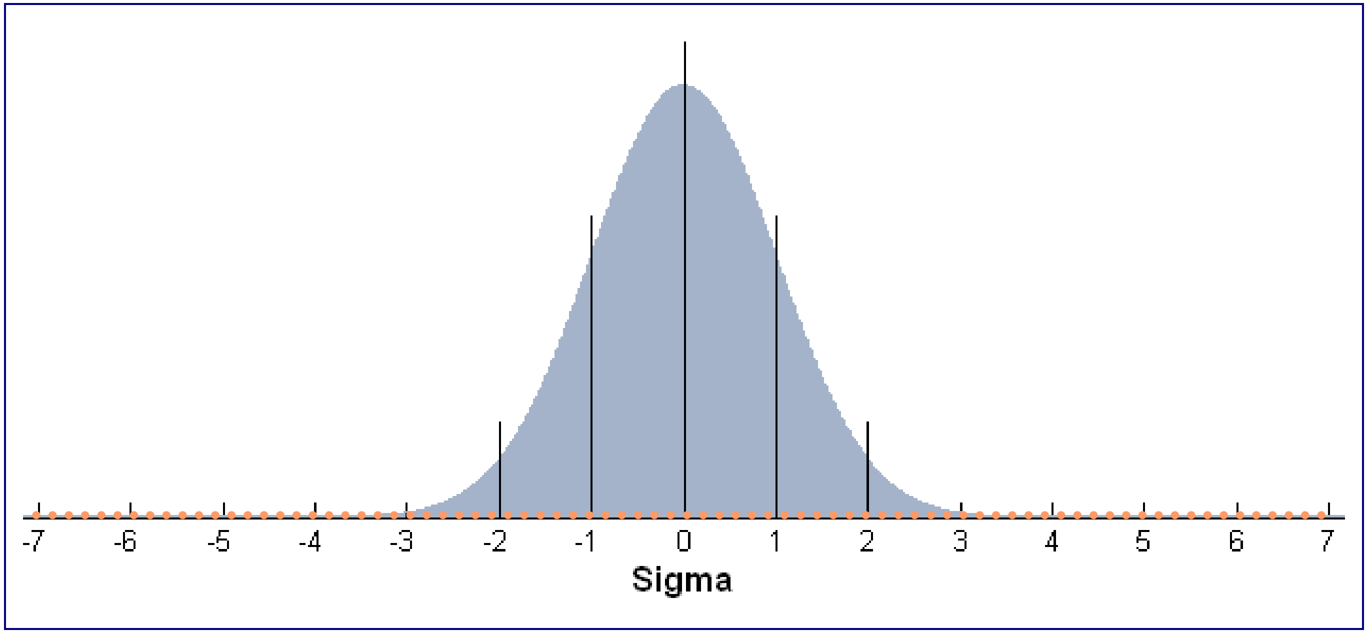
# Random Jitter (RJ)



- Jitter of a random nature is assumed to have a Gaussian distribution (Central Limit Theorem)
- Histogram (estimate) ↔ pdf (mathematical model)
- Peak-to-Peak = … unbounded!



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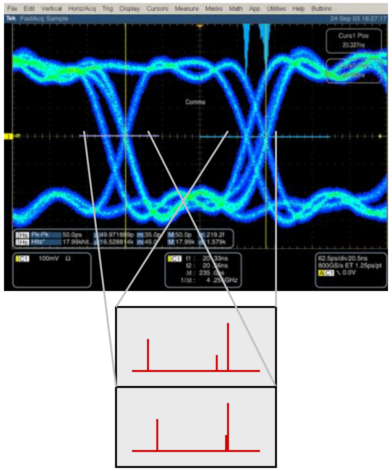
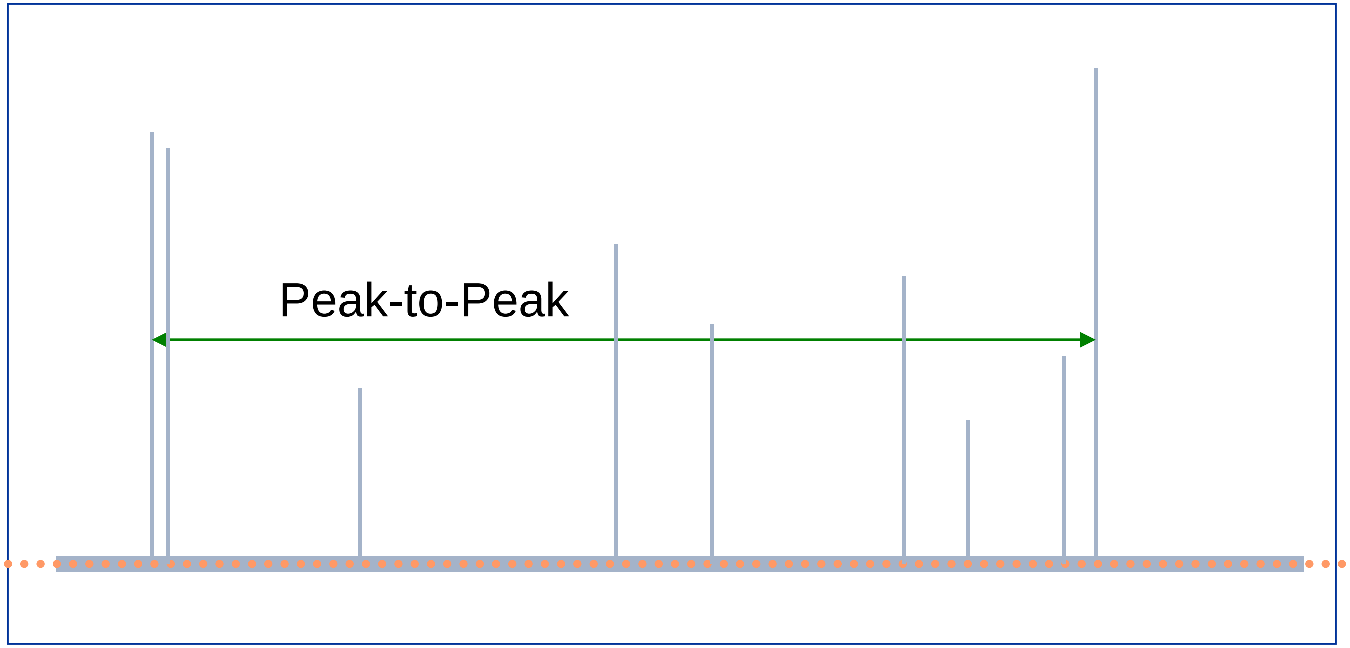
# Deterministic Jitter (DJ)

- Deterministic jitter has a bounded distribution:  the observed peak-to-peak value will not grow over time
- Histogram = pdf (close enough)





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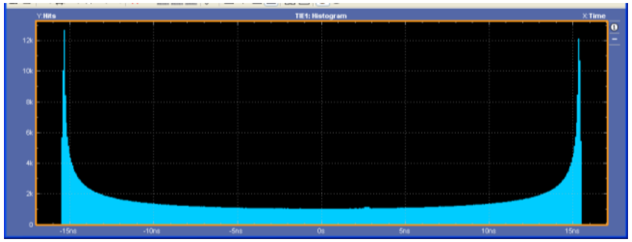
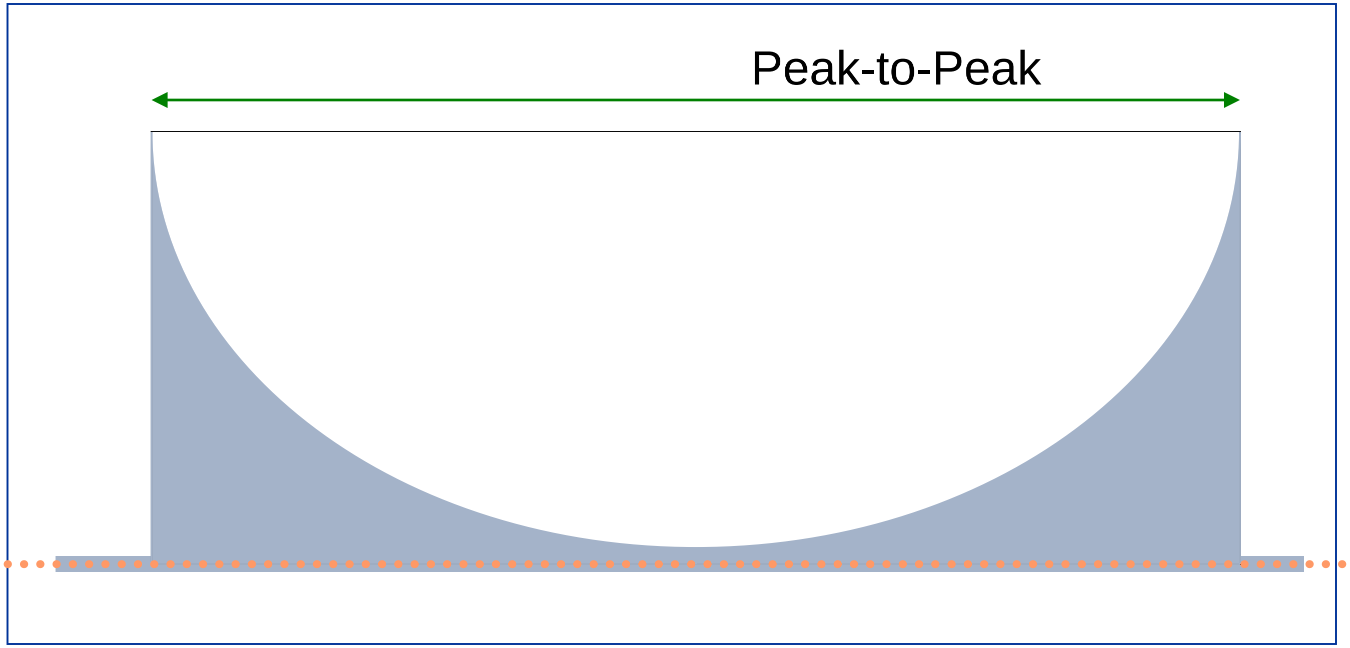
# Periodic Jitter (PJ, SJ)



- TIE vs. time is a repetitive waveform
- Assumed to be uncorrelated with the data pattern (if any)
- Sinusoidal jitter is a subset of Periodic Jitter



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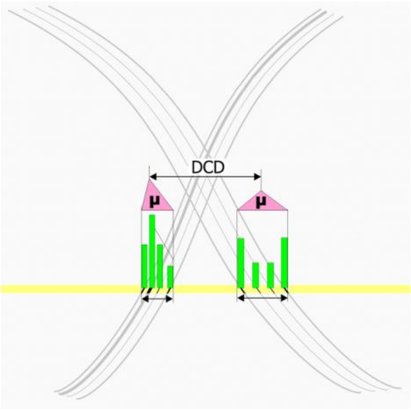
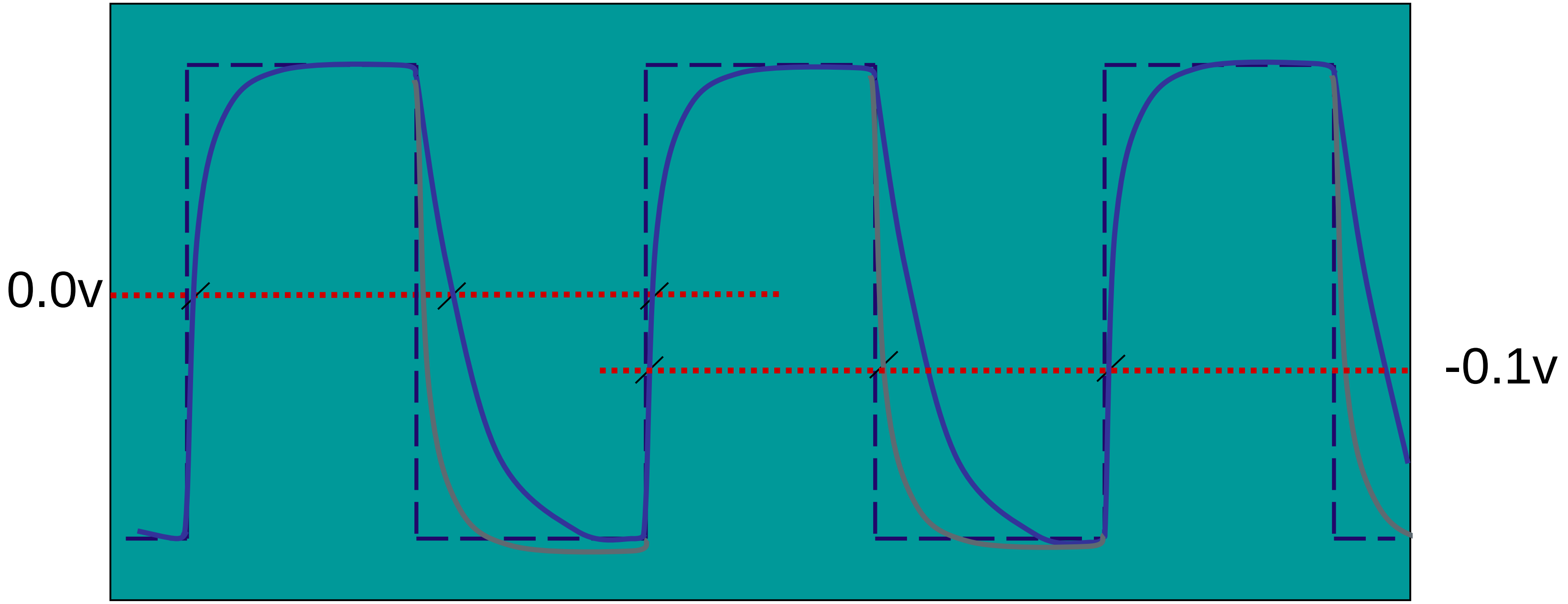
# Duty Cycle Distortion (DCD)

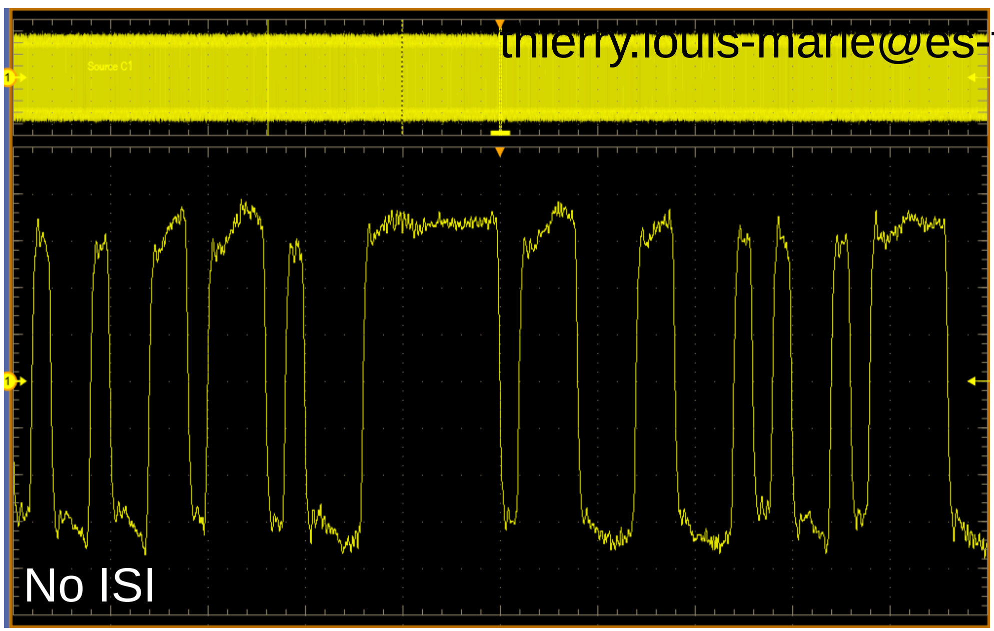
- DCD is the difference between the mean TIE for rising edges and the mean TIE for falling edges
- Causes
  - Asymmetrical rise-time vs. fall-time
  - Non-optimal choice of decision threshold
- For a clock signal, the pdf consists of two impulses



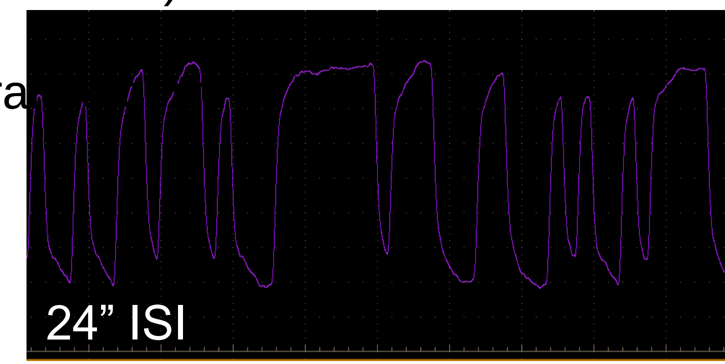



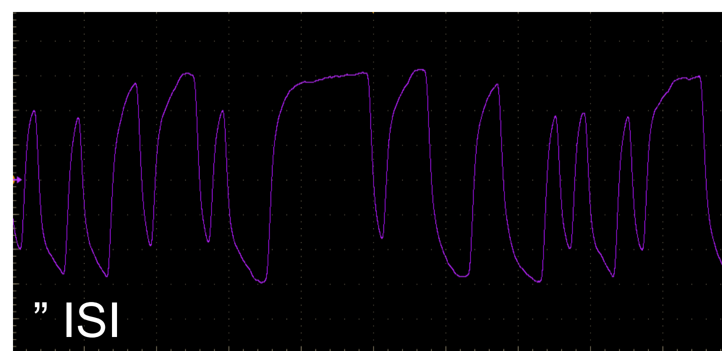
# Data-Dependent Jitter

- DDJ or PDJ – used interchangeably
- ISI – usually considered to be the physical effect that causes DDJ
- Characterizes how the jitter on each transition is correlated with specific patterns of prior bits
  - Due to the step response of the system
  - Due to transmission line effects (e.g. reflections)



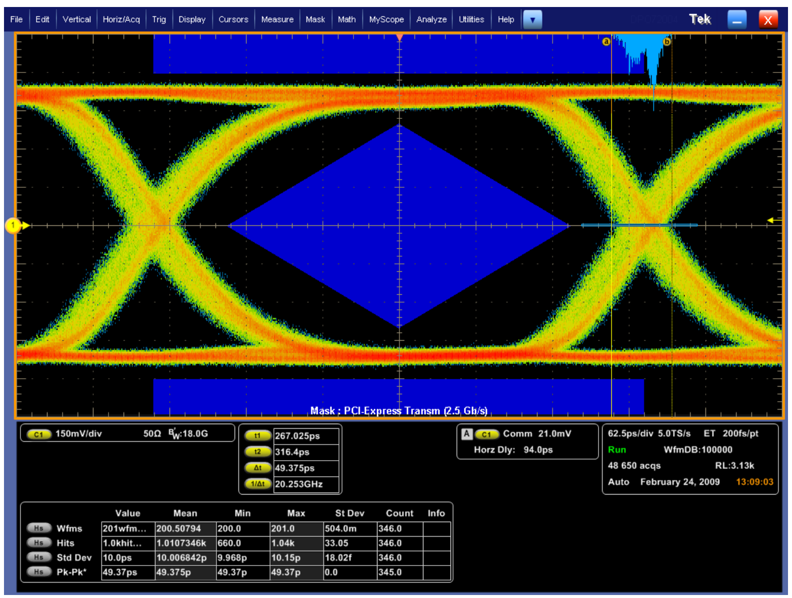


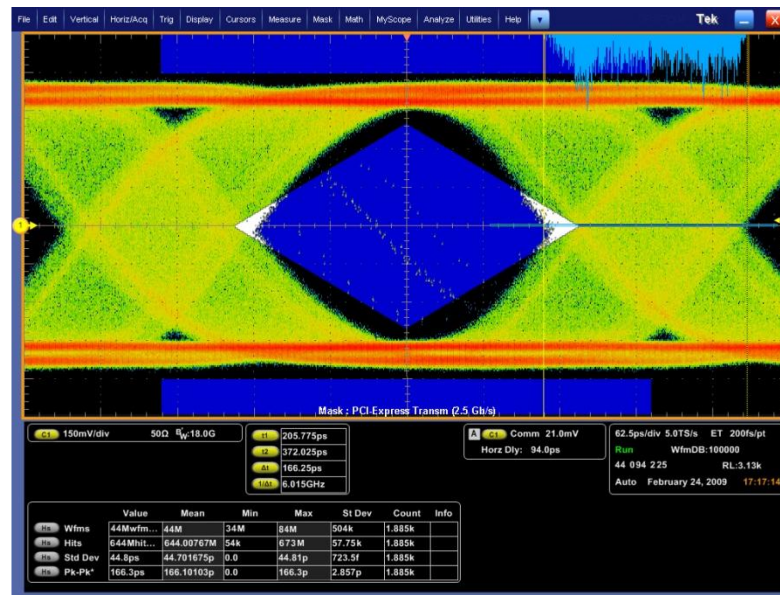



# Composite Jitter Rj/Dj using dual-dirac or Spectral method?

- “Turn it on and run it for a while…”
- Historical Eye-Closure Measurement
- Jitter value including all Rj+Dj components
- Expressed as 1 sigma RMS or Pk-Pk
- Unbounded, result depends on measurement interval




1000 Hits, 10 ps RMS, 40 ps Pk-Pk

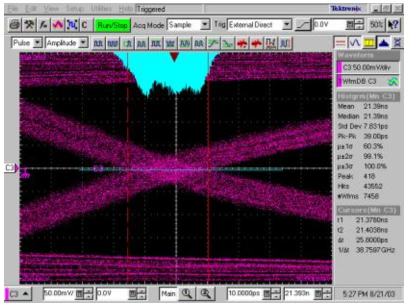


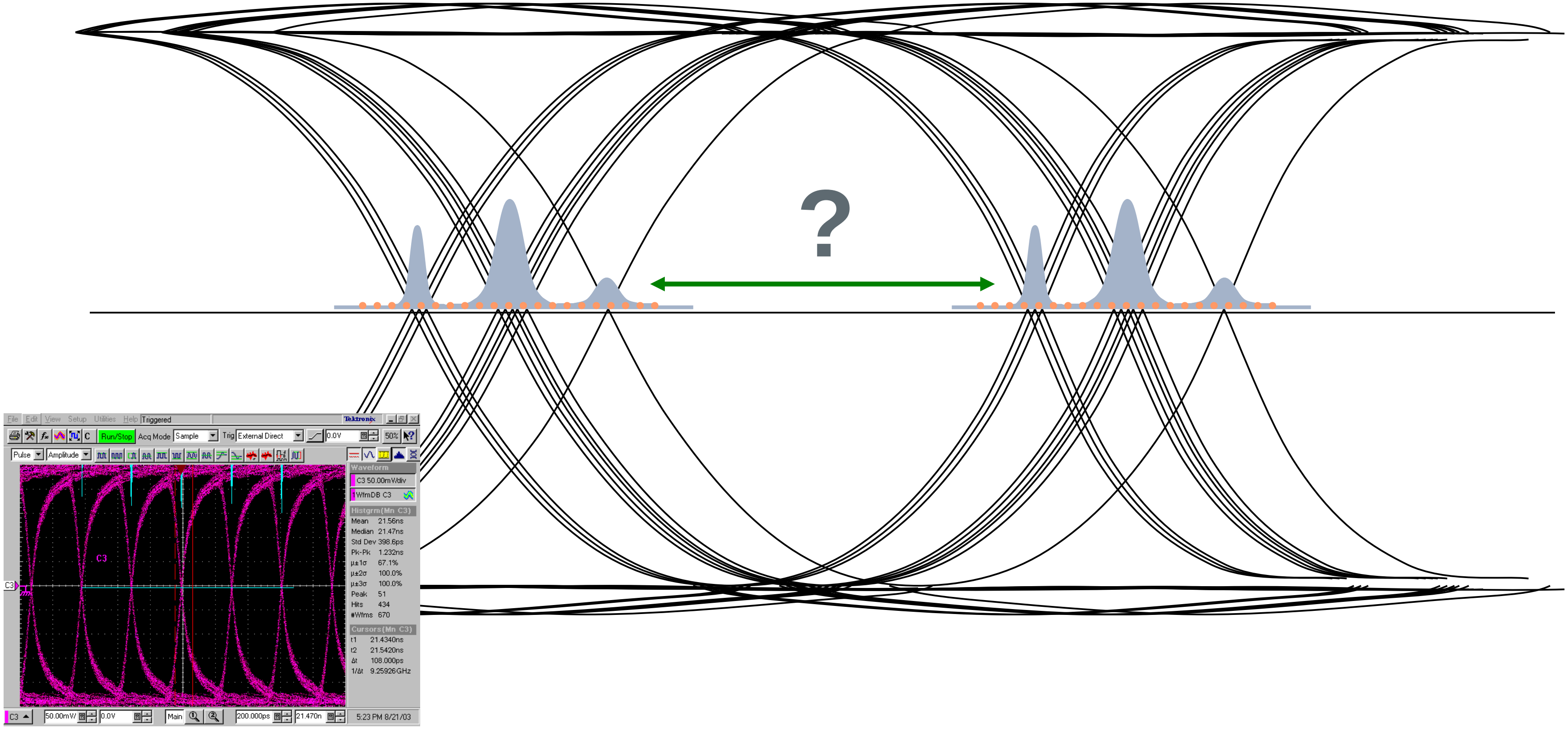

644M Hits, 44 ps RMS, 166 ps Pk-Pk

# ► Histograms vs. Eye Diagrams : Dual Dirac method, Rj and Dj

- How open is the eye, anyway?

