Jitter and Jitter Breakdown Analysis

"Measurements and Best Practice for Signal Integrity"

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Agenda

- **Jitter concept**
  - Traditional methods to estimate jitter
  - TIE (Time Interval Error) definition and measurements
- **Reference Clock Reconstruction**
  - Phase Locked Loop (PLL) transfer function
- **The two types of Jitter**
  - Bounded and UnBounded Jitter
- **Jitter Breakdown Components**
  - DDj, Pj
- **Jitter breakdown model methods**
  - **Spectrum based vs. NQ-scale**
  - **Crosstalk measurements**
- **Measurement processing flow on the oscilloscope**

Jitter concept

- ***The term "jitter" refers to the deviation of a timing properties of a signal with respect to a specific reference time .***

- ***In serial data communication, the transmit clock is embedded along with the data :***
  - ***Eliminate the problem of parallel communication to maintain alignment between clock signal and data signal paths***
  - ***Create the problem to have enough signal transitions so that a clock may be reconstructed***
  - ***Create the need to maintain adequate alignment between the recovered clock and the incoming data.***

- ***Time interval error or TIE is the fundamental measurement for all the jitter measurements.***

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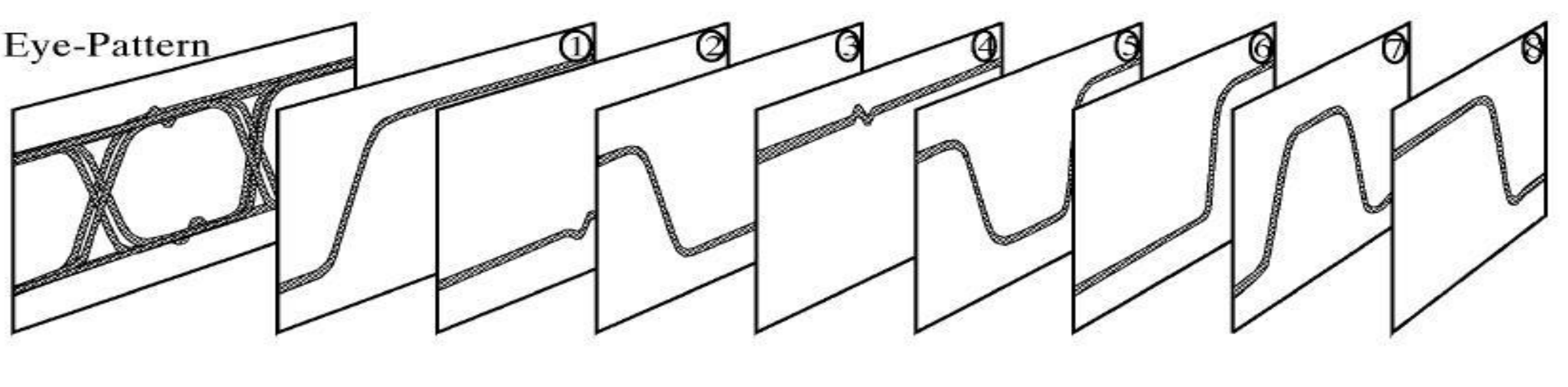
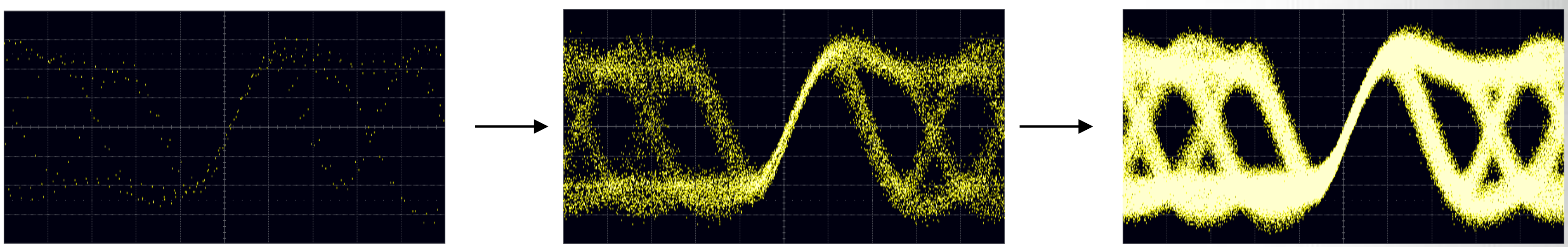
Traditional Method