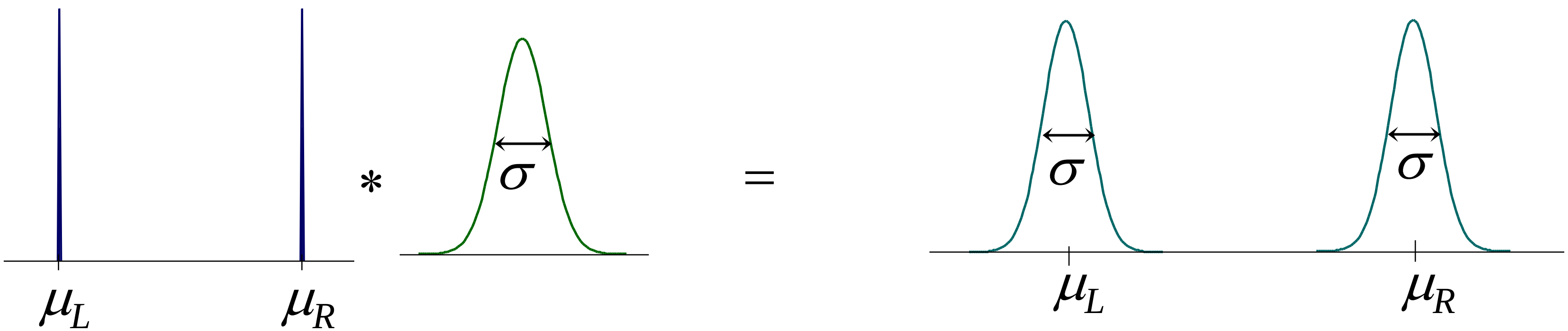
  (…depends how long you watch)





# Elements of the Dual-Dirac Model

$$[\delta(x-\mu_L)+\delta(x-\mu_R)] * \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{x^2}{2\sigma^2}\right) = \frac{1}{\sqrt{2\pi}\sigma}\left[\exp\left(-\frac{(x-\mu_L)^2}{2\sigma^2}\right)+\exp\left(-\frac{(x-\mu_R)^2}{2\sigma^2}\right)\right]$$




Dual-Dirac DJ    Gaussian RJ

Tj = Dj ⊗ Rj (convolution)

**Pk-Pk: Tj = (N*Rj) + Dj , where N is desired sigma**

DJ(p-p) = $\mu_R - \mu_L$    RJ = $\sigma$

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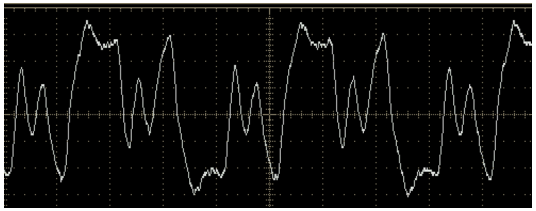
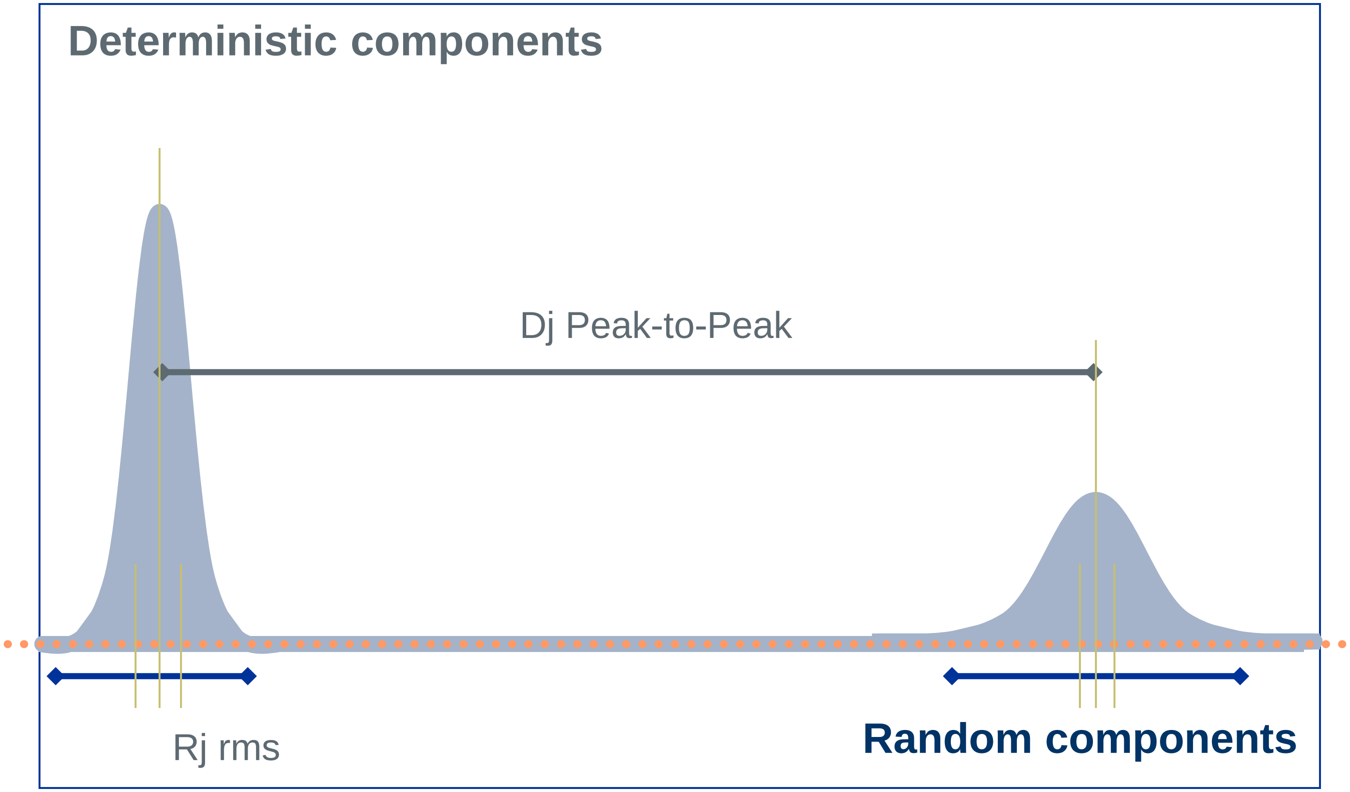
# ► Total Jitter @ BER

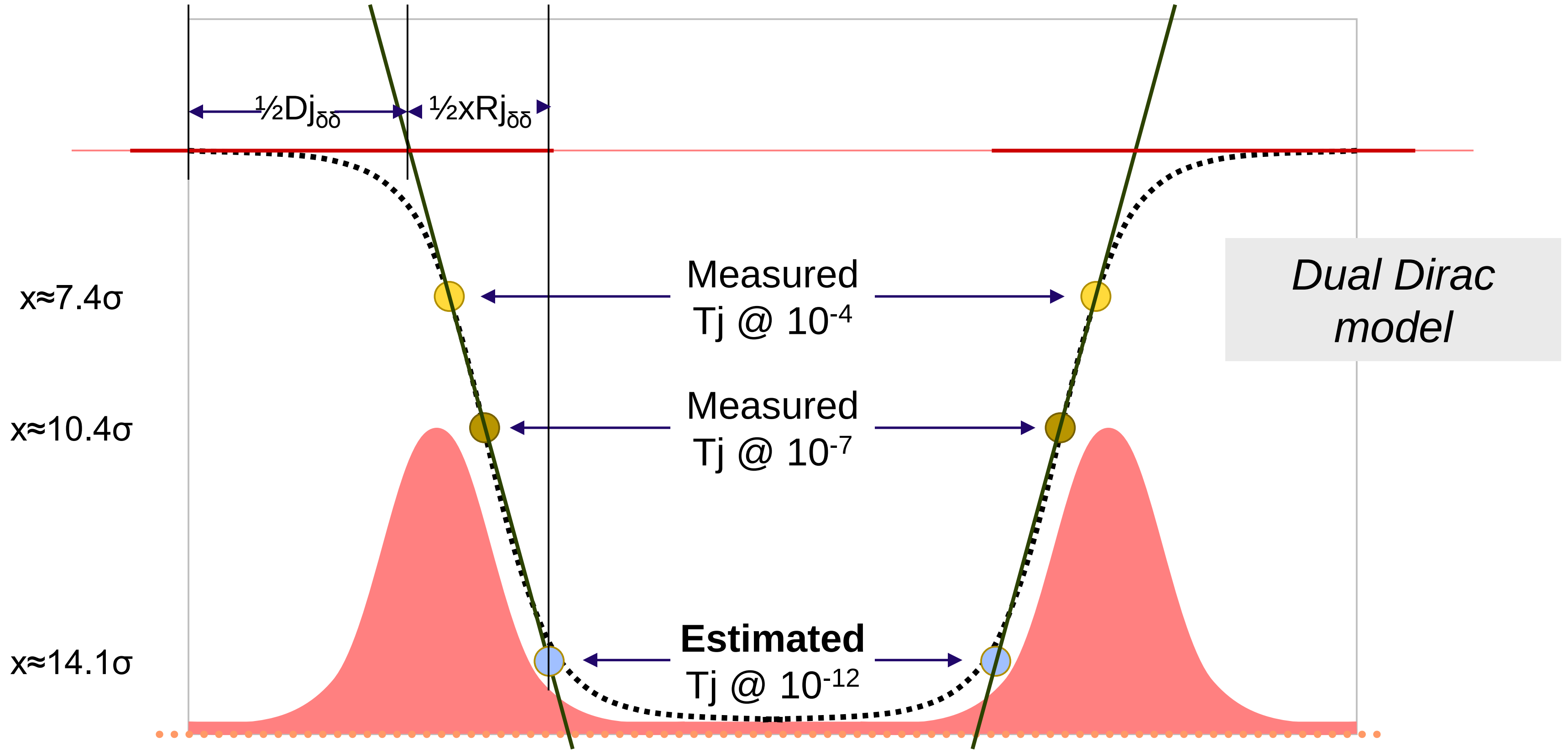




# More about Bathtub
# $Rj_{\delta\delta}/Dj_{\delta\delta}$ *from* Tj @ BER

Assume bi-modal distribution (dual-Dirac), measure Tj at two BER

Fit curve to points, slope is Rj, Intercept is Dj




Conditions: only where Gaussian.

# DJ(dd): Model Dependence of DJ (2)

$$DJ(\delta\delta) \le DJ(p\text{-}p)$$

… Is the reason dual-Dirac is controversial

- It's okay for a model to have model-dependent parameters
- Make sure to use $DJ(\delta\delta)$ in $TJ(BER) = 2Q_{BER} \times RJ + DJ$

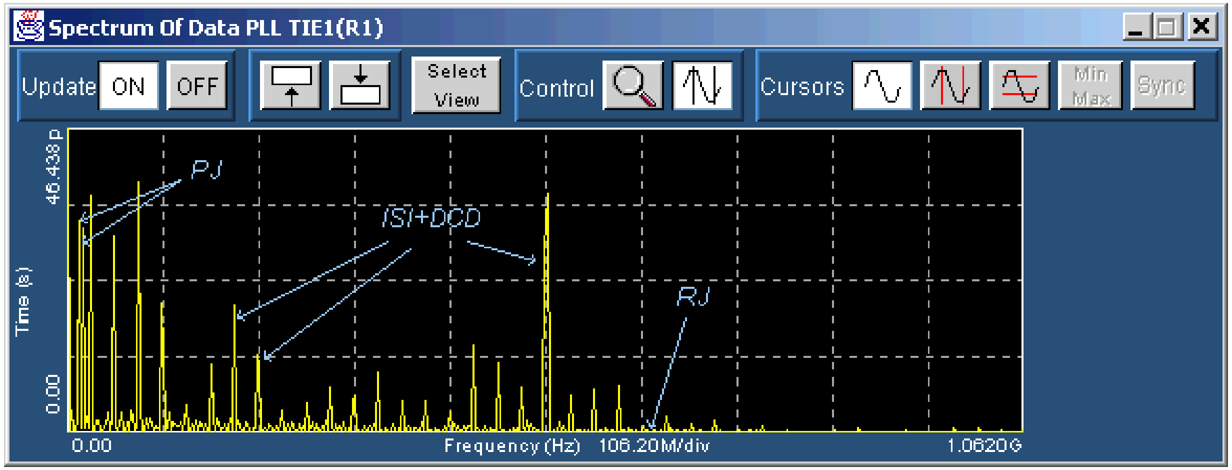
| BER | $Q_{BER}$ |
|---|---|
| $10^{-10}$ | 6.35 |
| $10^{-11}$ | 6.70 |
| $10^{-12}$ | 7.05 |
| $10^{-13}$ | 7.35 |
| $10^{-14}$ | 7.65 |

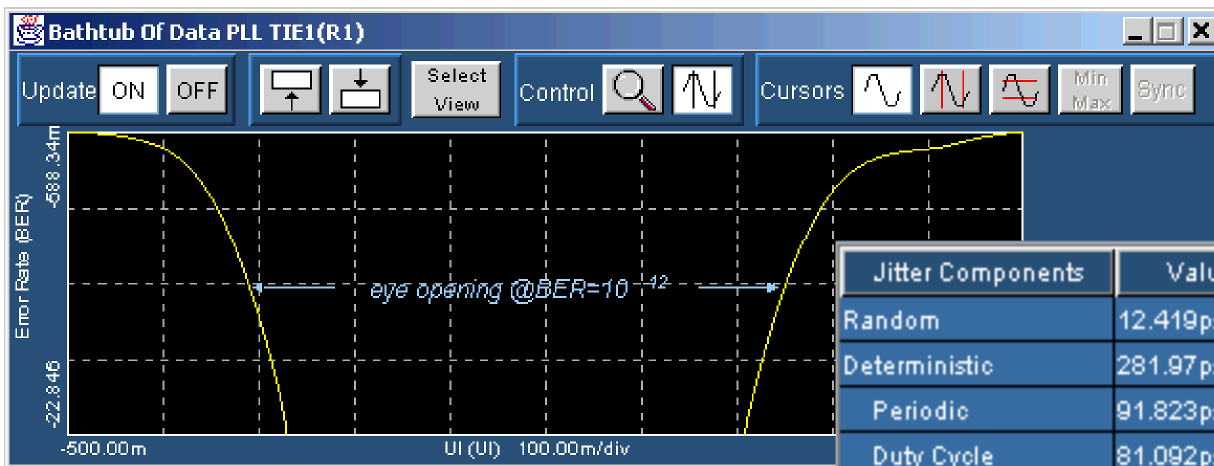
Besides

- It's easier to measure $DJ(\delta\delta)$ than $DJ(p\text{-}p)$
- For getting TJ(BER), $DJ(\delta\delta)$ is more useful than $DJ(p\text{-}p)$

# Spectral Method Rj/Dj but Pj DCD and ISI

- Start with
  - TIE
  - PLL TIE
- Perform FFT
  - Determine frequency and pattern rate
  - Measure RMS of background bins
  - Sum pattern related bins
  - Sum unrelated periodic bins via iFFT
  - Estimate BER




| Jitter Components | Value |
|---|---|
| Random | 12.419ps |
| Deterministic | 281.97ps |
| Periodic | 91.823ps |
| Duty Cycle | 81.092ps |
| Data Dependent(ISI) | 109.06ps |
| Total Jitter | 455.84ps |
| BER Eye Opening | 548.16m ui |

# Bounded Uncorrelated Jitter

- Interconnect and board layout technology is advancing and the greatest area of focus is in reducing the insertion loss and Signal-to-Crosstalk ratio.
- The implications of complex channel interaction can be observed and identified by examining the type and amount of Bounded Uncorrelated Jitter or BUJ.
- There is a strong Cause–and-Effect relationship between Crosstalk and BUJ which often gets classified as Random if special steps are not observed.

**Table 4-6. Stressed Receiver Conditions**

| Symbol | Description |
|---|---|
| Input swing | Inner eye voltage |
| AC-CM_rms | AC Common Mode Voltage rms |
| AC-CM_pk_pk | AC Common Mode Voltage pp |
| BUJ | Bounded Uncorrelated Jitter |
| DDJ | Data Dependent Jitter |
| RJ | Random Jitter |
| TJ | Total Jitter |



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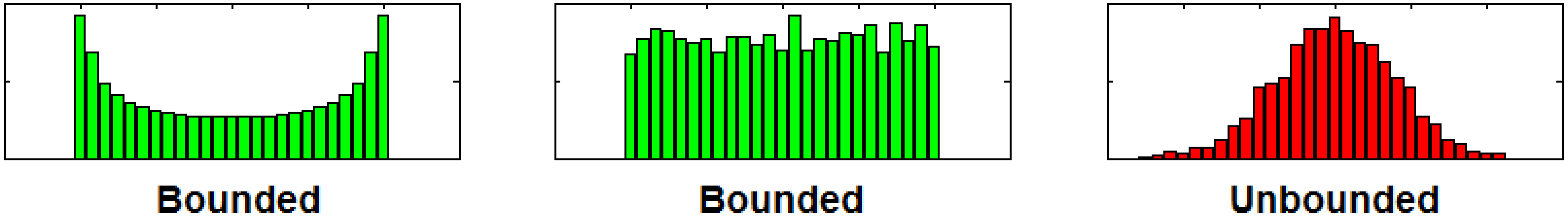
# Bounded Uncorrelated Jitter (BUJ)

- Definitions of Jitter Properties:
  - **Bounded**:  Having a PDF (histogram) that does not grow in width as the observation interval increases




  - **Uncorrelated**: Specifically, not correlated to the pattern of data bits
    - Note that PJ (Periodic Jitter) is both bounded and uncorrelated → BUJ!
  - **Deterministic**: Future behavior can be predicted based on observed past.
    - Deterministic jitter is always bounded
    - But… bounded jitter isn't necessarily deterministic
  - **RJ**:  By convention, random jitter with a Gaussian histogram
  - **NPJ or NP-BUJ**:  Non-Periodic (Bounded Uncorrelated) Jitter.  This is basically random jitter with a bounded PDF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# Jitter Measurement in the Presence of Crosstalk: Problem Summary

- Crosstalk-caused jitter typically is Bounded Uncorrelated Jitter (BUJ); depending on the spectra this should be separated as either
  - PJ (Periodic BUJ)

    or
  - NPJ (Non-Periodic BUJ)
- In traditional oscilloscope-based jitter measurement methodology the more spectrally diffuse BUJ components (i.e. NPJ) are not distinguished from RJ.
  - The inflated RJ is multiplied by a factor, thereby grossly inflating TJ.

Example: TJ = DJ + **14***RJ (at BER = 1e-12)

- This is well known and was documented e.g. in "*Method of BER Analysis of High Speed Serial Data Transmission in Presence of Jitter and Noise*", Zivny at all, DesignCon 2007.



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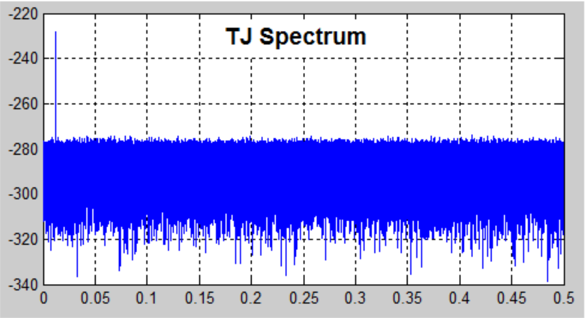
# Crosstalk Problem Summary (Graphical Version)

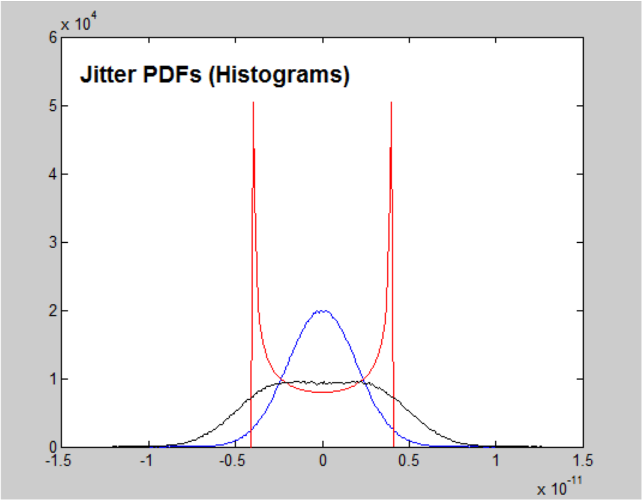
## Case 1:
## RJ + PJ

Spectral separation works very well

**Simulated Jitter, Population = 1e6 observations**

**Blue = Gaussian RJ, 2 ps rms**
**Red = Sinusoidal Jitter, 8 ps p-p**
**Black = RJ + PJ = TJ**



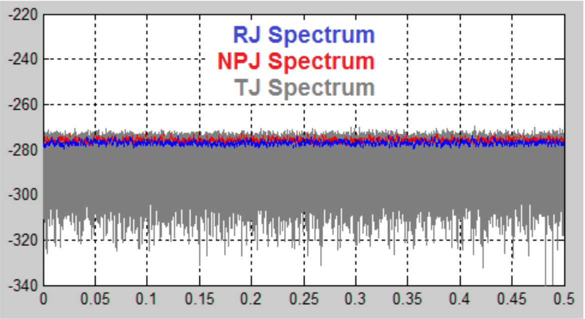



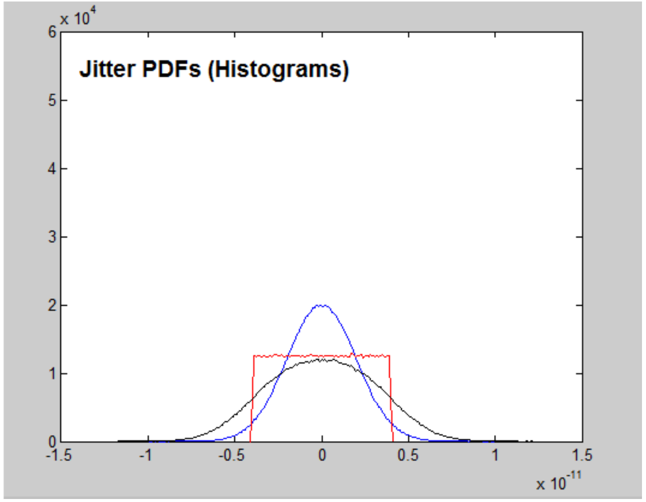

## Case 2:
## RJ + NPJ

Spectral separation is no help at all

**Simulated Jitter, Population = 1e6 observations**

**Blue = Gaussian RJ, 2 ps rms**
**Red = Uniformly Distributed NPJ, 8 ps p-p**
**Black = RJ + NPJ = TJ**



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# Theory: Q-Scale Analysis for Detecting NPJ

- Cumulative Distribution Function (CDF) for a Gaussian Distribution:

$$CDF(x_{Gaus}) = \frac{1 + erf\left(\frac{x}{\sigma\sqrt{2}}\right)}{2}$$

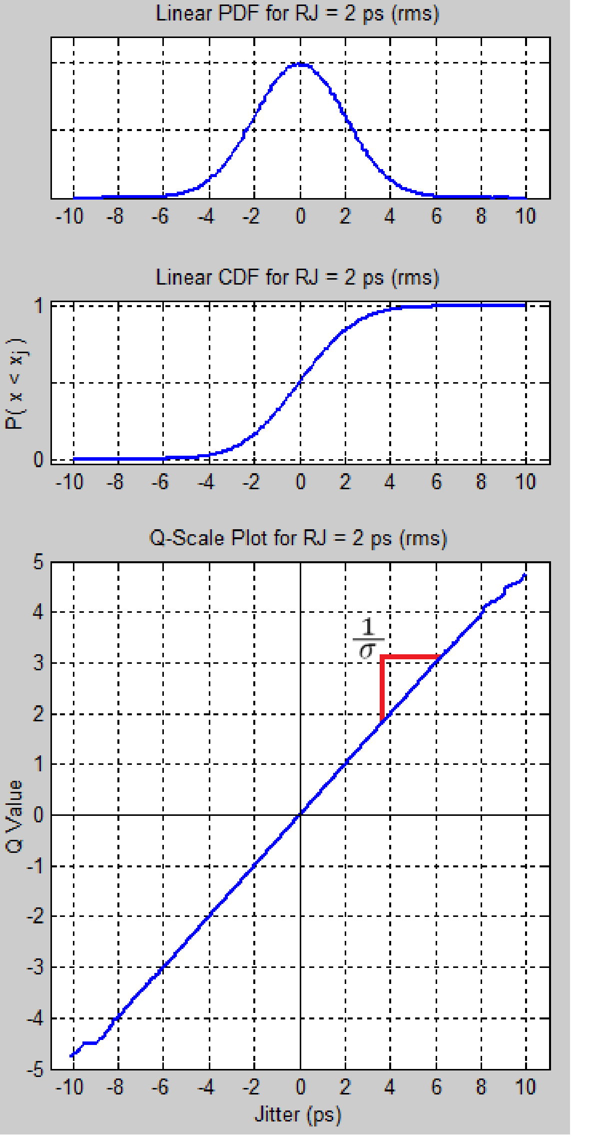
- Q Scale Definition:

$$Q(x) = \sqrt{2} * erf^{-1}(2CDF(x) - 1)$$

- Q Scale for a Gaussian:

$$Q(x_{Gaus}) = \frac{x}{\sigma}$$

  – This is a straight line with a slope of 1/σ!



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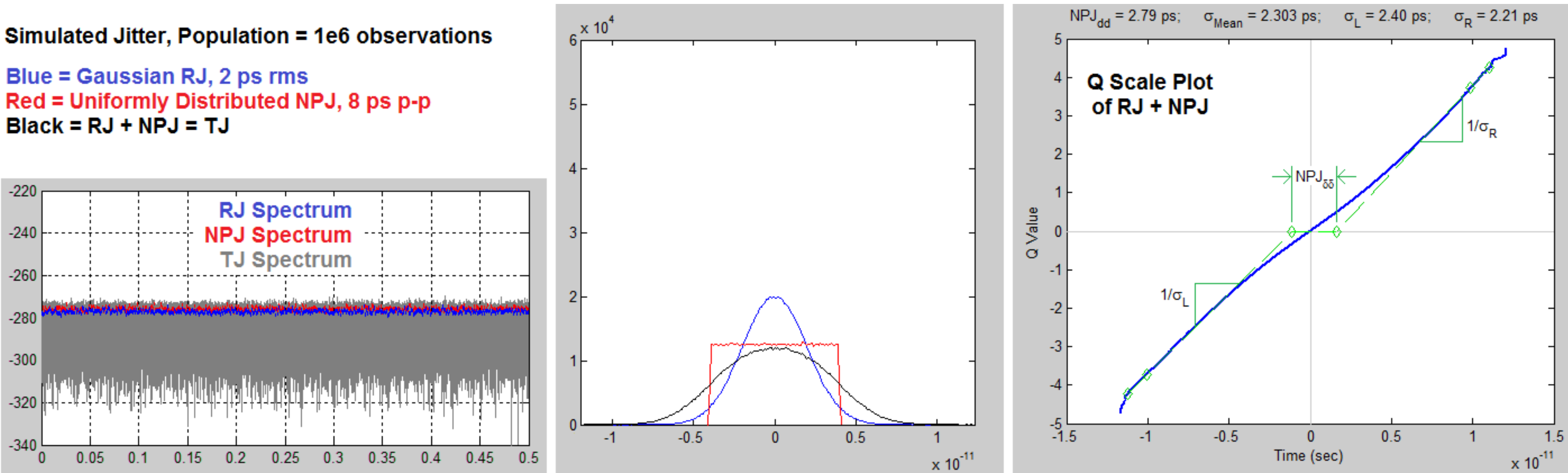
# Separation of BUJ and RJ Jitter Components Methodology

- After PJ and DDJ are removed using the spectral approach, RJ + NPJ is converted to a histogram and then plotted using the Q Scale
- Straight lines are fitted to the left and right tails to determine both the RJ sigma and the dual-dirac weight of the NPJ




Spectral-Only Method: TJ(1e-12) = 0.00 + 3.056 * 14 = 42.8 ps

Spectral+BUJ Method: TJ(1e-12) = 2.79 + 2.303 * 14 = 35.0 ps



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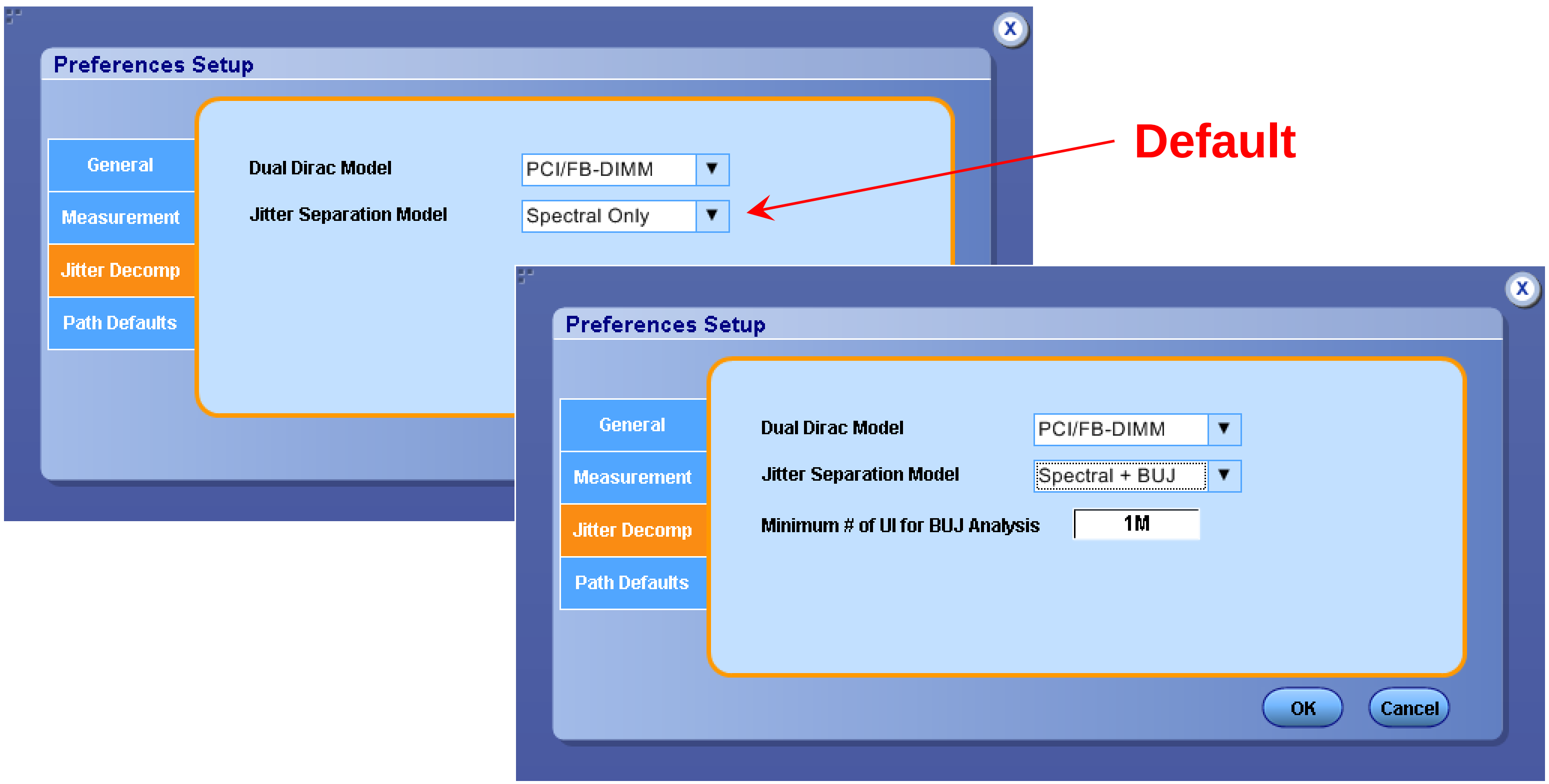
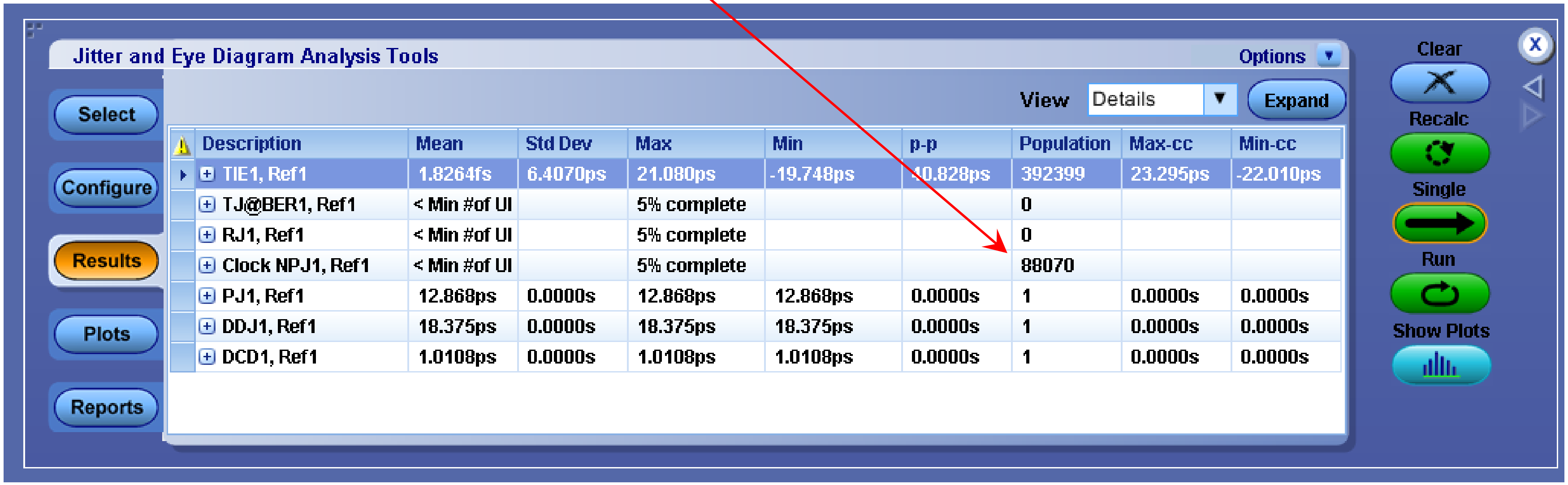
# DPOJET Setup for BUJ / NPJ Measurements

- **Enable** Spectral+BUJ either through the Preferences Setup or the Jitter Map
- **Minimum # of UI** control is only available via Preferences Setup
  - Default is 1M but it can be reduced as low as 10k.
  - Agilent EZJIT has a similar (non-adjustable) population requirement, ~ 150k



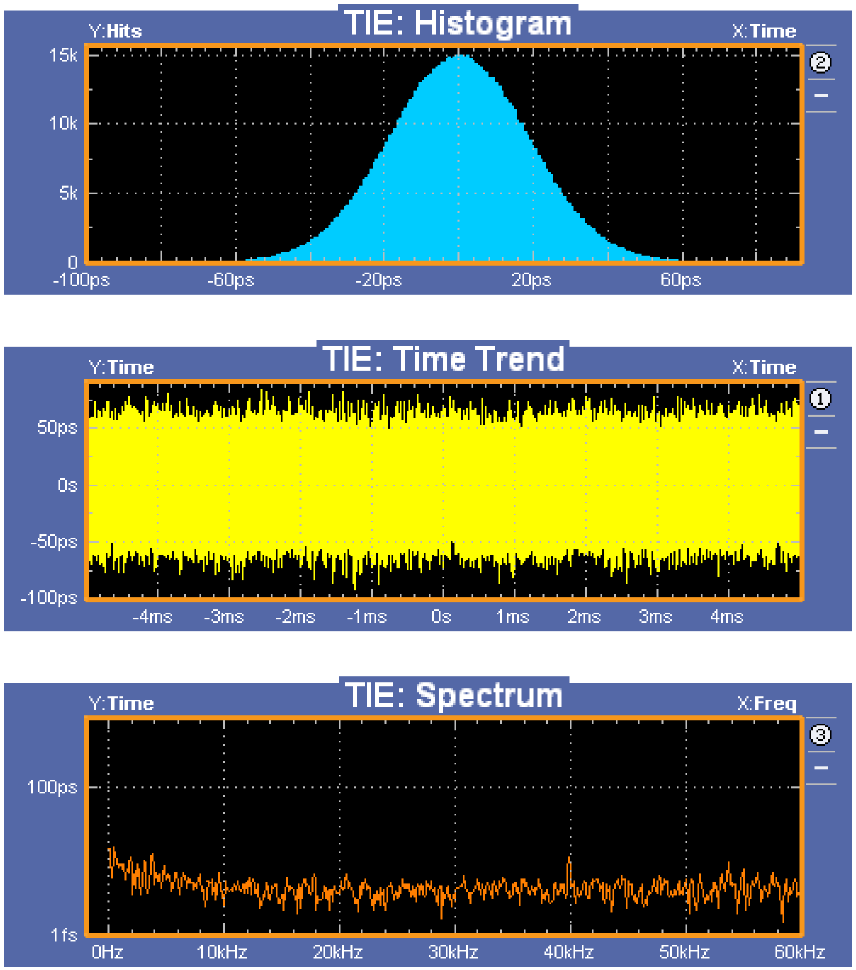
# DPOJET Results for BUJ / NPJ Measurements

- Clock NPJ measurement shows actual progress toward the population requirement

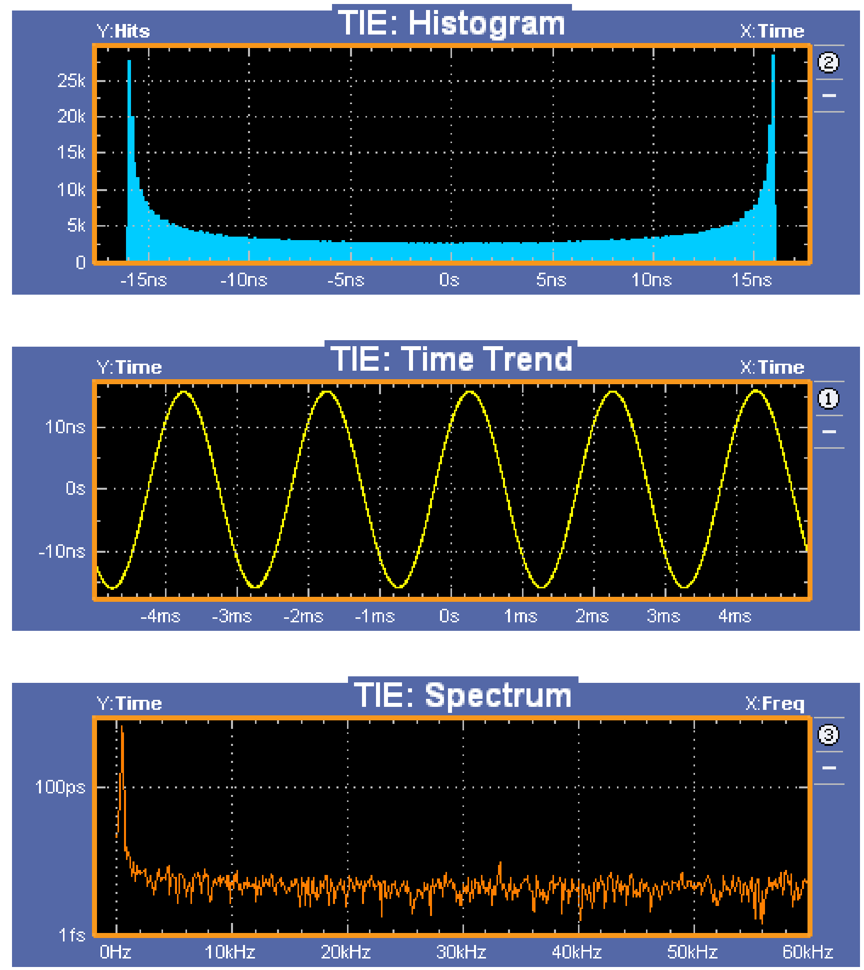



| Description | Mean | Std Dev | Max | Min | p-p | Population | Max-cc | Min-cc |
|---|---|---|---|---|---|---|---|---|
| TIE1, Ref1 | 1.8264fs | 6.4070ps | 21.080ps | -19.748ps | 40.828ps | 392399 | 23.295ps | -22.010ps |
| TJ@BER1, Ref1 | < Min #of UI | | 5% complete | | | 0 | | |
| RJ1, Ref1 | < Min #of UI | | 5% complete | | | 0 | | |
| Clock NPJ1, Ref1 | < Min #of UI | | 5% complete | | | 88070 | | |
| PJ1, Ref1 | 12.868ps | 0.0000s | 12.868ps | 12.868ps | 0.0000s | 1 | 0.0000s | 0.0000s |
| DDJ1, Ref1 | 18.375ps | 0.0000s | 18.375ps | 18.375ps | 0.0000s | 1 | 0.0000s | 0.0000s |
| DCD1, Ref1 | 1.0108ps | 0.0000s | 1.0108ps | 1.0108ps | 0.0000s | 1 | 0.0000s | 0.0000s |

# Jitter Visualization



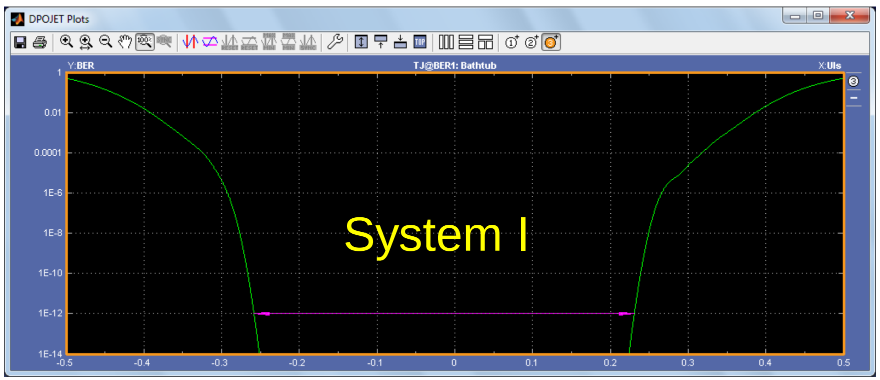

Gaussian Random Noise

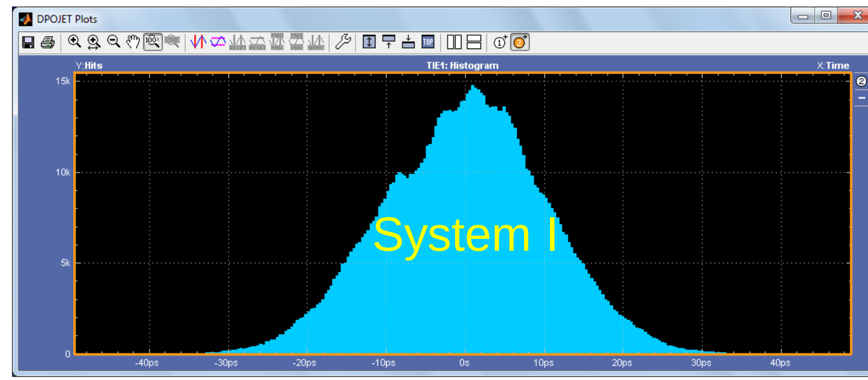


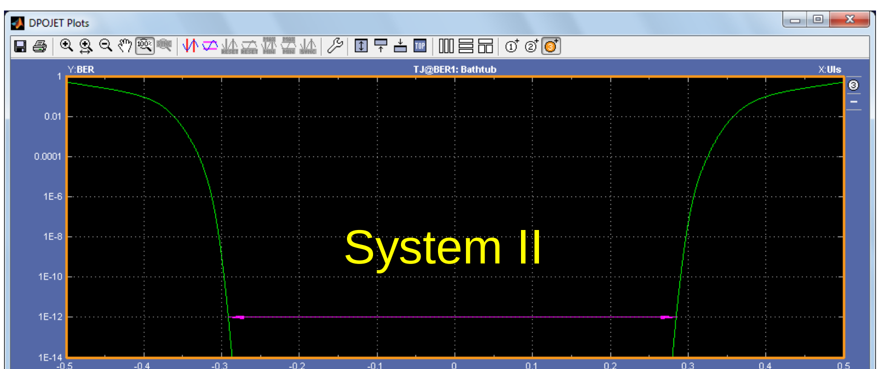

Sinusoidal Jitter

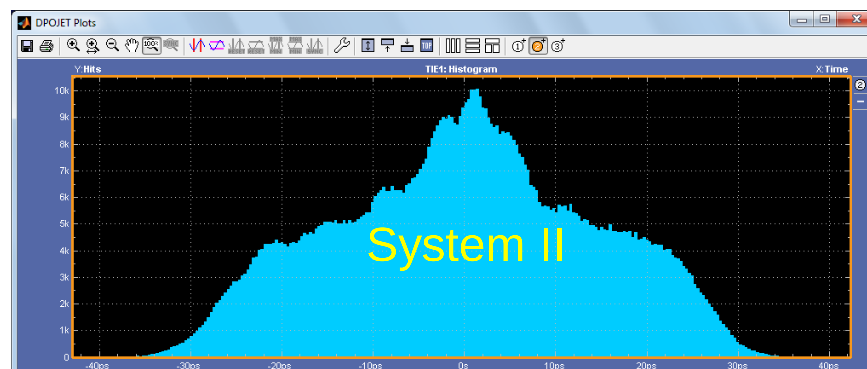
# Jitter Visualization – Bathtub Plot

- Shows the Eye Opening at a Specified BER Level
- Note the eye closure of System I vs. System II due to the RJ- RJ is unbounded so the closure increases as BER level increases
    - System I has .053UI of RJ with no PJ
    - System II has .018UI of RJ and .14UI of PJ @ 5 and 10Mhz



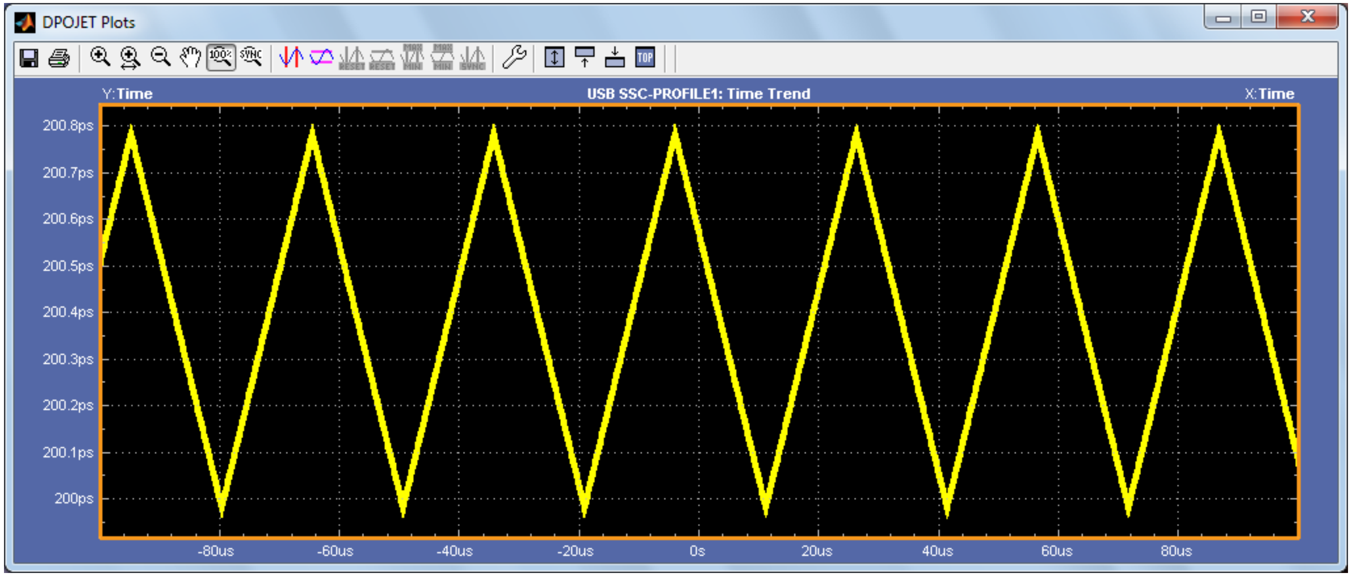



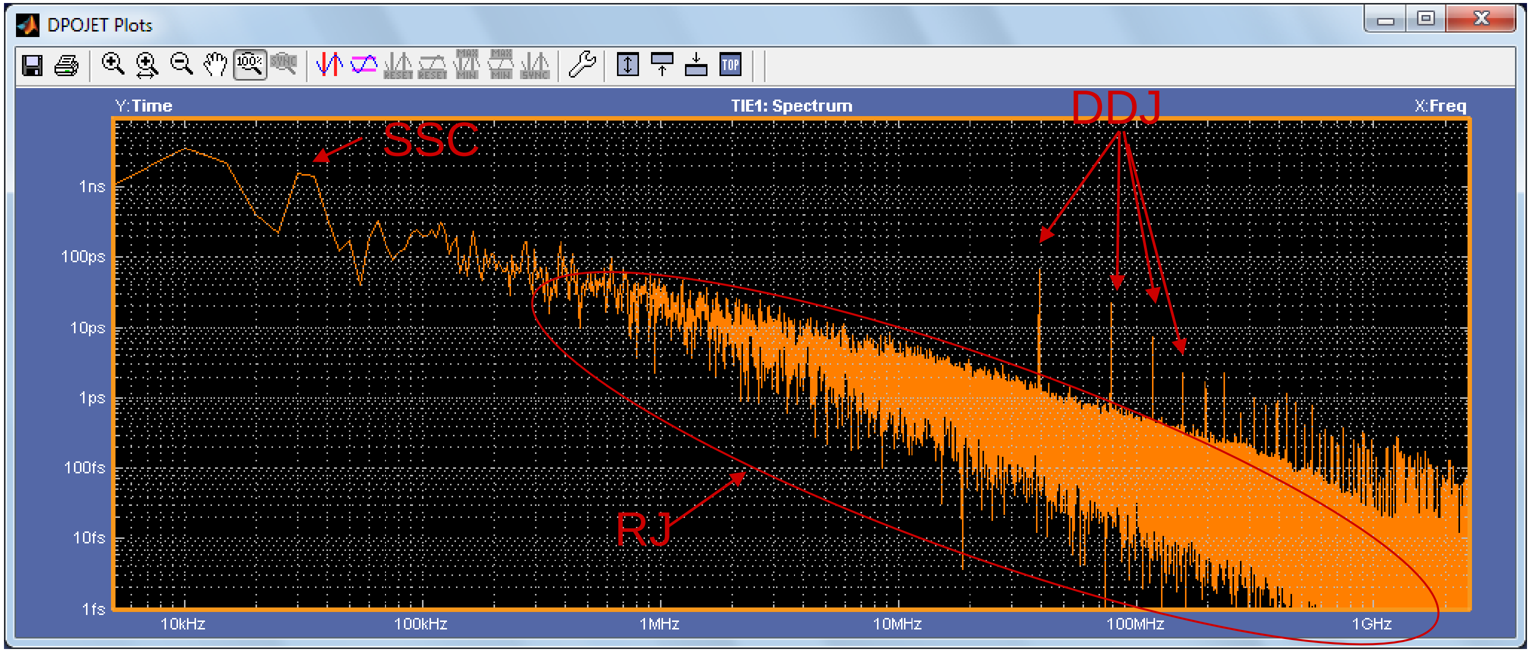
# Jitter Visualization – Time Trend

- Histogram does not have any context of time
- Time Trend can reveal repeating patterns that may indicate modulation on the signal
  - For example 5 cycle of  SSC @ 30khz  as shown below