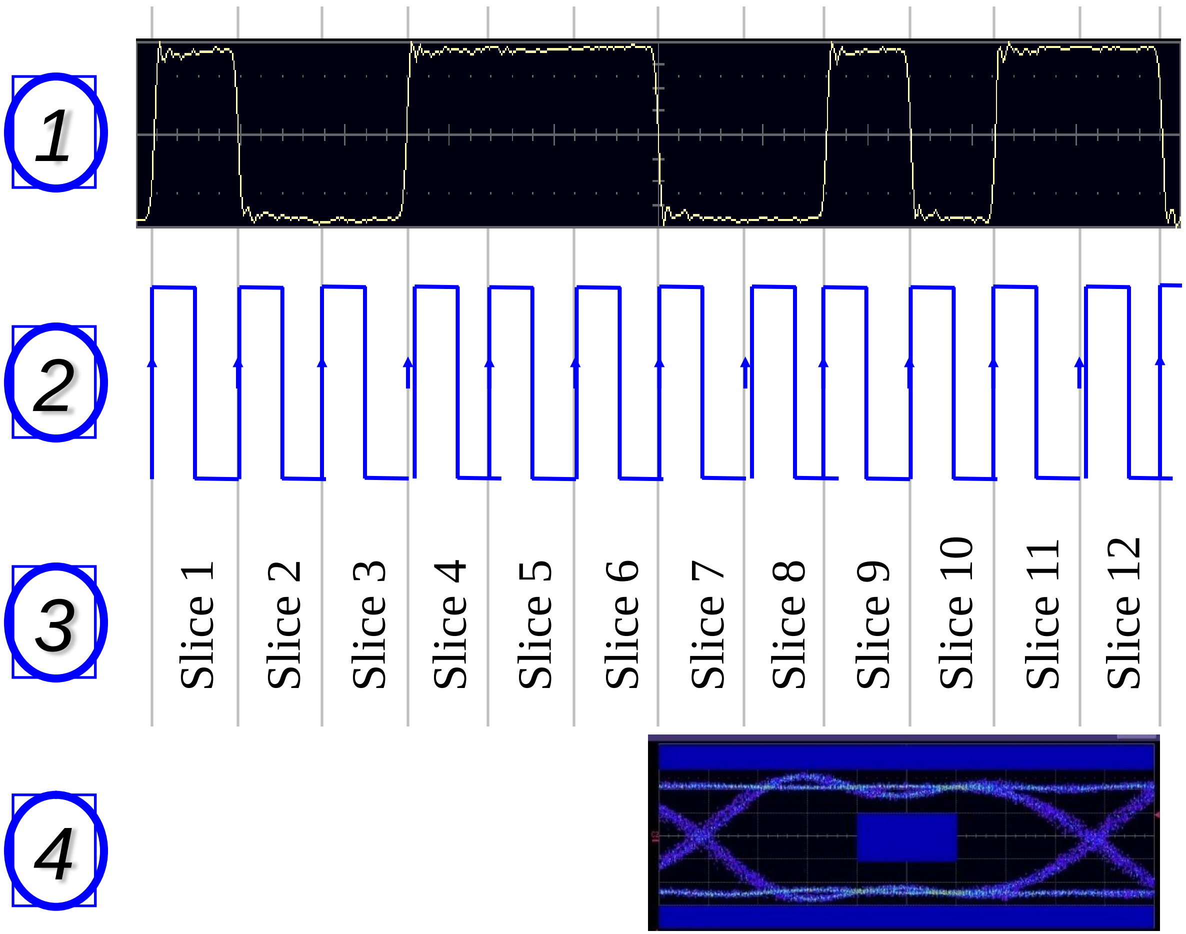




1. Transitions are aligned regarding trigger position
2. Use persistence mode to accumulate all transitions
3. Instrument *Trigger-Jitter influences the value of jitter*