# Jitter Visualization – Spectral Plot

- Frequency domain view of the signal content
- Deterministic components show as lines above the noise
  - DDJ is at frequencies of the bit rate / pattern length (example below is 5Gb/s PRBS7) Note the spikes at intervals of 40Mhz in the plot.
  - Constant Clock CR was used



# TIE Jitter needs a Reference Clock

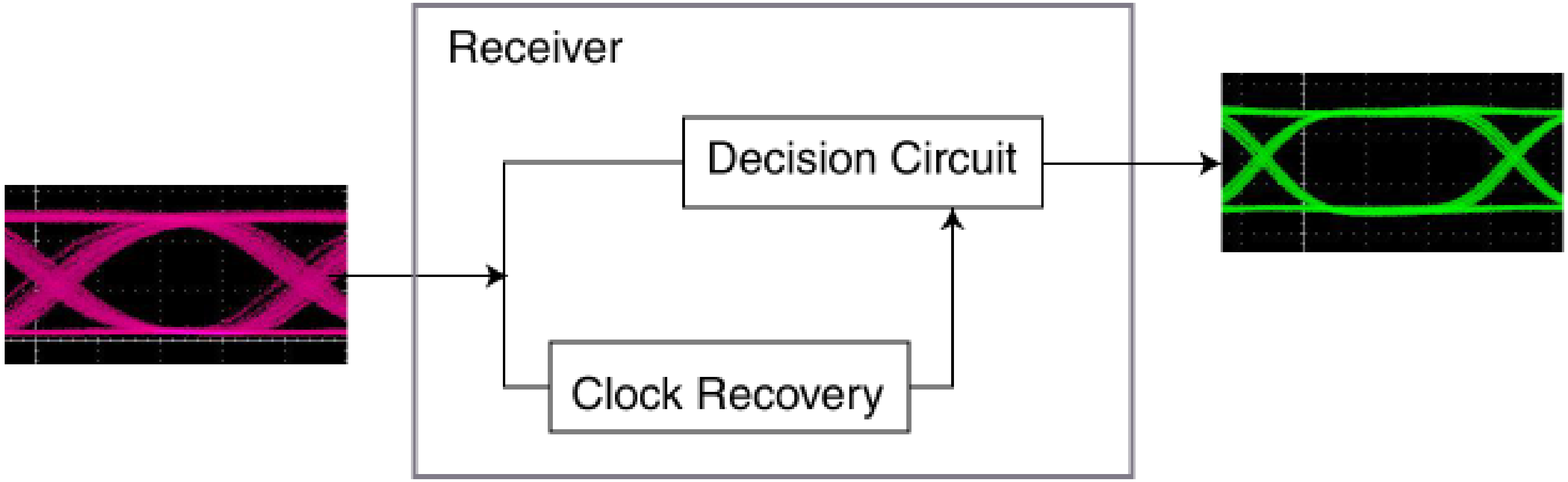
- The process of identifying the reference clock is called Clock Recovery.
- There are several ways to define the reference clock:
  - Constant Clock with Minimum Mean Squared Error
    - This is the mathematically “ideal” clock
    - But, only applicable when post-processing a finite-length waveform
    - Best for showing very-low-frequency effects
    - Also shows very-low-frequency effects of scope’s timebase
  - Phase Locked Loop (e.g. Golden PLL)
    - Tracks low-frequency jitter (e.g. clock drift)
    - Models “real world” clock recovery circuits very well
  - Explicit Clock
    - The clock is not recovered, but is directly probed
  - Explicit Clock (Subrate)
    - The clock is directly probed, but must be multiplied up by some integral factor

# Reference Clock for Jitter : Clock Recovery?

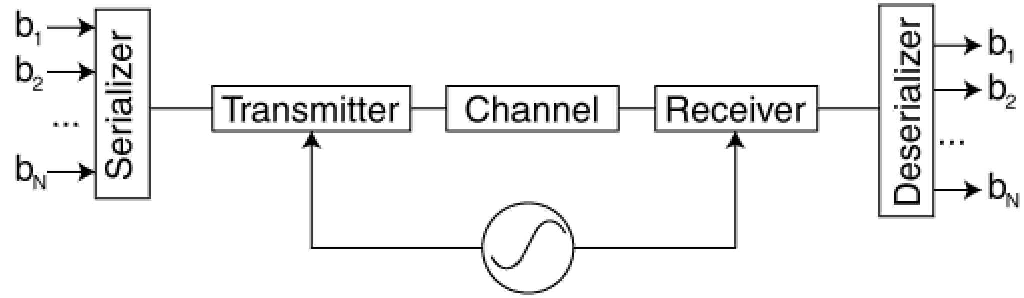
In a receiver

- The clock positions the sampling point
- Comparator determines logic level

How can we reduce the effect of jitter in the decision circuit?



a)




“Obvious approach” with an absolute reference clock:

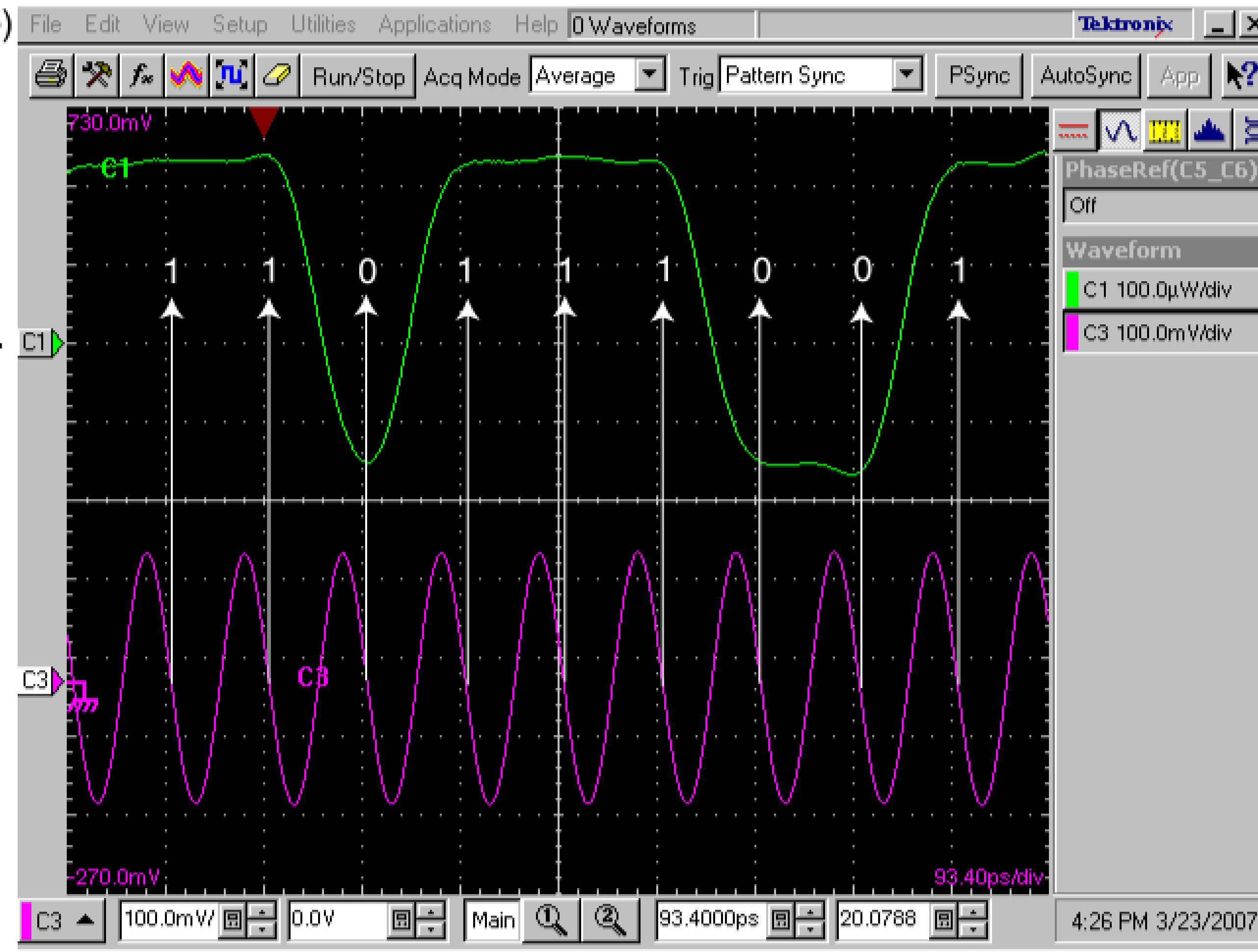
$UI = 1/T_{Bit}$

$Skew = mod(\Delta t, T_{BIT})$

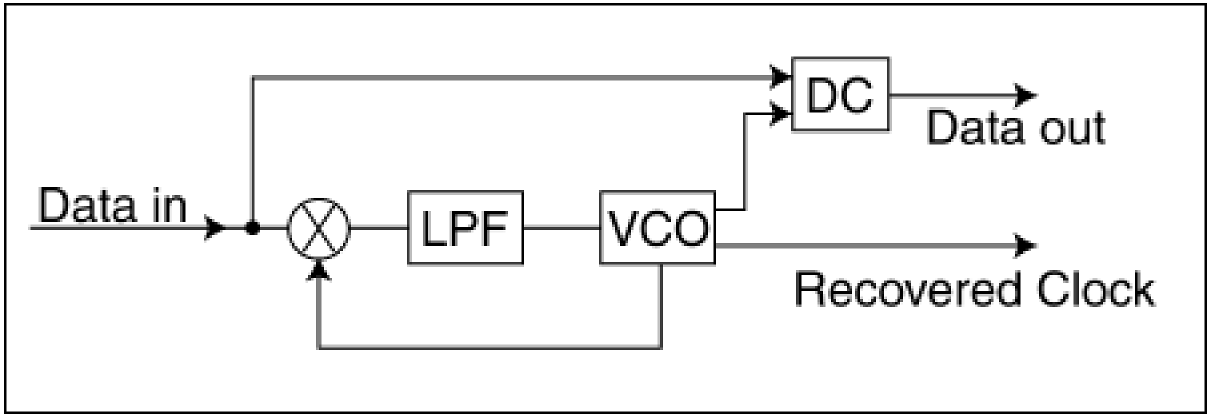
Rx samples at the center of each bit…

doesn’t it?

b)



# Phase Locked Loop Clock Recovery




To extract a useful clock, the data must…

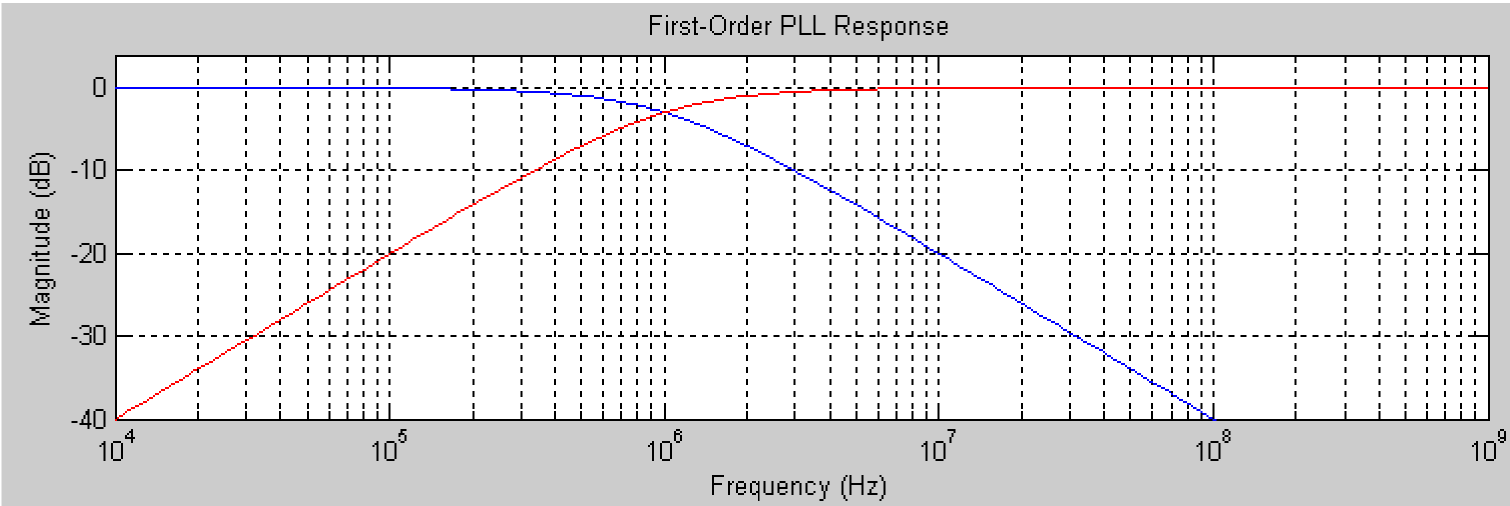
- Have plenty of logic transitions
  - No long runs of identical bits
- Be DC balanced

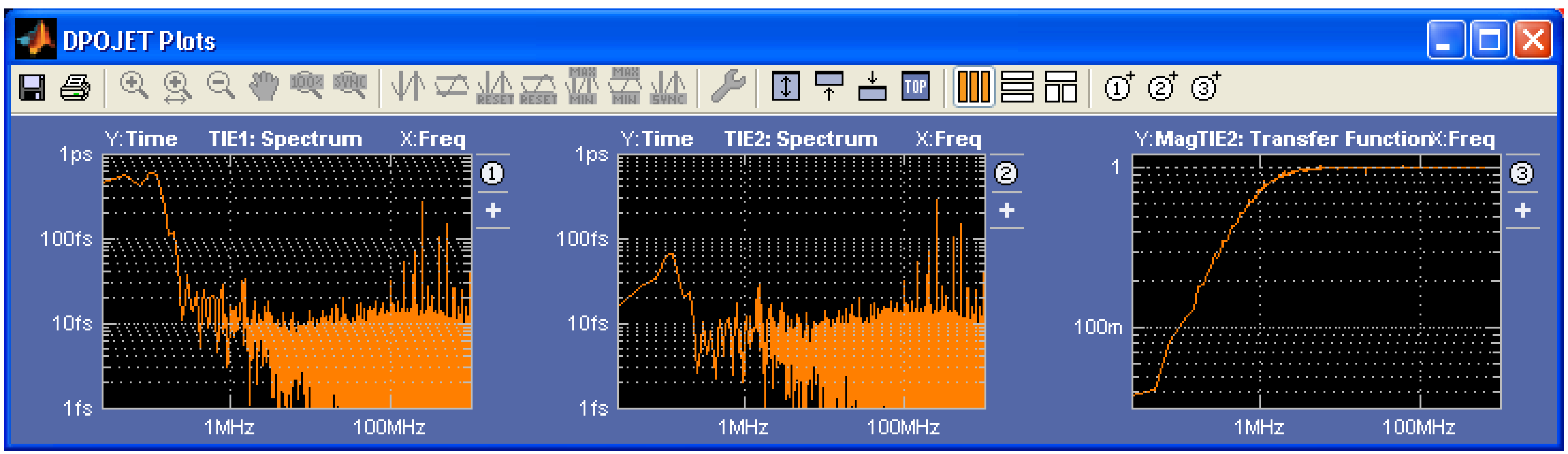
Data signals are encoded, e.g., 8B/10B encoding

# JTF vs PLL Loop Bandwidth

- Configuring the correct PLL settings is key to correct measurements
- Most standards have a reference/defined CR setup
  - For example, USB 3.0 uses a Type II with JTF of 4.9Mhz
- Type I PLL
  - Type I PLL has 20dB of roll off per decade
  - JTF and PLL Loop Bandwidth are Equal
- Type 2 PLL
  - Type II PLL has 40dB of roll off per decade
  - JTF and PLL Loop Bandwidth are not Equal
    - For example, USB 3.0 uses a Type 2 PLL with a JTF of 4.9Mhz. The corresponding loop bandwidth is 10.126 Mhz
    - Setting the Loop Bandwidth as opposed to JTF will lead to incorrect jitter measurement results

# PLL Loop Bandwidth vs. Jitter Transfer Function (JTF)




A: Constant Clock Recovery B: PLL Clock Recovery Ratio of B/A



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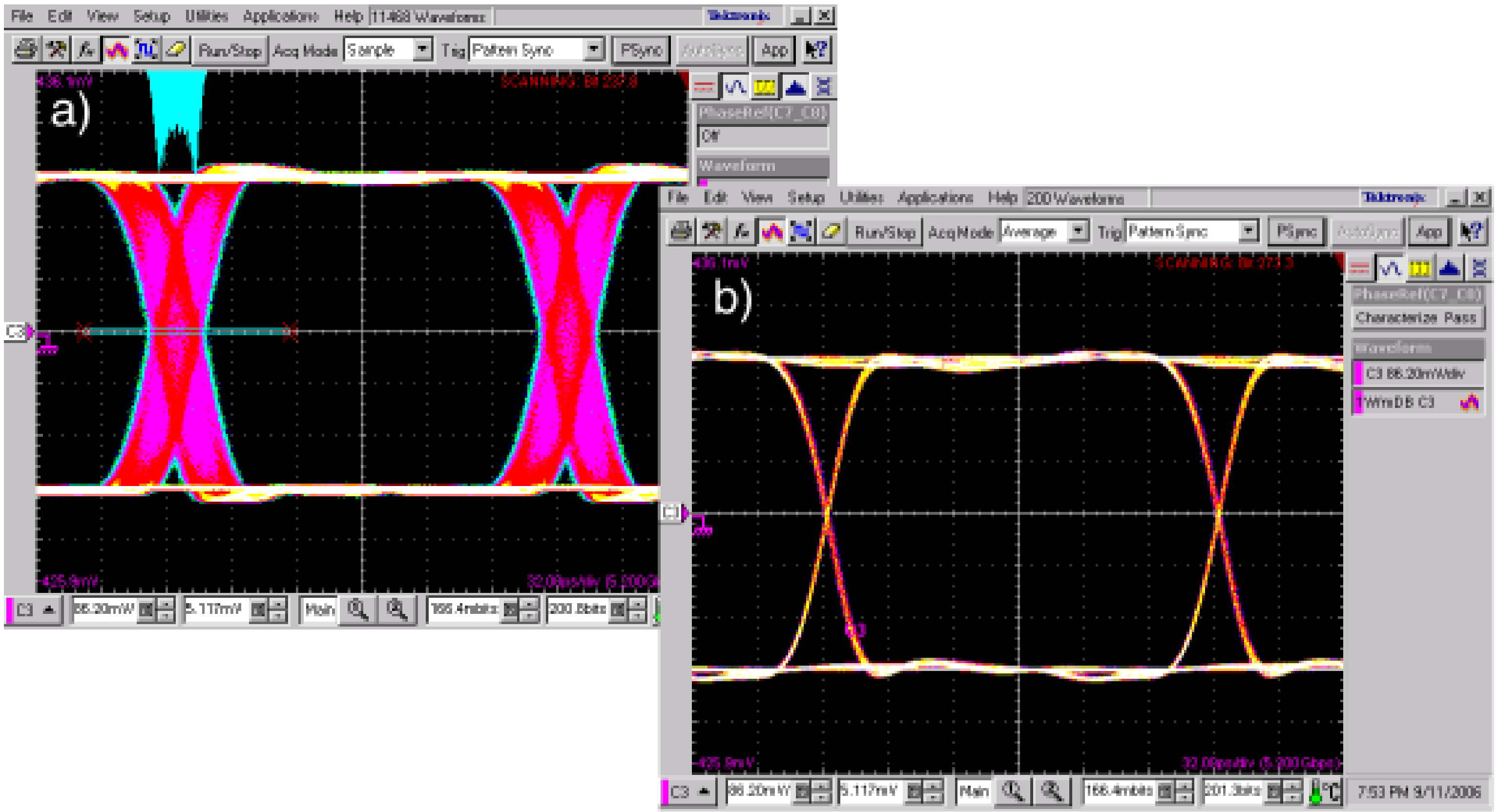
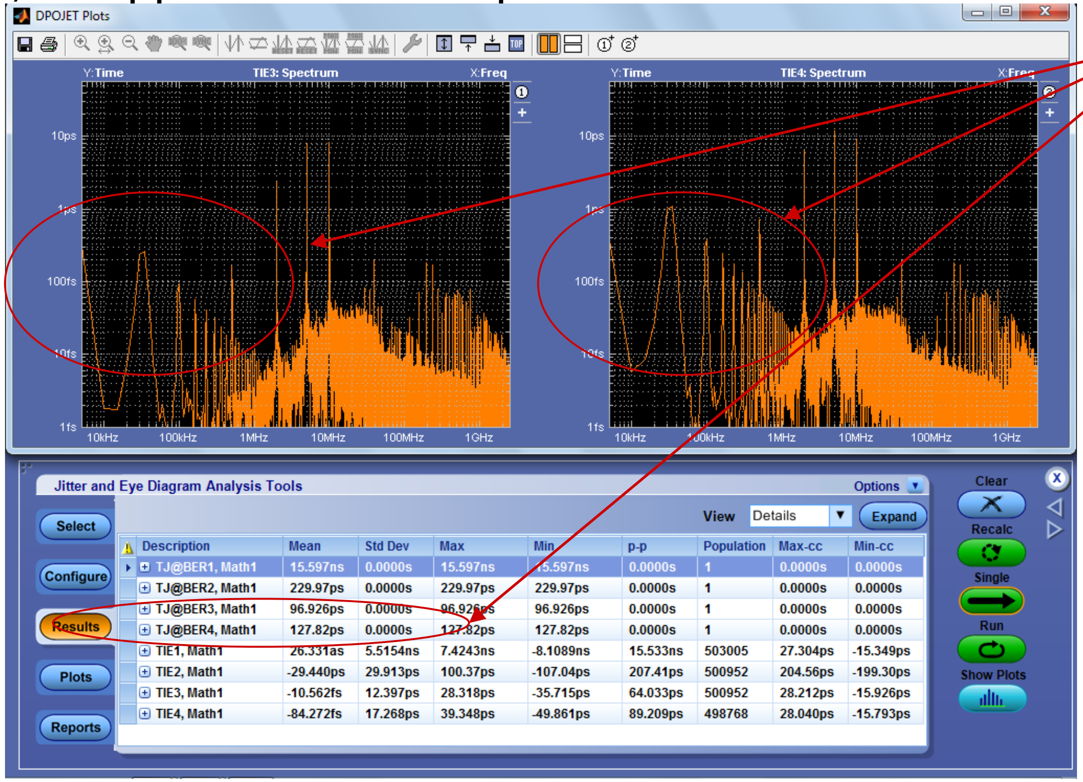
# Effect of CR Bandwidth on Eye Opening



# Results depend on CR Settings USB 3.0 Example

- The example below shows the effects of using a JTF set to 4.9Mhz vs. Loop Bandwidth set to 4.9Mhz for a Type II PLL
- Note the difference in the jitter that is tracked
  - The results on the left are correct as the JTF was properly set to 4.9Mhz, as opposed to the loop bandwidth