Continuous Bit Eye Pattern rendering

Modern approach to eye pattern test



← NRZ data record acquired from a single trigger

← Clock recovered using software "golden PLL"

ZERO CDR JITTER

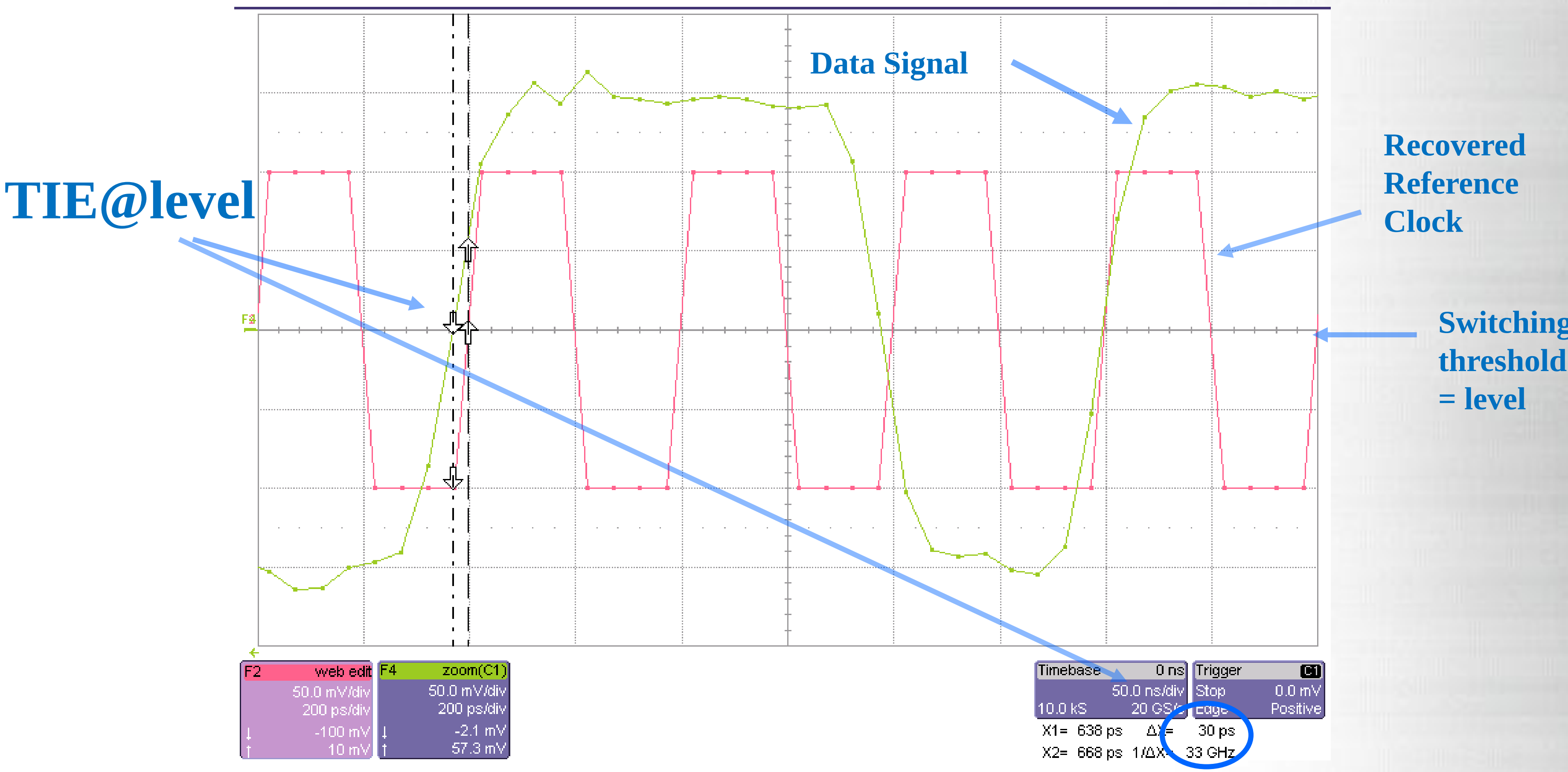
← Data record divided into 1 UI segments equal to recovered clock period