Note: More LF Attenuation for case where JTF set to 4.9Mhz and lower TJ



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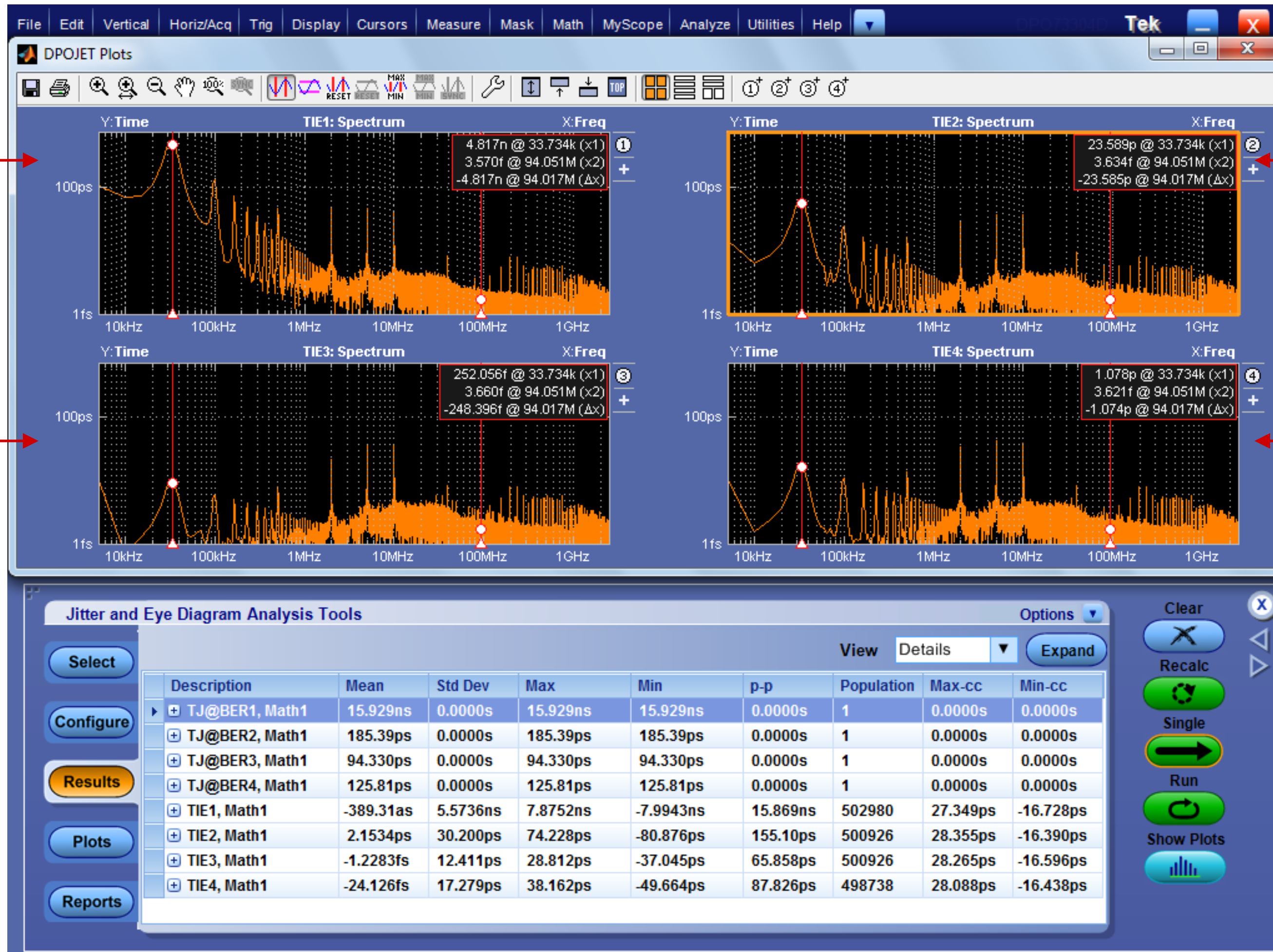
# Further Comparison of PLL Types using Spectrum Plots

**Constant Clock**
All Jitter Passes Through

**Type II**
40 dB roll off per decade @ 4.9Mhz




**Type I**
20 dB roll off per decade @ 4.9Mhz

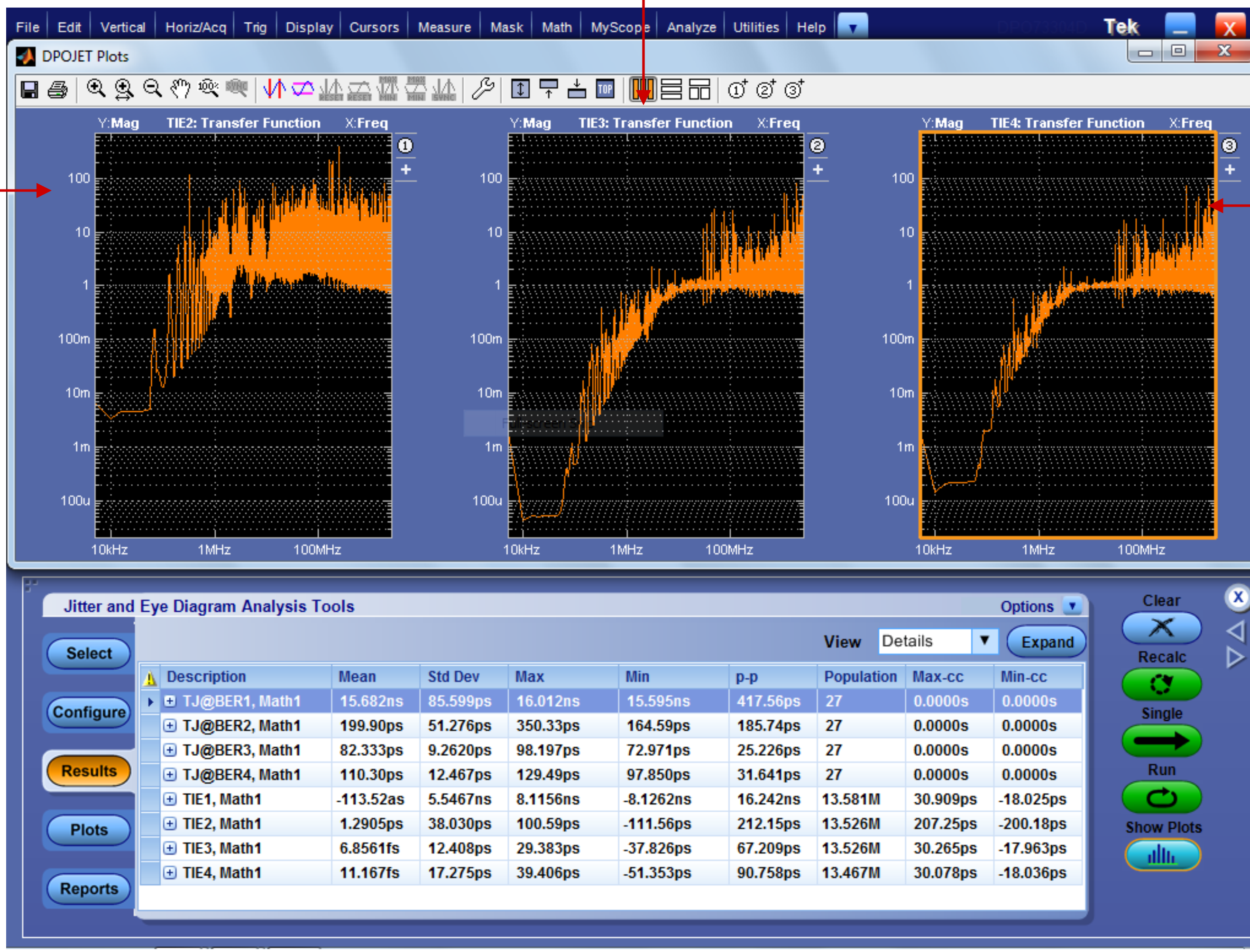
**Type II**
40 dB roll off per decade @ 2.3Mhz (JTF to illustrate JTF ! = Loop Bandwidth

First Cursor in each plot is @ 33Khz to illustrate effect on SSC

# Further Comparison of PLL Types using Transfer Function Plots

**Type II**
40 dB roll off per decade @ 4.9Mhz

**Type I**
20 dB roll off per decade @ 4.9Mhz

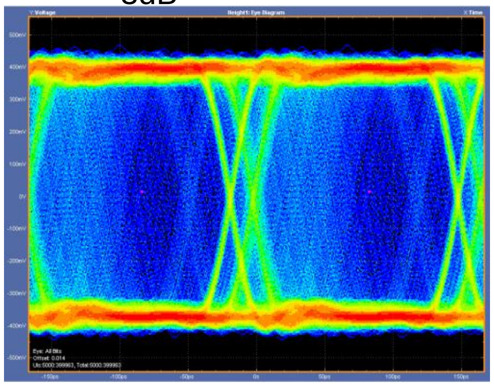



| Description | Mean | Std Dev | Max | Min | p-p | Population | Max-cc | Min-cc |
|---|---|---|---|---|---|---|---|---|
| TJ@BER1, Math1 | 15.682ns | 85.599ps | 16.012ns | 15.595ns | 417.56ps | 27 | 0.0000s | 0.0000s |
| TJ@BER2, Math1 | 199.90ps | 51.276ps | 350.33ps | 164.59ps | 185.74ps | 27 | 0.0000s | 0.0000s |
| TJ@BER3, Math1 | 82.333ps | 9.2620ps | 98.197ps | 72.971ps | 25.226ps | 27 | 0.0000s | 0.0000s |
| TJ@BER4, Math1 | 110.30ps | 12.467ps | 129.49ps | 97.850ps | 31.641ps | 27 | 0.0000s | 0.0000s |
| TIE1, Math1 | -113.52as | 5.5467ns | 8.1156ns | -8.1262ns | 16.242ns | 13.581M | 30.909ps | -18.025ps |
| TIE2, Math1 | 1.2905ps | 38.030ps | 100.59ps | -111.56ps | 212.15ps | 13.526M | 207.25ps | -200.18ps |
| TIE3, Math1 | 6.8561fs | 12.408ps | 29.383ps | -37.826ps | 67.209ps | 13.526M | 30.265ps | -17.963ps |
| TIE4, Math1 | 11.167fs | 17.275ps | 39.406ps | -51.353ps | 90.758ps | 13.467M | 30.078ps | -18.036ps |

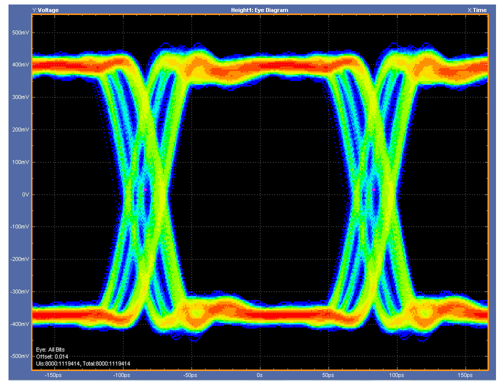
**Type II**
40 dB roll off per decade @ 2.3Mhz (JTF to illustrate JTF != Loop Bandwidth

# JTF Filtering Effects based on different PLL bandwidths

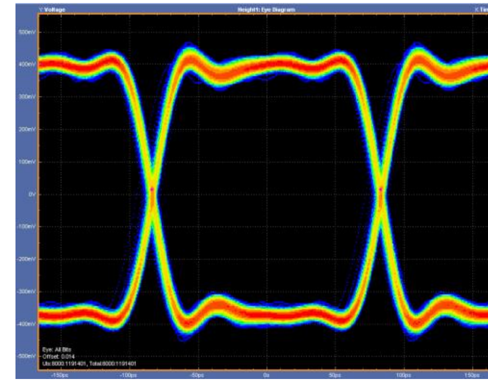
$f_{3dB}$ = 30 kHz

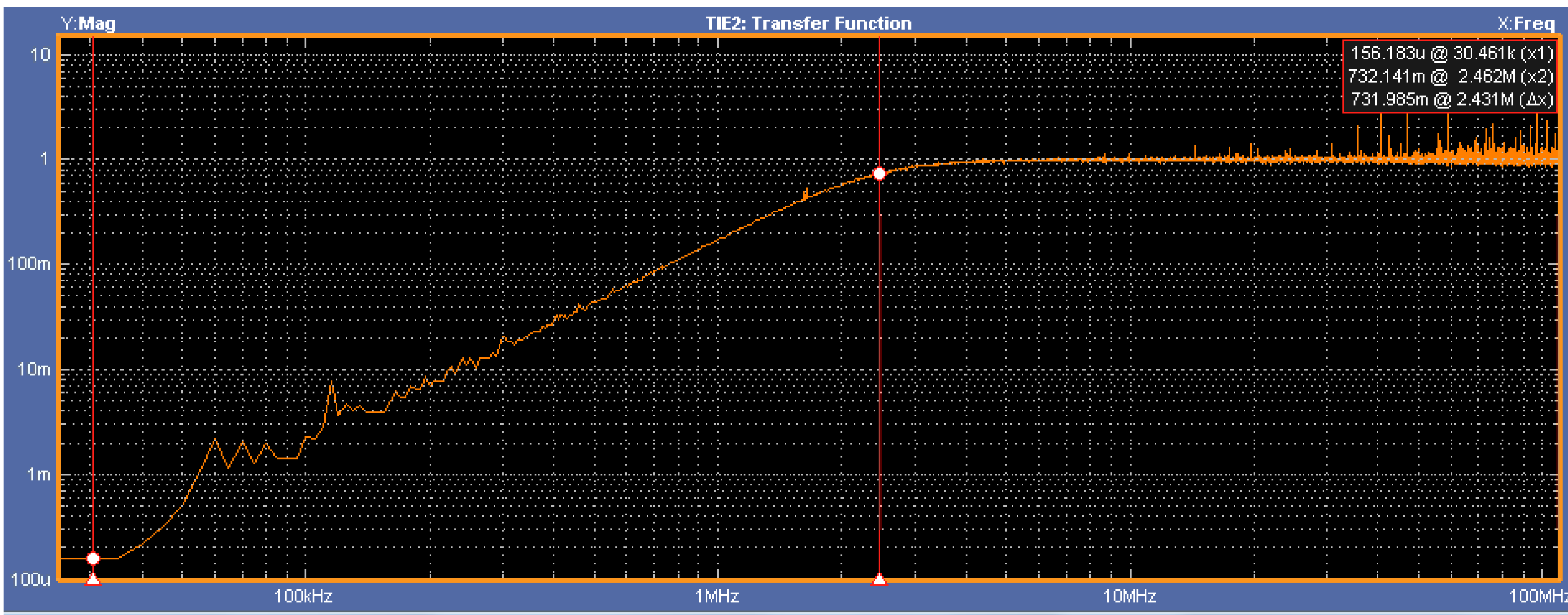


$f_{3dB}$ = 300 kHz



$f_{3dB}$ = 3 MHz

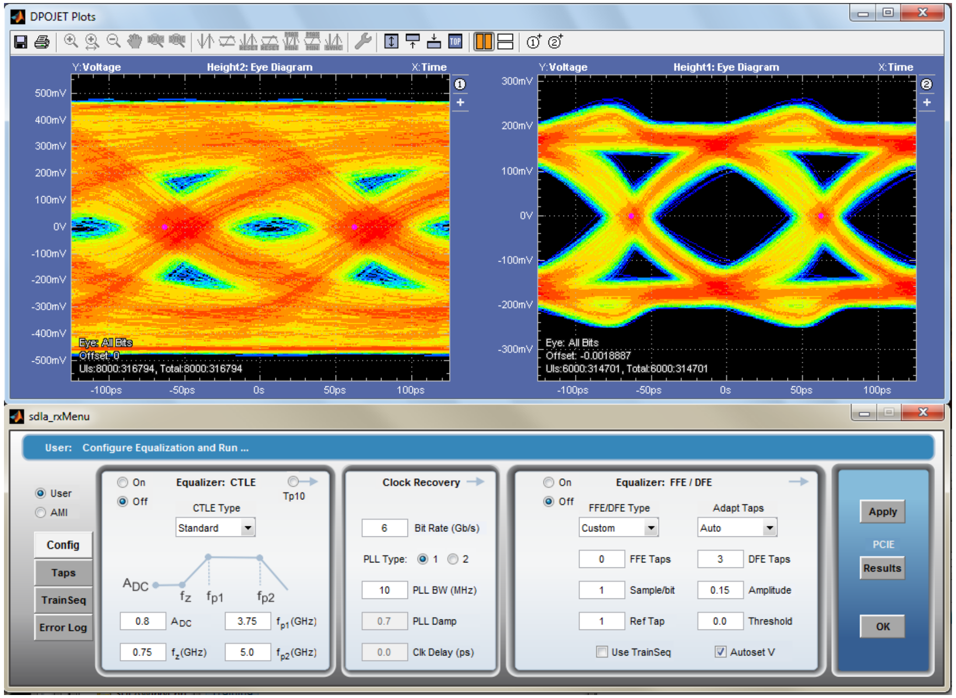




# Open Closed Eyes

*Apply Receiver Equalization*

- The example below shows a PCI Express 3.0 signal at the far end (input to the receiver)
  - Note that the eye is closed
  - Note that clock recovery would have failed due to the channel loss
  - After applying DFE equalization the signal can be measured with DPOJET

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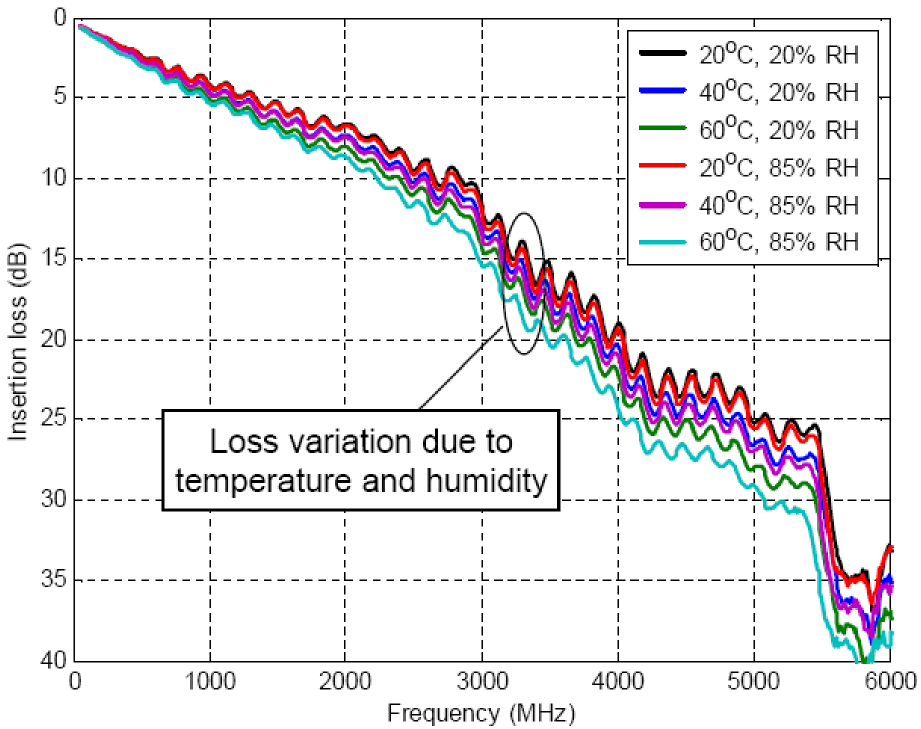
# The problem *is the channel* …

→ Channel exhibits large frequency dependent loss



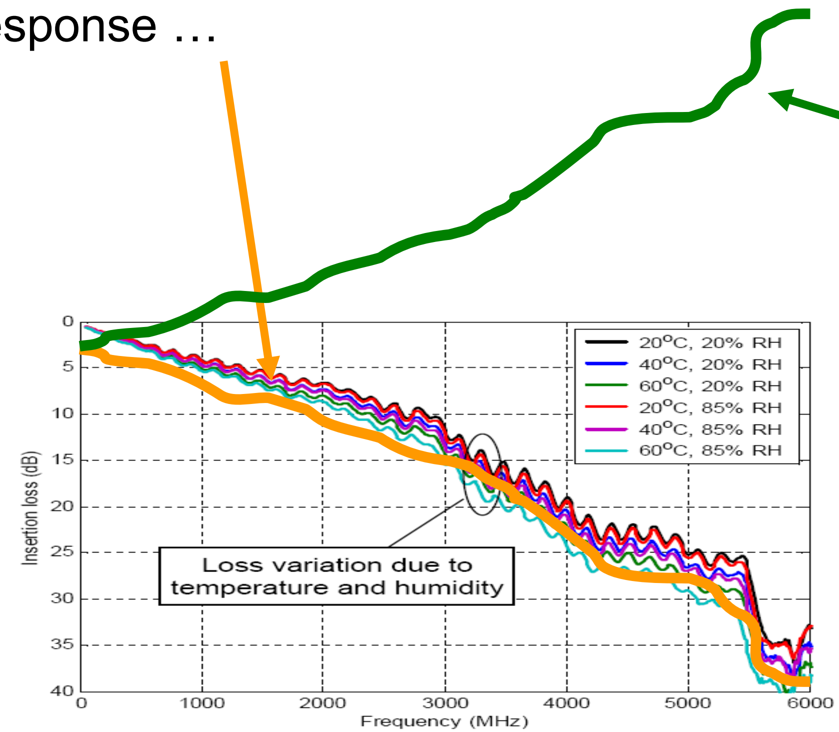

- Loss/dispersion of the channel closes the eye
- Receivers now incorporate methods to compensate for loss (equalization)

Graph from IEEE 802.3ap effort

# Equalization: The solution #1: High Frequency "Boost"

The problem is just what you'd think it would be:

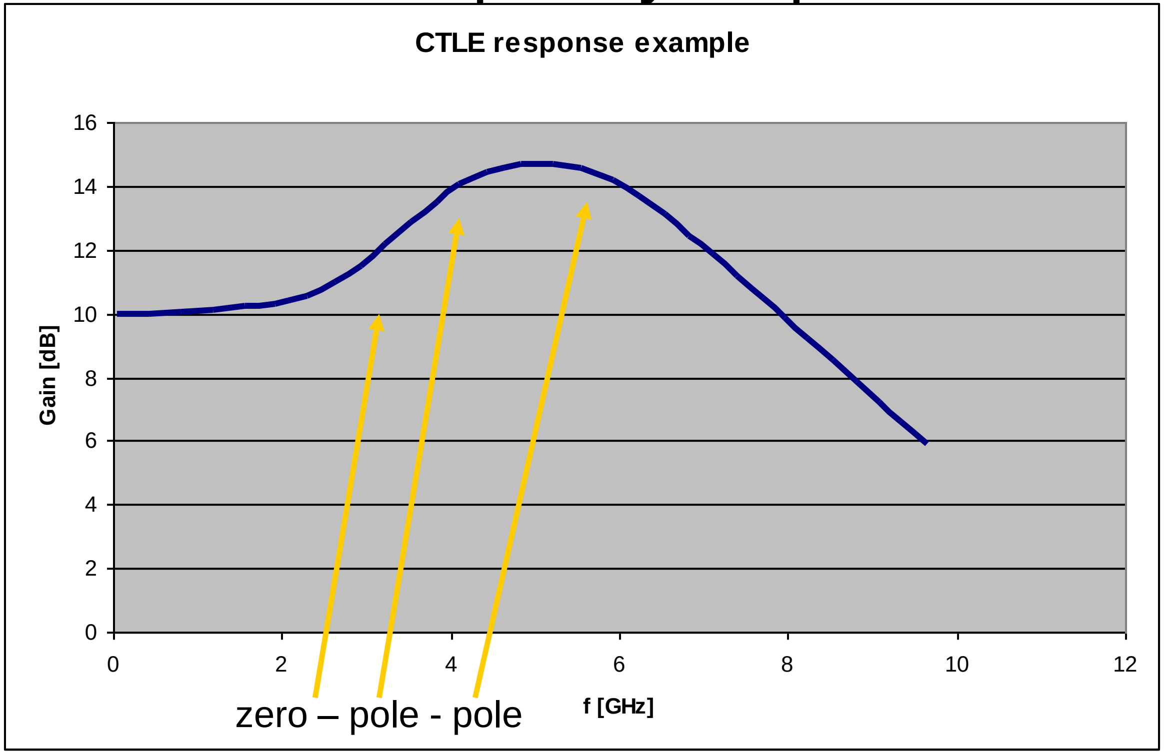
- To compensate for this channel response …




- …you need to boost the channel so much.