← Segments overlayed to form eye pattern

ZERO TRIGGER JITTER

1. *This method is immune to trigger jitter because data is aligned with the unit interval, not the trigger*
2. Multiple acquisitions (multiple triggers) can be used and still no trigger jitter will be introduced because data from those acquisitions are not combined using a trigger point reference

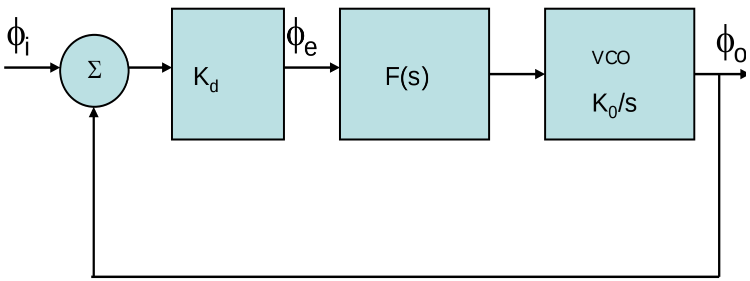
Time Interval Error (TIE@level)

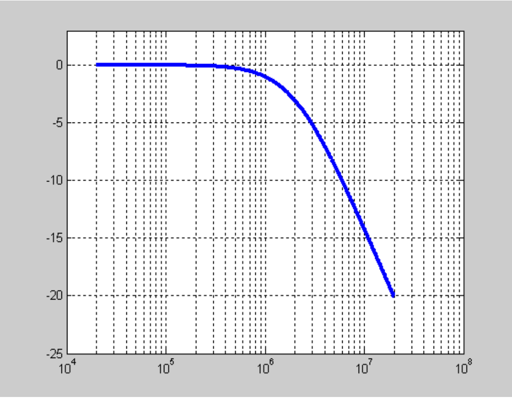


TIE is the difference between the measured clock edge and the ideal clock edge locations at the nominal switching threshold of the signal

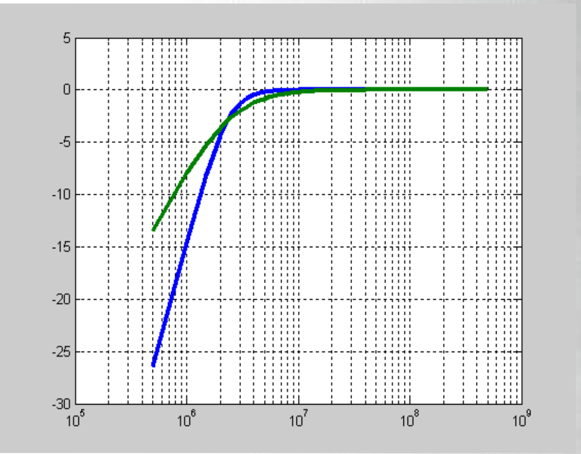
Reference Clock Reconstruction

- ***CDR may be analog PLL (Phase-Locked Loops)-based or digital-based***
- ***For the signal rate of change within the PLL-close loop bandwidth and gradual (i.e. "trackable" by the CDR) , reference clock follow the signal.***
- ***Measured jitter is a function of the PLL loop response.***
  - *Each Serial Data Standards define precisely the PLL characteristics to be applied*
  - *In cases where SSC (spread spectrum clocking) is used, PLL tracks large jitter at 30 KHz rate from the SSC while allowing jitter measurements at higher rates.*
  - *JTF(Jitter transfert function) HighPass*