The noise amplification is huge, and it hurts the improvement you get (Signal to noise)

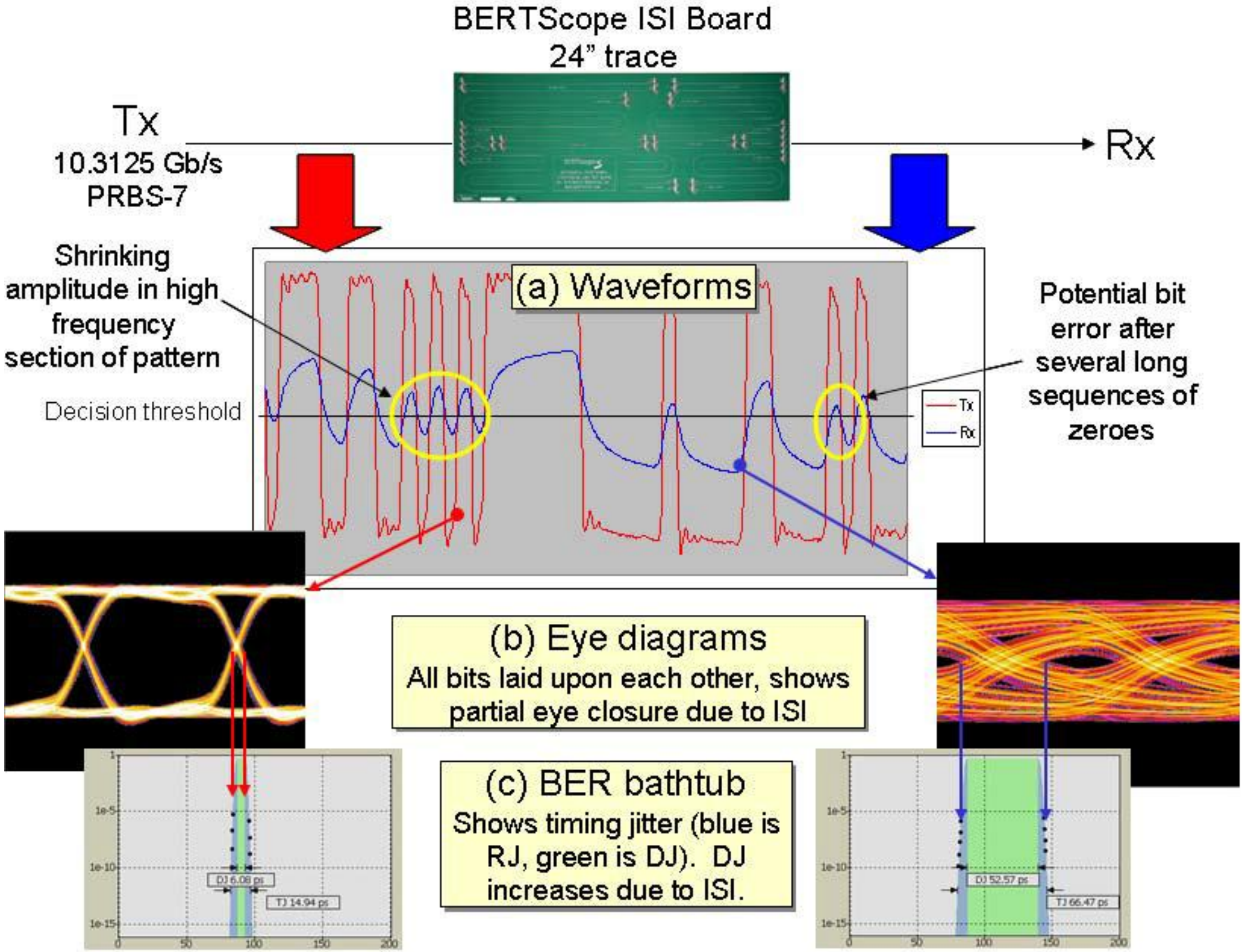
# Equalization: CTLE frequency response




- CTLE – Continuous Time Linear Equalization
- Linear HF filter/boost
- Advantages: Low power & Simple implementation
- … but it amplifies noise

# Channel Testing

## *Simulate Compliance Channels*

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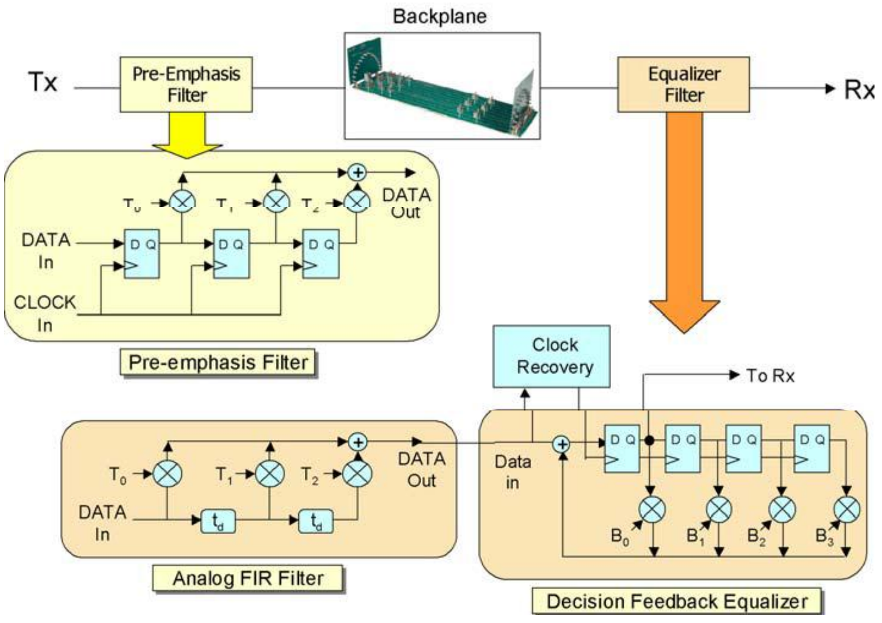
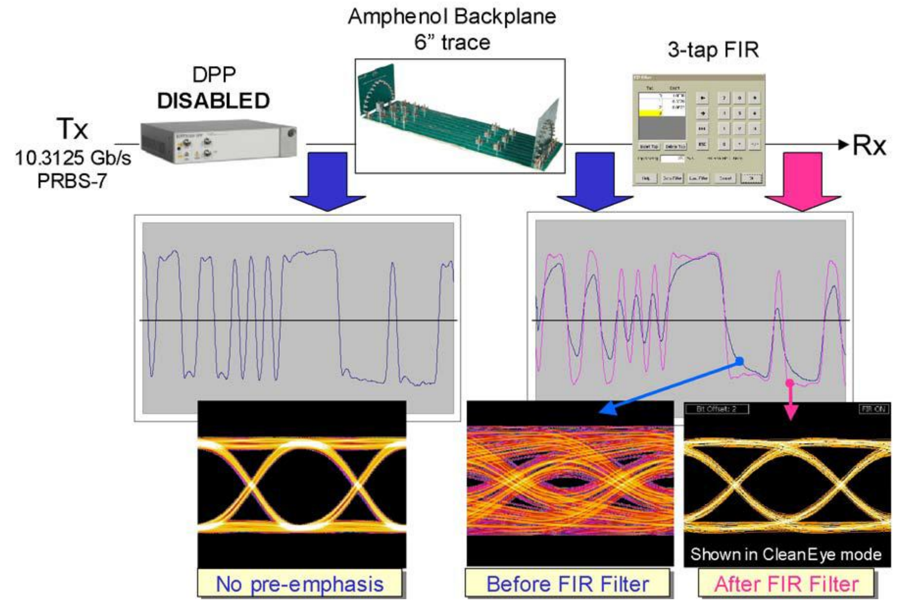
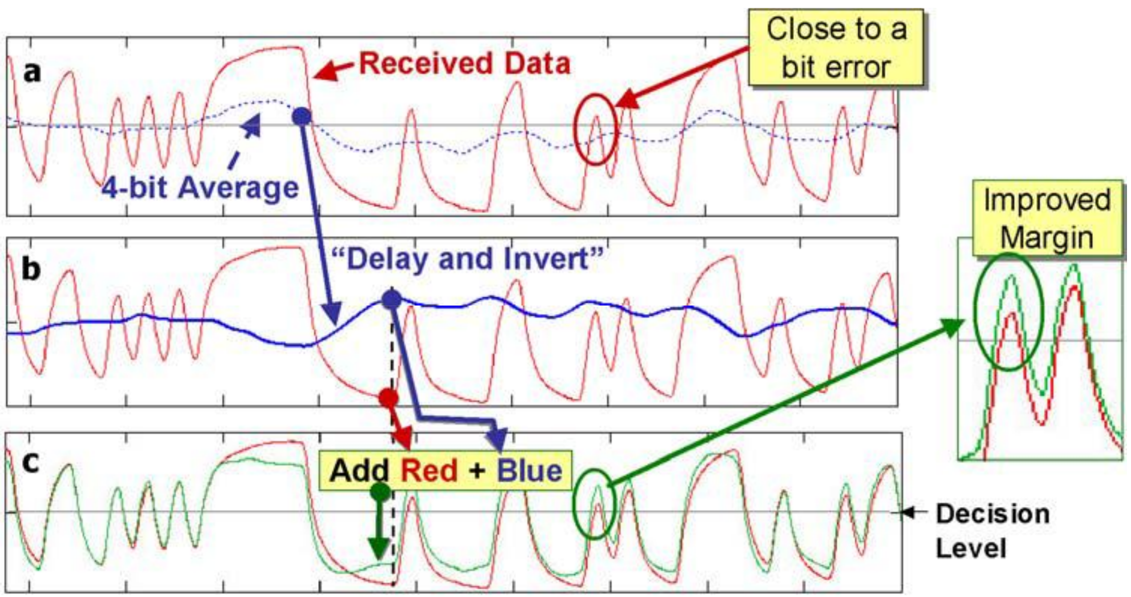
# Channel Testing

## *Simulate Compliance Channels*

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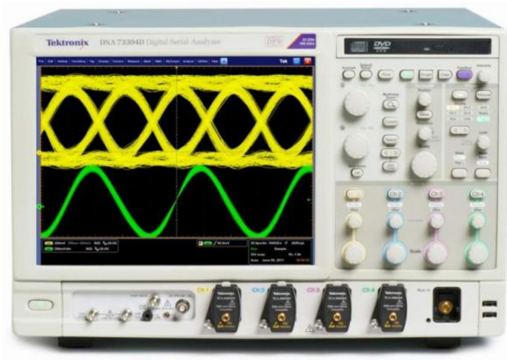
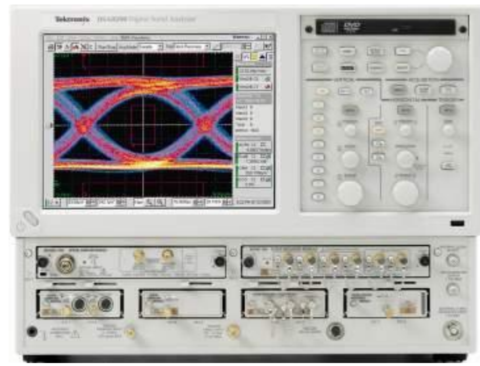
# Trois Instruments pour la même mesure Tx?

# Real-time Scope, Sampling Scope, BERT Scope





**Scope BW 70GHz**
**AWG BW 18GHz**

**Standard tool for Tx test Datacom**

**Rx test < 6.25Gbits**

**Optical and Electrical BW 80GHz**

**Standard tool for Tx test Telecom**

**No Rx test**

**BERT Scope**
**28.6Gbits Tx/Rx**

**PPG 40Gbits Tx/Rx**

**Standard tool for Rx test Super High speed**

**No Tx test**

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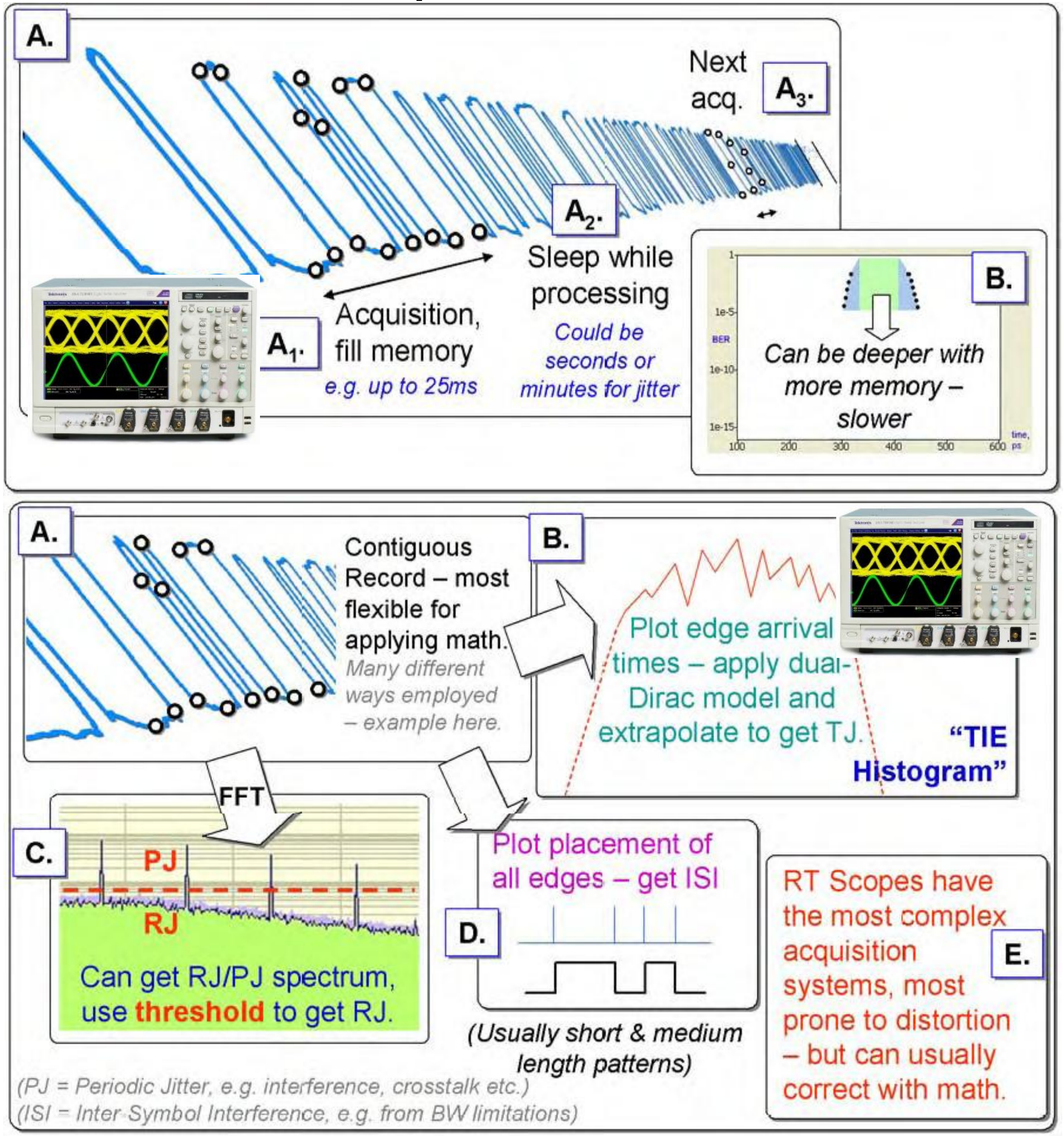
# Real-time Scope




**Advanced trigger on signal**
**No clock need**

**Built in Clock recovery**

**One sample every 5ps with continue acquisition (depend on memory)**

**Dual-Dirac /spectral and Q-scale method for complete Tx analysis**

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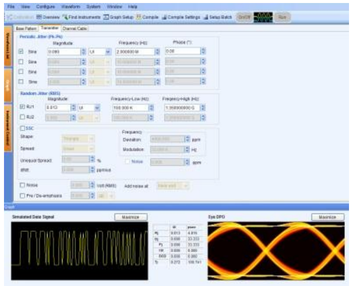
# High Speed Serial Data solution TX + RX

AWG70000

Serial Express



*HSSD with Jitter, ISI, Channel, SSC & emphasis up to 12.5Gbits*

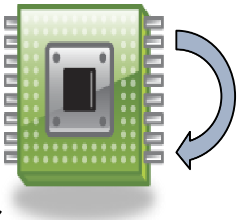
SERIAL ATA

SUPERSPEED CERTIFIED USB

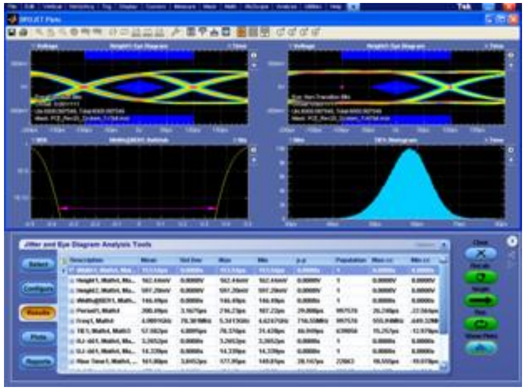
DisplayPort

mipi alliance member

*loopback*



Device Under Test (DUT)

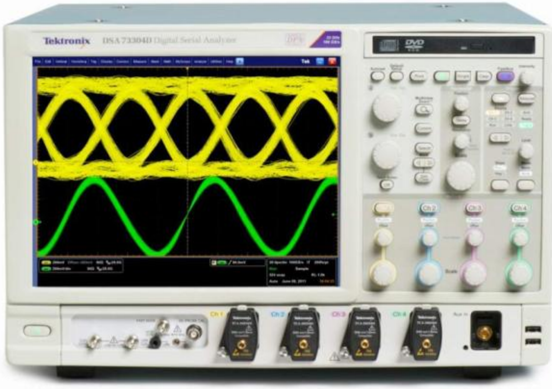


*Tx Analysis with* ***DPOJET & SDLA***

*Compliance with* ***Tekexpress***

*To One box for Error detector & Jitter analysis*

PCI EXPRESS



*BER Tester 6.25Gbit with* ***ERRDT***

HDMI

ddr3 A JEDEC STANDARD

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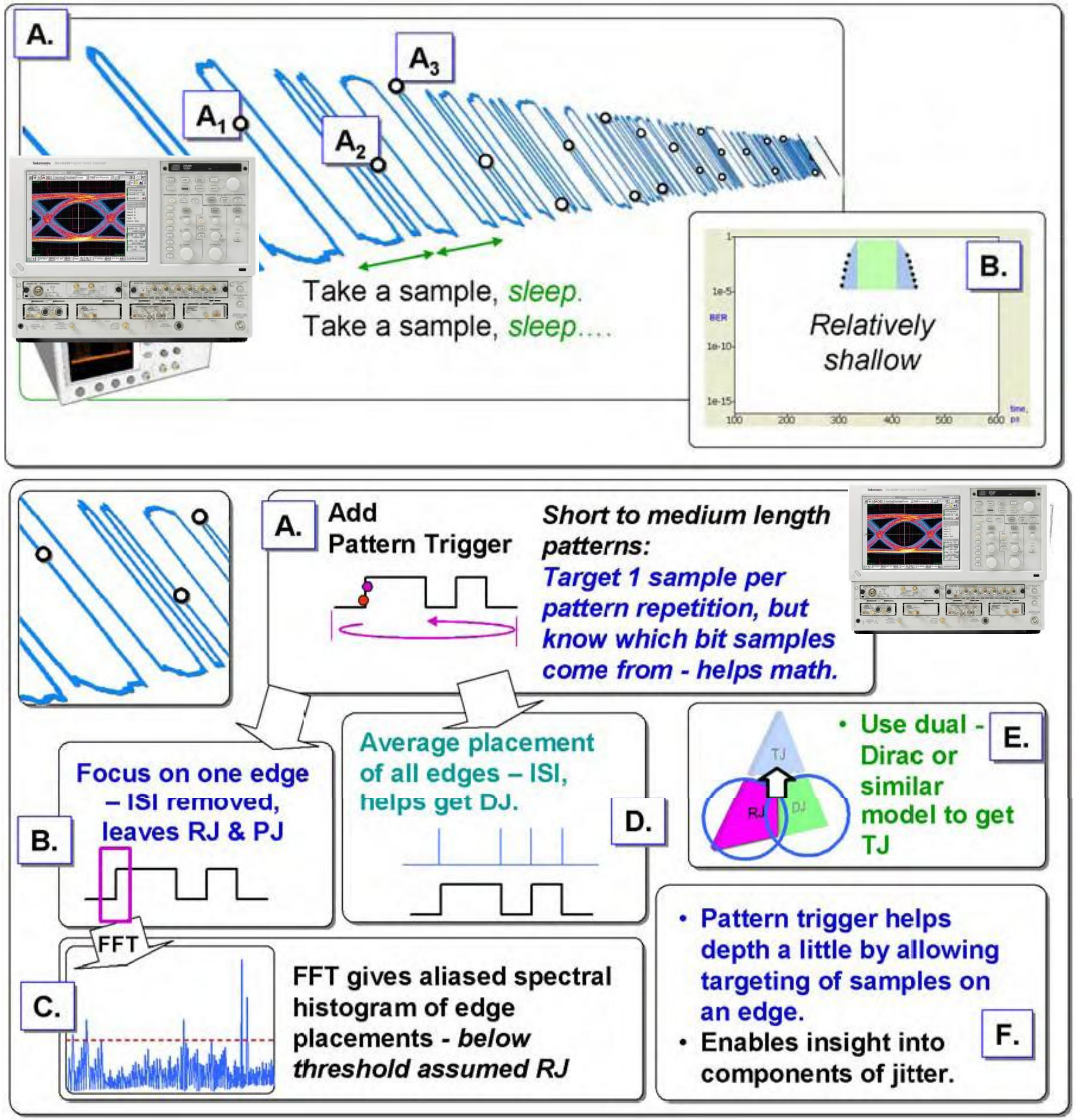
# Sampling Scope




**Electrical and Optical acquisition**

**Need external trigger clock**

**Need external Clock recovery**

**Only Tx measurement**

**80GHz BW but only repetitive acquisition at 300kS/s**

**Very precise Rj measurement. Trigger Jitter scope <100fs**

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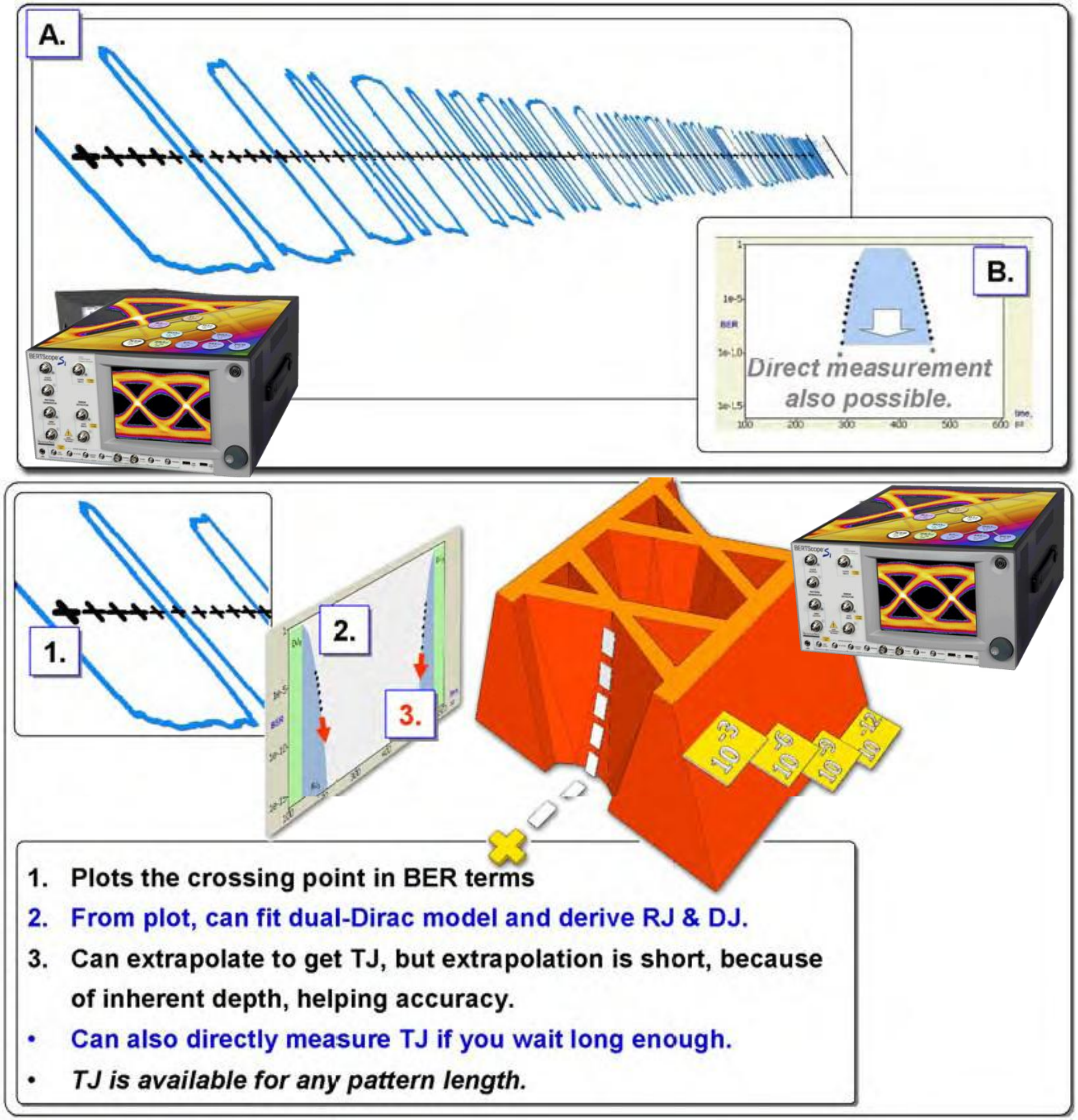
# BERT Scope