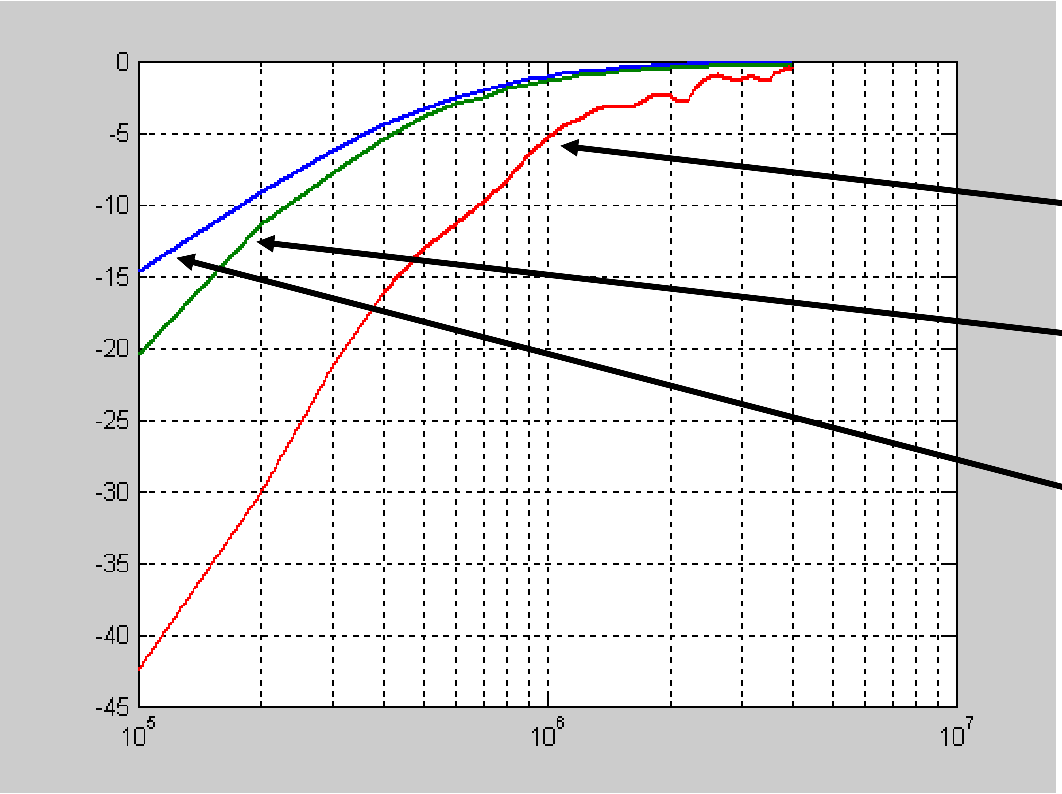


Closed Loop Phase-Locked Loop Response



JTF = 1 - PLL

Effect of record length on measured JTF



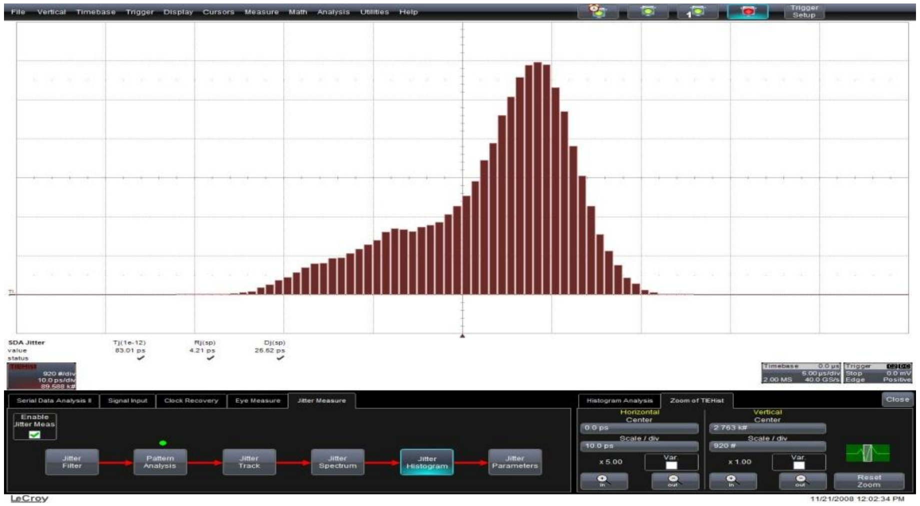
2 us record

20 us record

Ideal response

- **The acquisition length (T) limits the low frequency response if 1/T is not significantly lower than the PLL cutoff**
- **Rule of thumb: 1/T < (PLL cutoff)/10   (T = horizontal scale)**

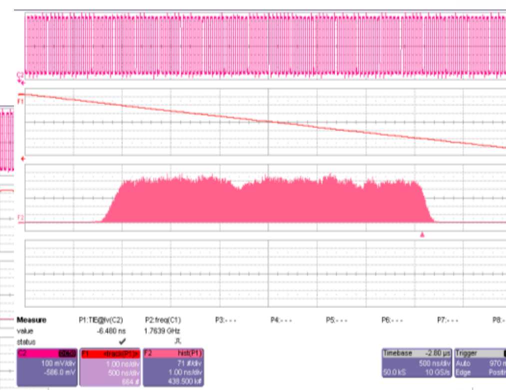
TIE is the fundamental measurement for all the jitter measurements



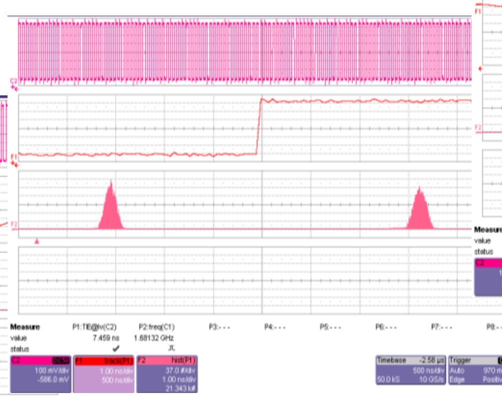
- The sequence of TIE measurements is collected in a track
  - One measurement on each transition of the signal
  - "virtual" transitions are added where no transition occurs
  - "virtual" transitions are needed to maintain time information