**Need external trigger clock**

**Need external Clock recovery**

**28.6Gbit Rx and Tx**

**See all bit and can measure Tj directly (no extrapolation)**

**Stressed Eye capability**

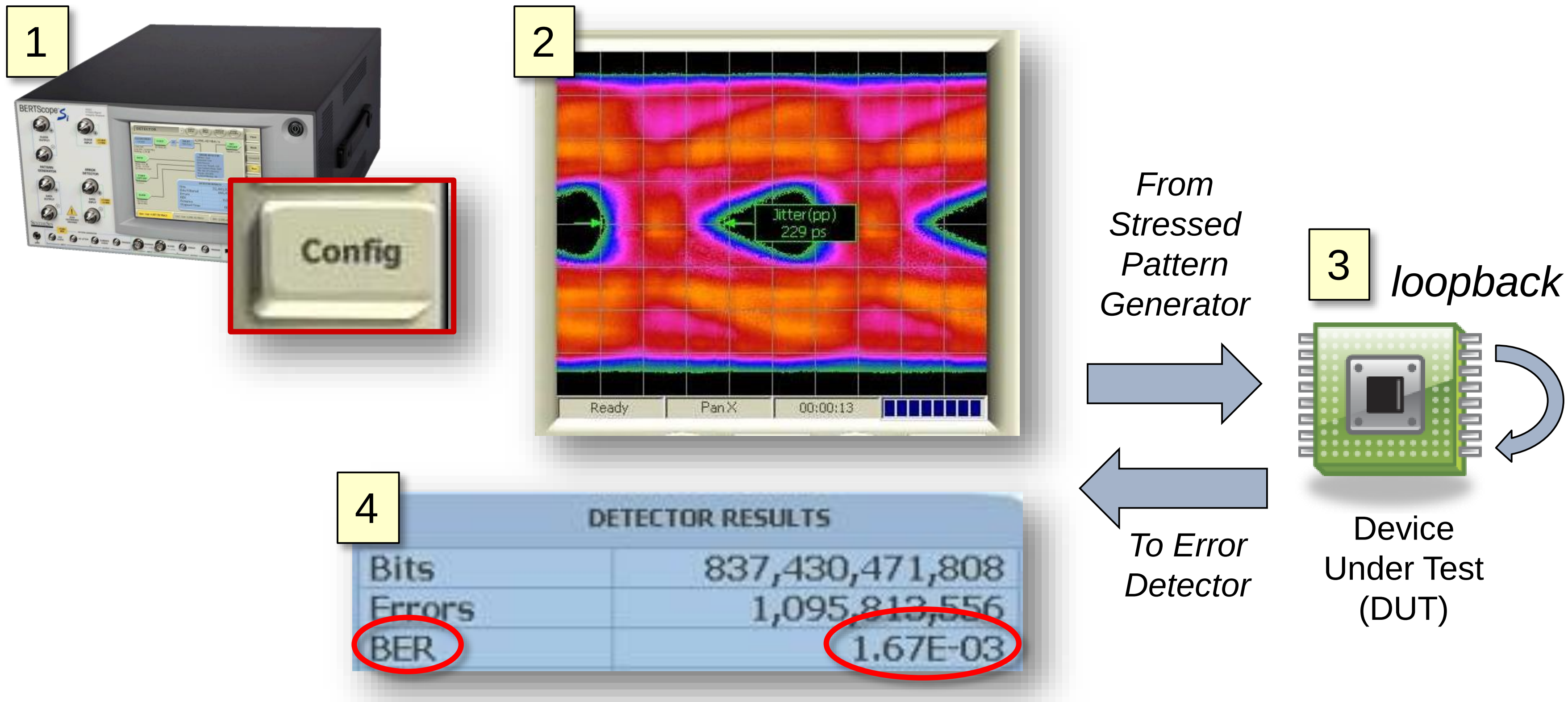
**Eye diagram and Jitter map capability**

**Error Location capability**

**PRBS31 length capability**

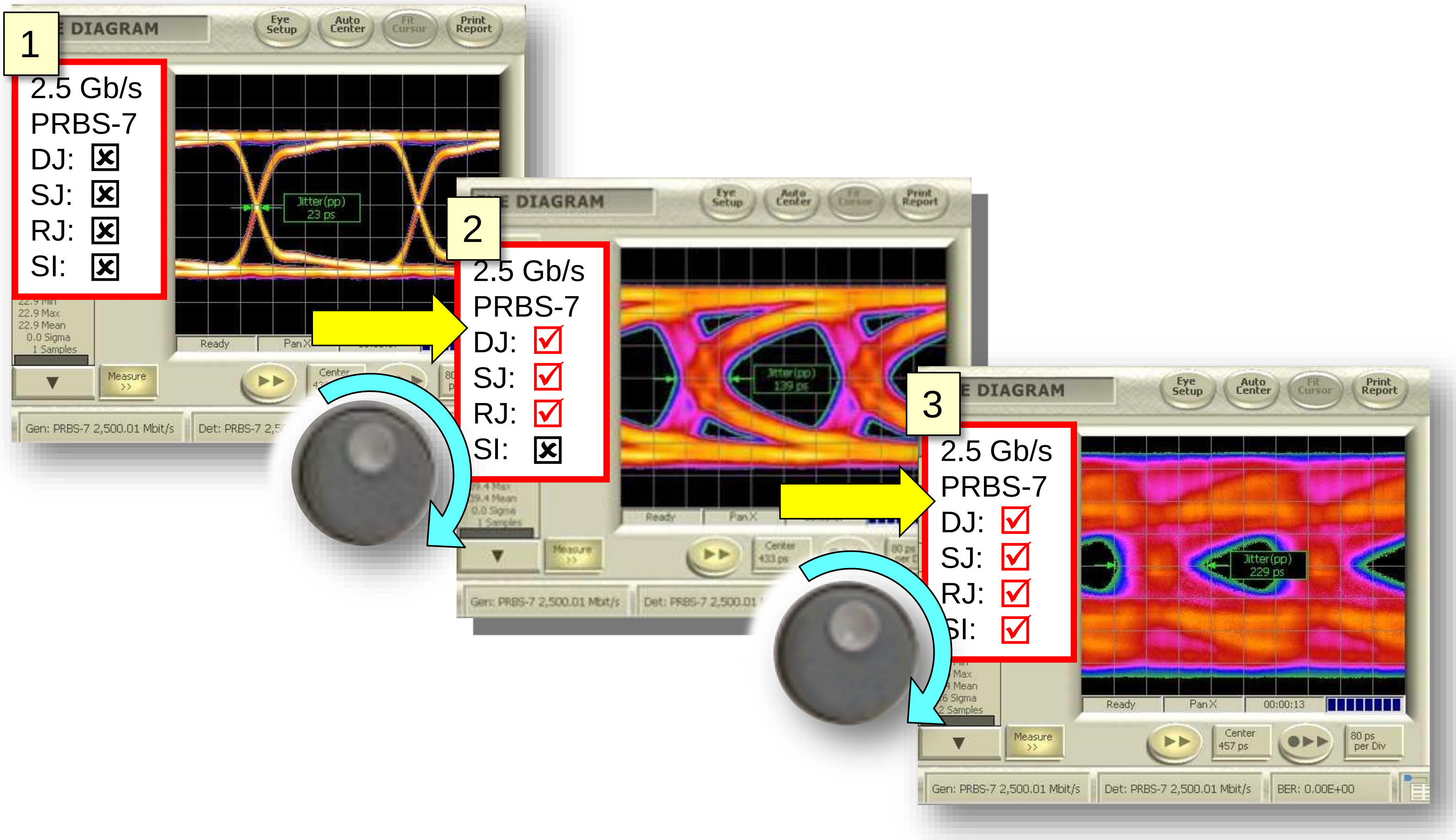
1. Stressed Receiver Tolerance Testing

# Start Testing Quickly

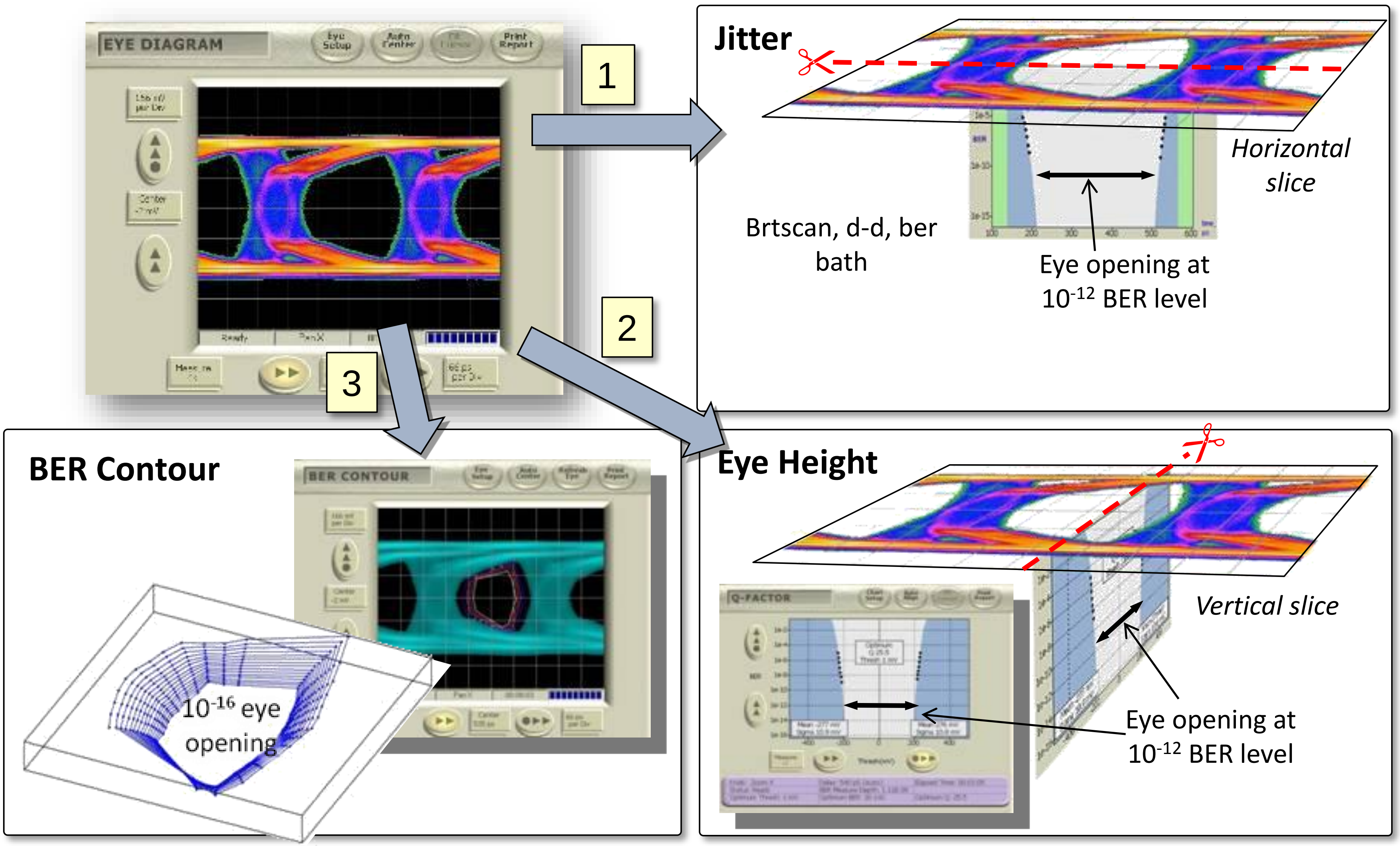



1. Recall stressed eye configuration
2. Apply stressed eye signal to DUT's receiver
3. DUT loops received bits back to BERTScope Error Detector
4. BERTScope counts any errors

# Dynamically change Data Rate, Stress, Pattern



# Deep Insight with the BERTScope Toolkit

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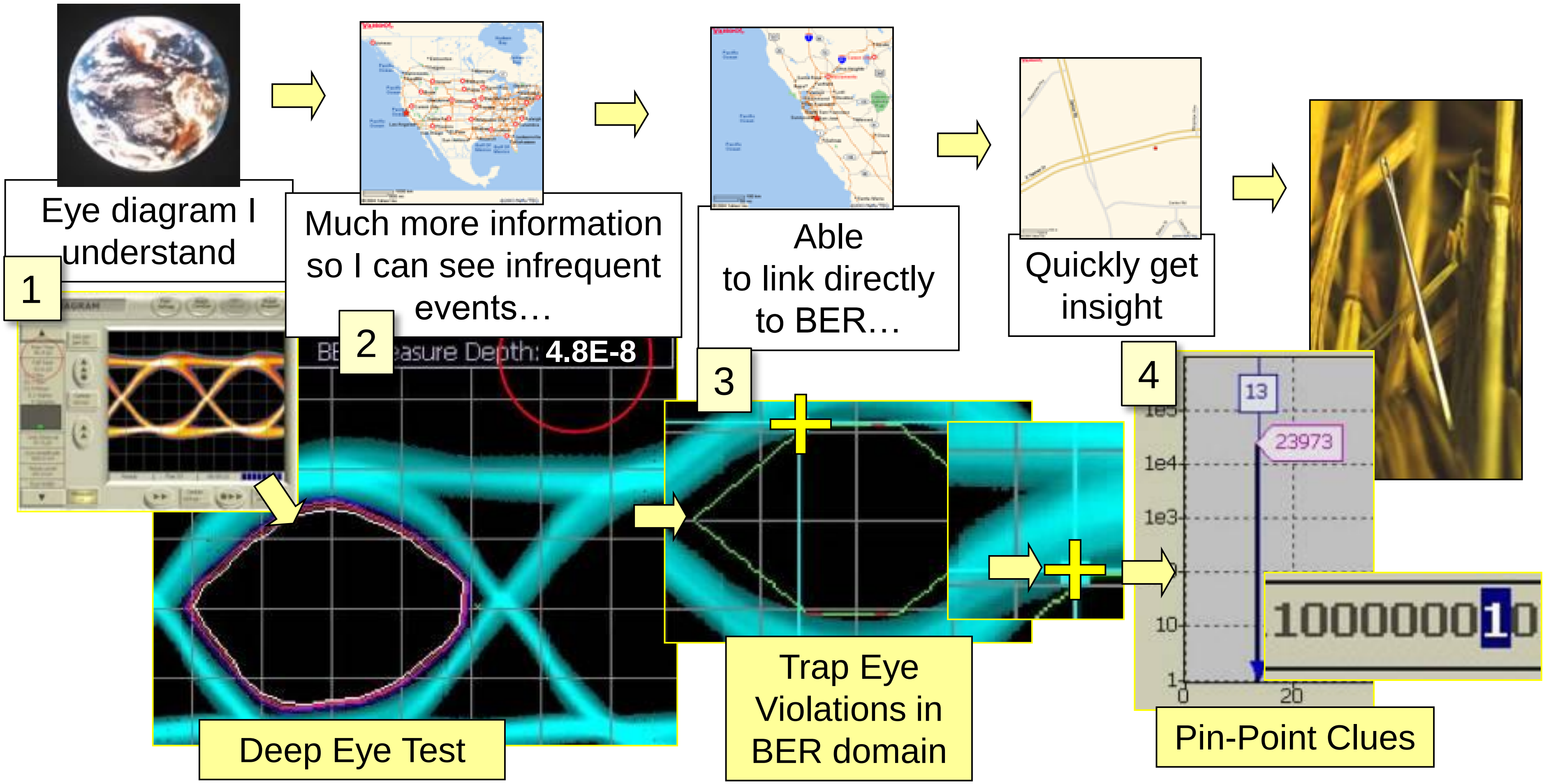
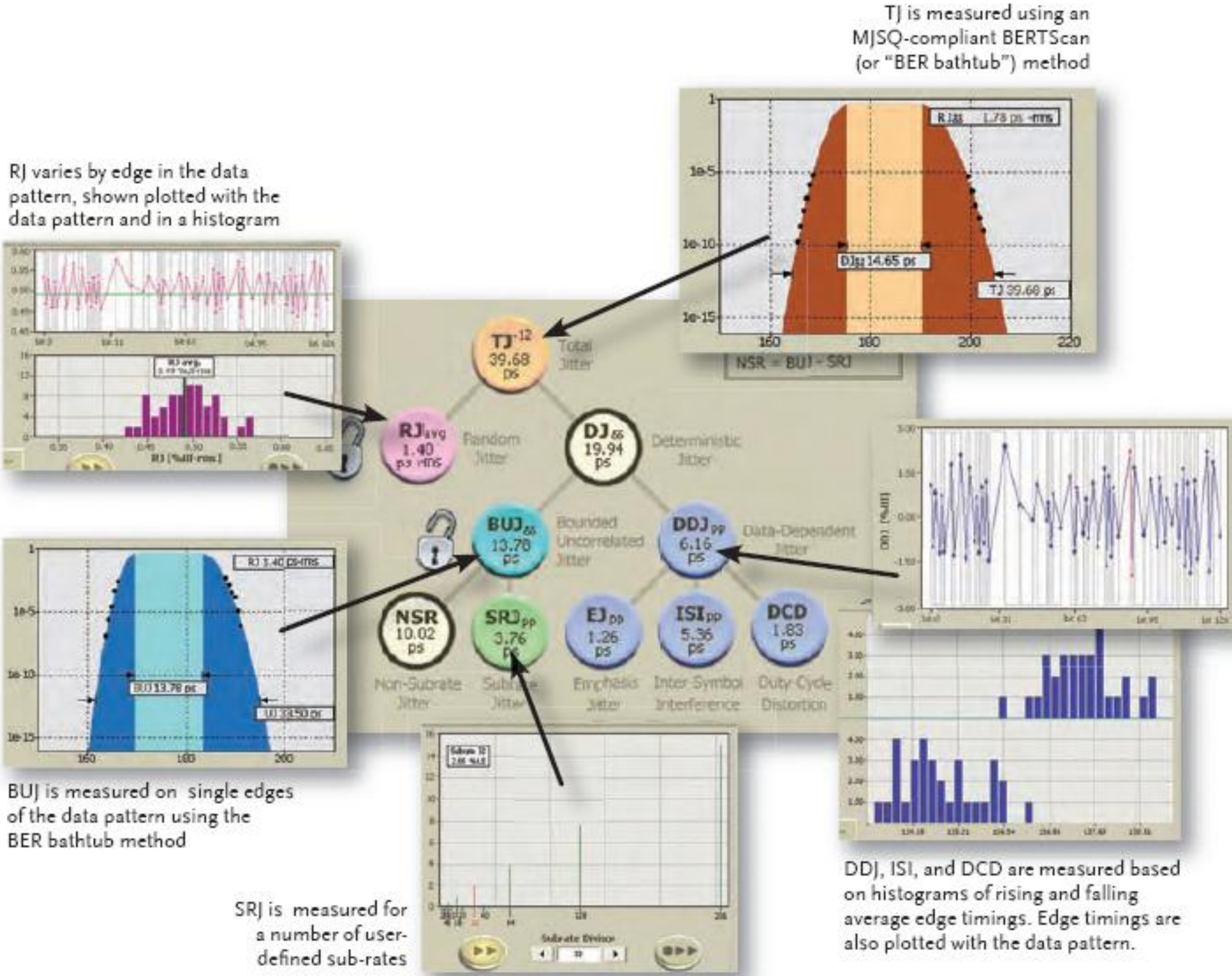
# Linked Tools Enable Deep Insight



# 5. Jitter Map


TJ is measured using an MJSQ-compliant BERTScan (or "BER bathtub") method
RJ varies by edge in the data pattern, shown plotted with the data pattern and in a histogram
TJ 39.68 ps
Total Jitter
RJavg 1.40 ps rms
Random Jitter
DJδδ 19.94 ps
Deterministic Jitter
BUJδδ 13.78 ps
Bounded Uncorrelated Jitter
DDJpp 6.16 ps
Data-Dependent Jitter
NSR 10.02 ps
Non-Subrate Jitter
SRJpp 3.76 ps
Subrate Jitter
EJpp 1.26 ps
Emphasis Jitter
ISIpp 5.36 ps
Inter-Symbol Interference
DCD 1.83 ps
Duty Cycle Distortion
NSR = BUJ - SRJ
DJδδ 14.65 ps
TJ 39.68 ps
BUJ is measured on single edges of the data pattern using the BER bathtub method
SRJ is measured for a number of user-defined sub-rates
DDJ, ISI, and DCD are measured based on histograms of rising and falling average edge timings. Edge timings are also plotted with the data pattern.

# The BERTScope Product Family Makes Compliance Easy

## A Typical Receiver Test Setup

**Stressed Pattern Generator**

1

**DPP provides pre-emphasis to emulate compliant transmitter**

**Error Detector**

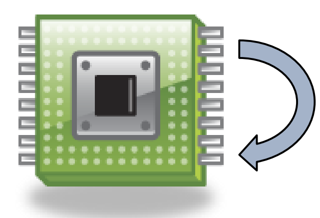
2

**CR recovers a clock from the retransmitted data from the DUT**

*From Stressed Pattern Generator*

*To Error Detector*

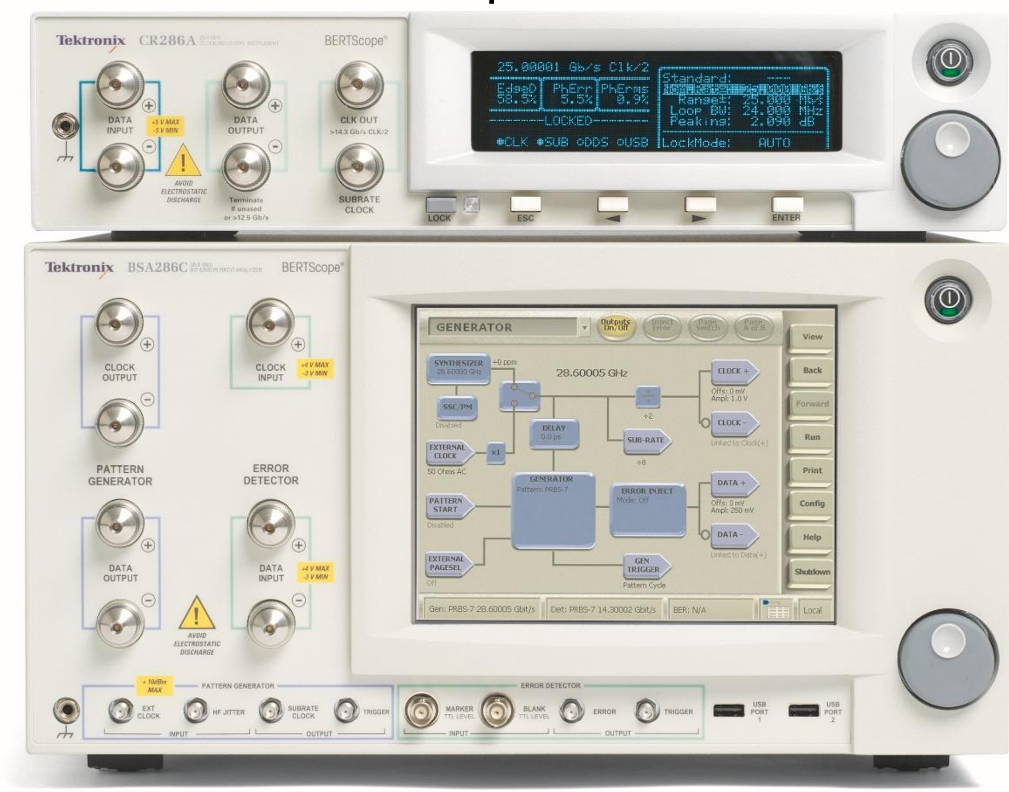
*loopback*

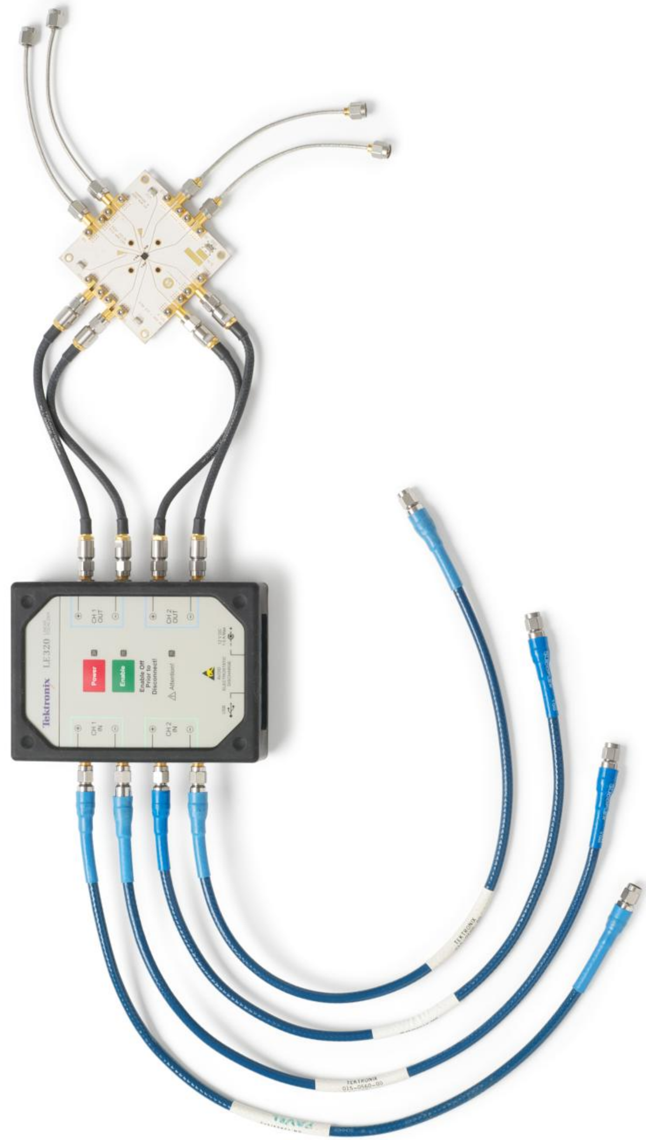


Device Under Test (DUT)

# BERTScope® Family of Products

- BSA Family is a series of BERT and Analysis tools  spanning 500Mbps to 28.6Gbps. Upgrades avenues from lower performing units to higher performing ones will continue to be preserved.





Tektronix®

# Tektronix LE320/LE160
## 32 & 16Gbps Linear Equalizer Product Introduction

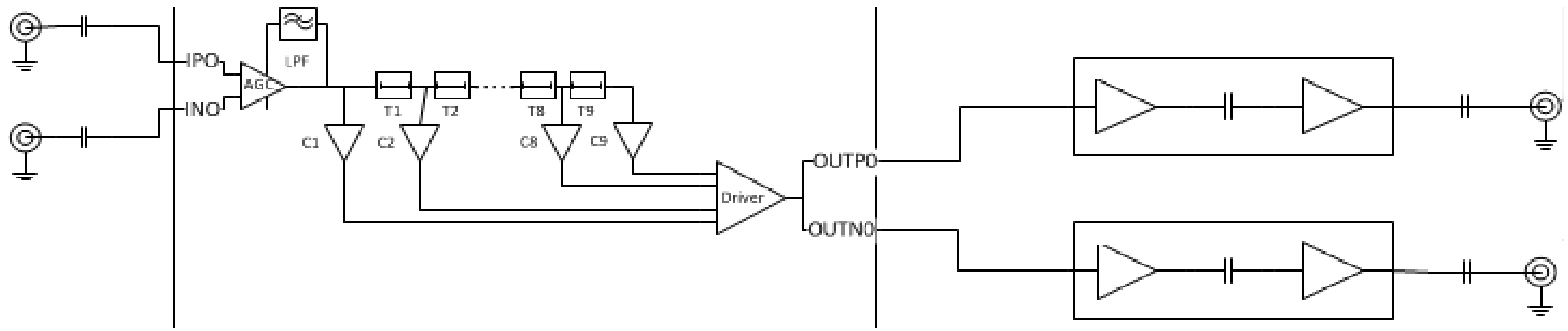
- Compact two channel 32Gbps 9 Tap linear equalizer design in a “remote module” configuration
- +-20dB tap controls offer flexible pre-emphais or channel de-embed capabilities.
- User (and PI) configurable filter properties allows flexible parametric equalization
- Electronically switchable frequency dependent filter capability permits DDJ tolerance testing and testing against known reference channel models
- Front-end signal path (CTLE) for Sampling or BERT Instruments




Tektronix

# Tektronix LE320
# 32G Linear Programmable Equalizer

**9 Tap linear equalizer design, supporting 14-32Gbps operation**




## SW - Base User Interface

"iPhone-ish" size

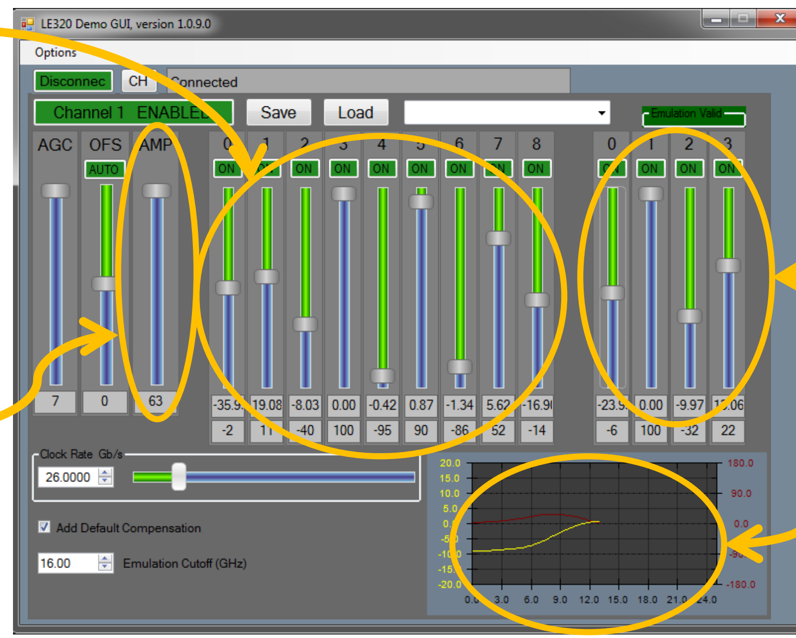
Mechanical Evolution

DPP125B size

9-tap UI

- Controlled by 4-tap UI
- Can also be controlled directly

Output gain or attenuation control




Traditional 4-tap UI

9-tap Response Calculated from 4-tap Input

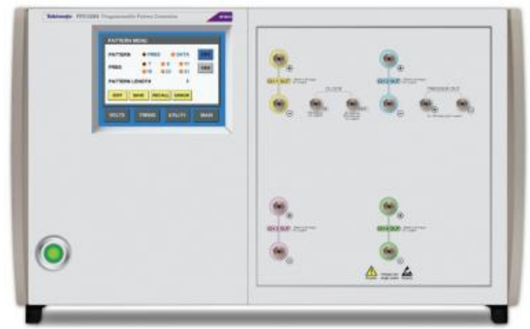


Tektronix

# PPG/PED

## PPG Base Instruments

- **PPG1251** 12.5Gb/s PPG
  - Jitter insertion (LF+HF)
- **PPG300X** 30Gb/s PPG
  - 1/2/4 Channel
  - LF jitter insertion
  - HF jitter insertion
- **PPG320X** 32Gb/s PPG
  - 1/2/4 Channel
  - Adjustable output
  - LF jitter insertion
  - HF jitter insertion
- **PPG4001** 40Gb/s PPG
  - LF jitter insertion
  - HF jitter insertion



PPG3204 32Gb/s
4 channel PPG

PED3202 32Gb/s
2 channel PED

## PED Base Instruments

- **PED320X** 32Gb/s PED
  - 1/2 Channel
  - Full or half rate clock input
  - AC or DC coupled input
- **PPG400X** 40Gb/s PED
  - 1/2 Channel
  - Full or half rate clock input
  - AC or DC coupled input

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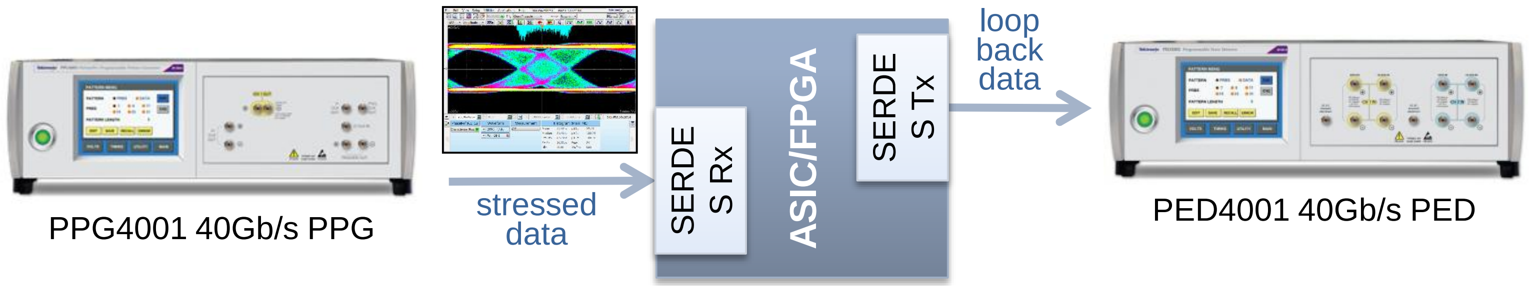
# 32Gb/s and 40Gb/s SERDES JTOL testing

**SERDES JTOL Testing**

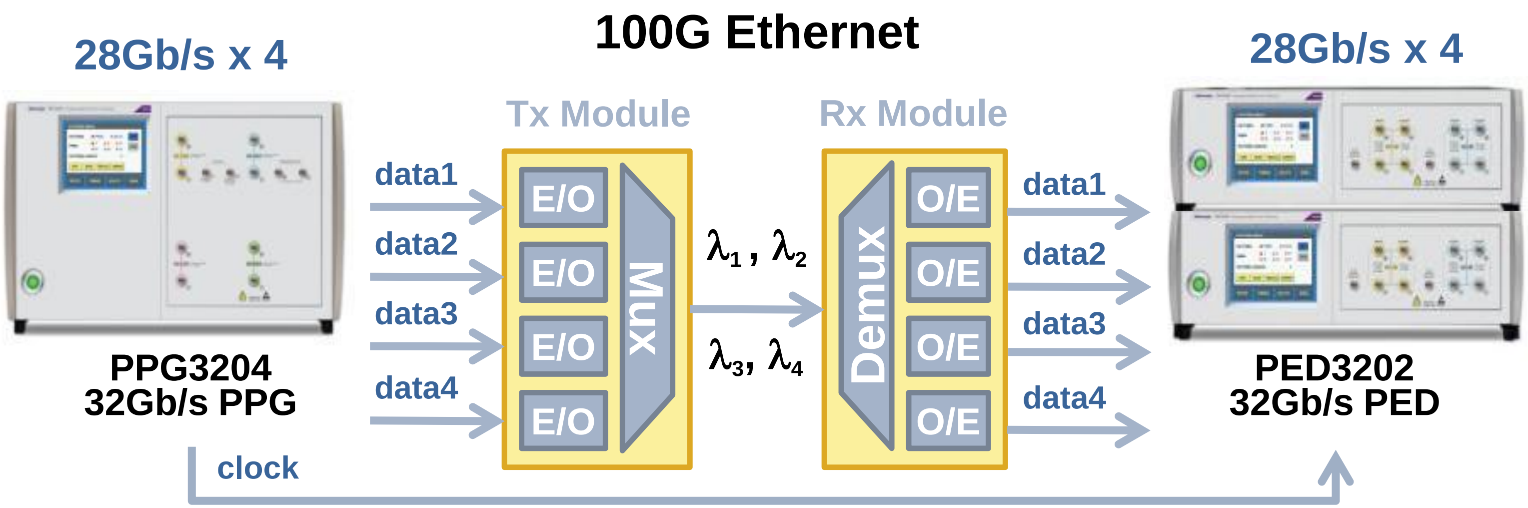



Some ASICs/FPGAs have built-in BER testing and don't require loop back with a PED

## Advantages

- Separate PPG and PED for users with on-chip BER capabilities
- Low intrinsic jitter
- Fast rise-fall times and high signal integrity
- SJ/RJ/BUJ insertion for standards compliance tests
- Software analysis tools *(bathtubs, JTOL, J2/J9, etc)*
- Easy-to-use touchscreen and USB programmability

# 100G Ethernet SR4/LR4/ER4 transceiver testing




Note: Tektronix CR286 may be added for clock recovery

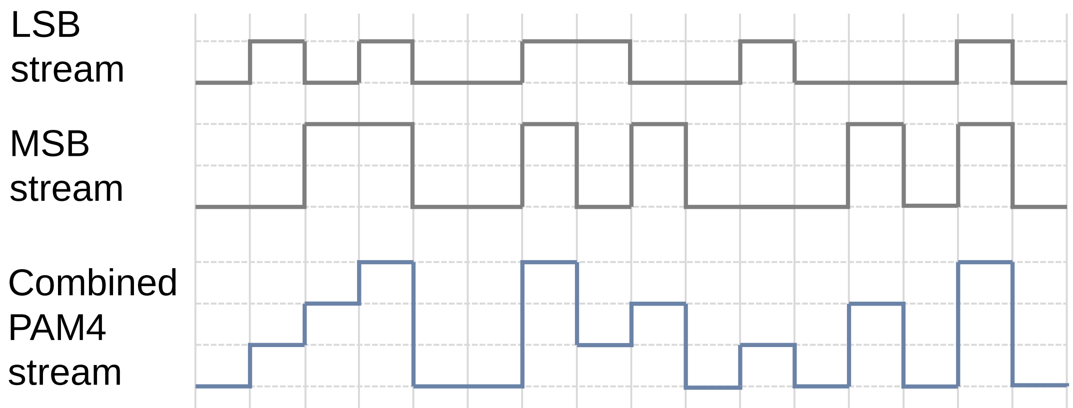
JDSU · Avago Technologies · Sumitomo Electric · Finisar

## Advantages

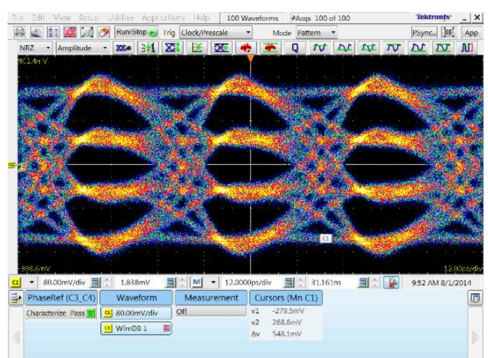
- Flexible multi-channel solution
- Low intrinsic jitter
- Fast rise-fall times and high signal integrity
- SJ/RJ/BUJ insertion for standards compliance tests
- Software analysis tools *(bathtubs, JTOL, J2/J9, etc)*
- Easy-to-use touchscreen and USB programmability

# What is PAM?

- **P**ulse **A**mplitude **M**odulation
  - –PAM4 combines two bit streams and uses 4 levels to encode 2 bits into 1 UI
  - –For Example, 56 Gbit/s PAM4 runs at a symbol rate of 28 GBaud

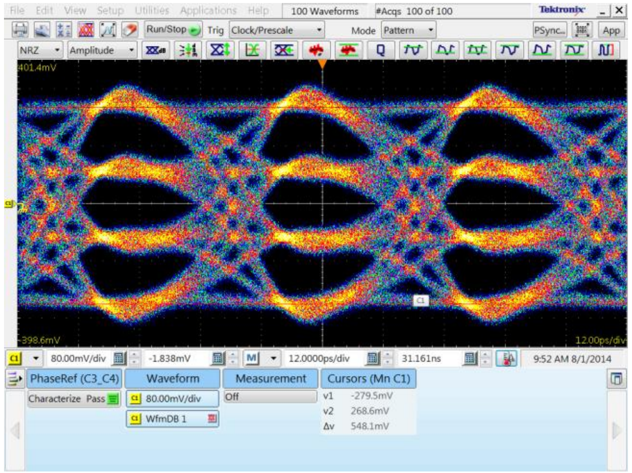


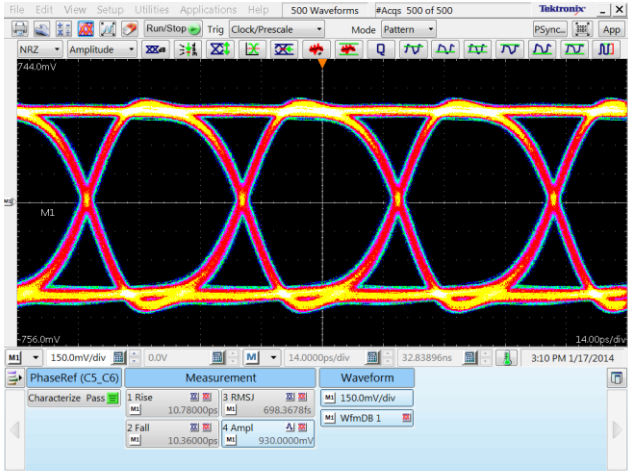

| MSB | LSB | PAM4 LEVEL |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 2 |
| 1 | 1 | 3 |



# What are the differences between PAM4 and NRZ?

- PAM4
  - 4 Levels → 3 Eyes
  - Sensitive to SNR (eyes smaller)
  - 2 bits into 1 UI
  - ½ Symbol Rate for same data throughput (28 GBaud = 56Gbps)
  - Adds complexity/cost to Tx/Rx
- NRZ
  - 2 Levels → 1 Eye
  - Less Sensitive to SNR
  - 1 bit in 1 UI
  - 2X Symbol Rate for same data throughput (28GBaud = 28Gbps)

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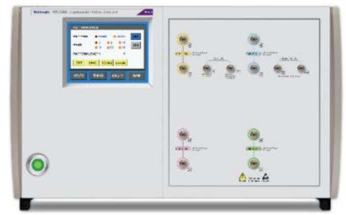
# Considerations for a PAM4 Signal Generation Engine

56Gbaud

28Gbaud

Baud Rate

Manufacturing



## Pattern Generators

Consistent application of patterns for validation & compliance at 40 Gbaud

- ✓ Easy to setup signal and add jitter impairments
- ✓ Real-time signal adjustability
- ✓ High BW, fast edge rates
- ✓ PRBS7-31 and user patterns

## Arbitrary Waveform Generators

For applications that place top priority on flexibility

- ✓ Deep pattern length
- ✓ Flexible multi-level signaling & modulation
- ✓ Easy waveform creation using Tek software or MATLAB

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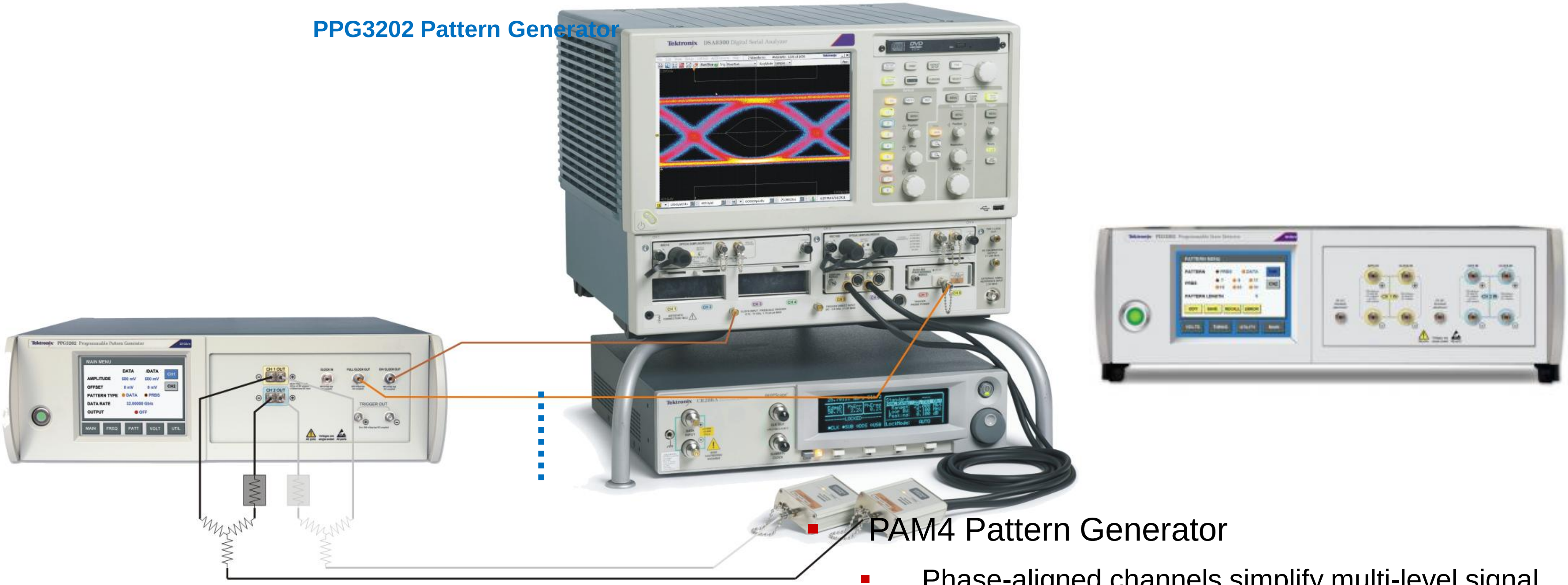
# PAM4 Generation & BER Analysis using Pattern Generators

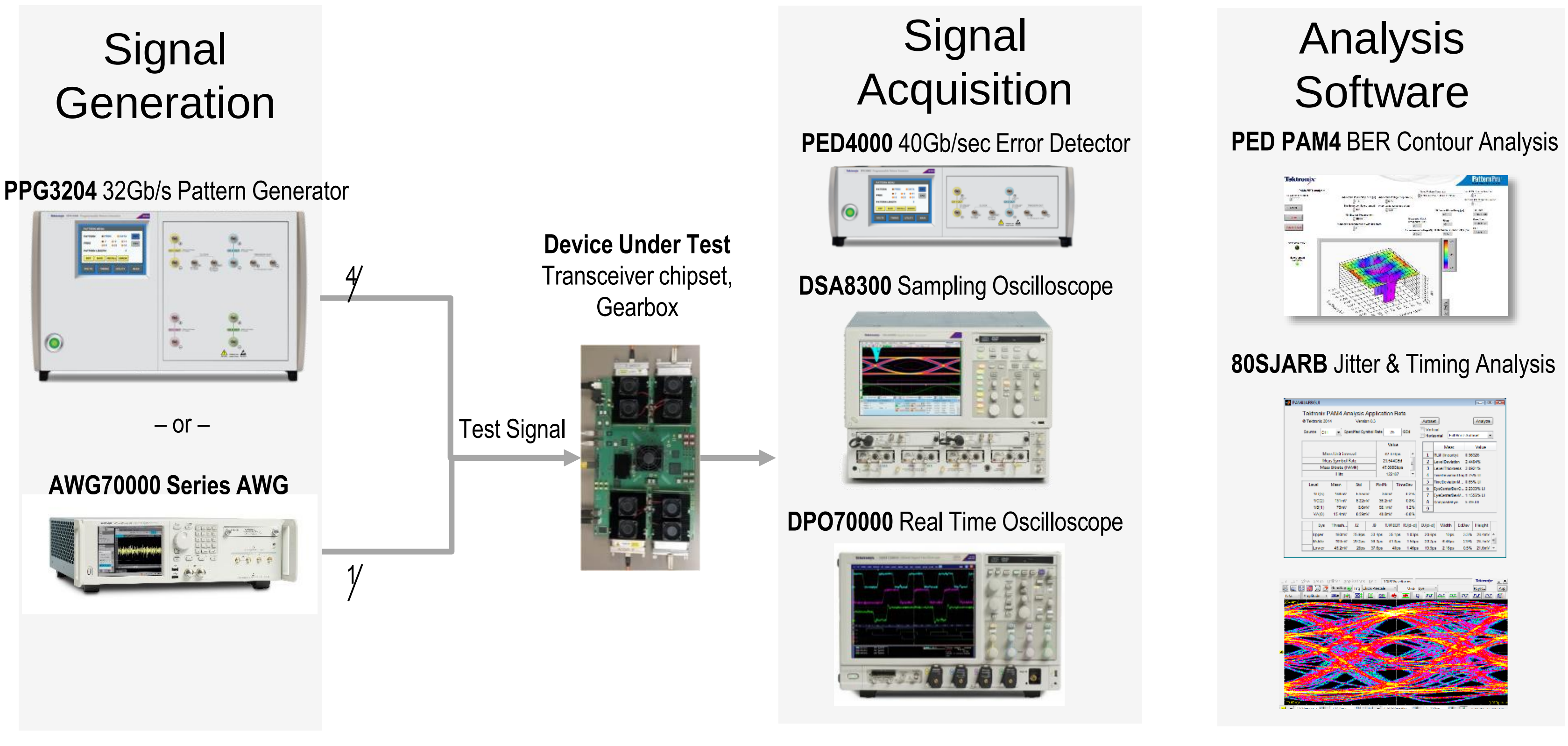



- PAM4 Pattern Generator
  - Phase-aligned channels simplify multi-level signal generation
  - User-programmable data patterns allow test of PAM4 custom data
- PAM4 Error Detector
  - BER measurements analyzes every bit of each pattern
  - Contour plots, bathtub curves, total jitter analysis via software tools
  - Can be used for BER measurements generated by PPG and/or AWG

- BERT products bundled into a PAM4 system:
  - Programmable pattern generator
  - Programmable error detector
  - Analysis software
  - Broadband components (power combiners/attenuators)

# Test Methodologies for PAM Signaling Validation

*Tektronix provides complete support for validation of PAM4 at 28 & 56G*

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