- Jitter TIE histogram analysis

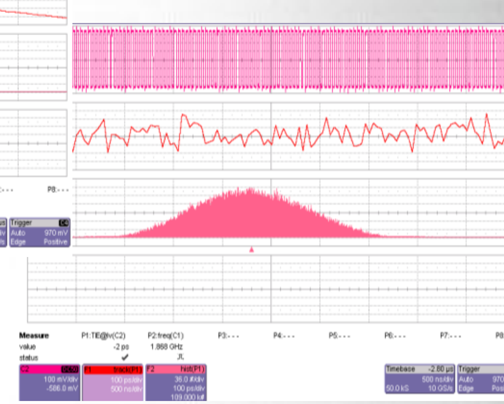
Uniform Jitter



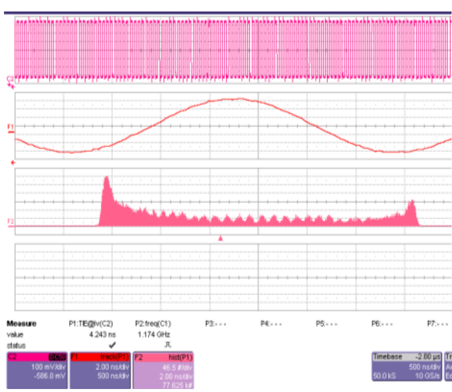
Bi-modal Jitter



Random Jitter – Thermal Noise



Sinusoidal Jitter



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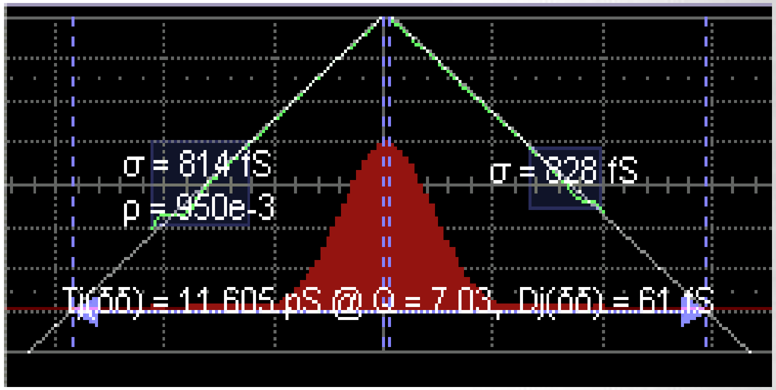
The two types of Jitter

Total Jitter (Tj)

Bounded Jitter
Deterministic Jitter (Dj)

UnBounded Jitter
Gaussian in Nature
Random Jitter (Rj)



✓Jitter can be treated as a random variable combination of random and deterministic sources

✓Bounded and UnBounded jitter types accumulate differently in the link and have different budgeting schemes

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Jitter breakdown

Total Jitter (Tj)

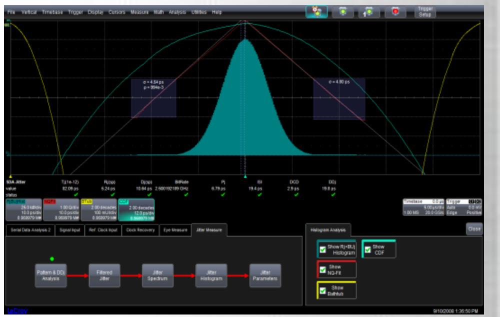
Deterministic Jitter (Dj)

Bounded Jitter

Random Jitter (Rj)

UnBounded Jitter

Gaussian in Nature



Data Dependent Jitter (DDj)

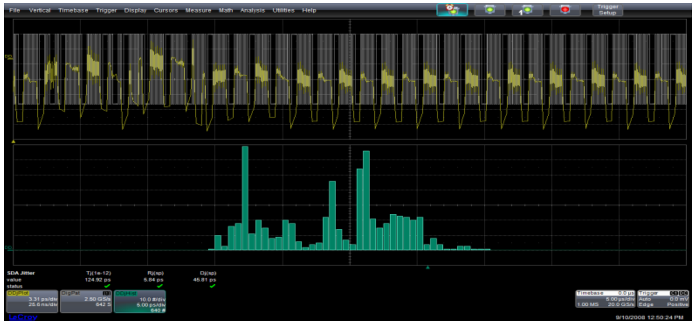
Correlated to Data Pattern

Bounded Uncorrelated Jitter (BUj)

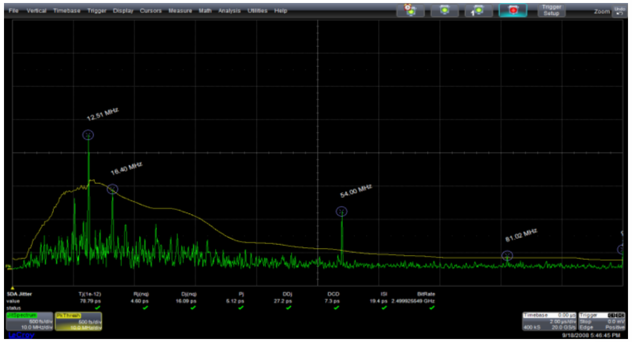
Independent of Data Pattern

Duty Cycle Distortion DCD

Inter-Symbolic Interference ISI



Periodic Jitter (Pj) & Other BUj



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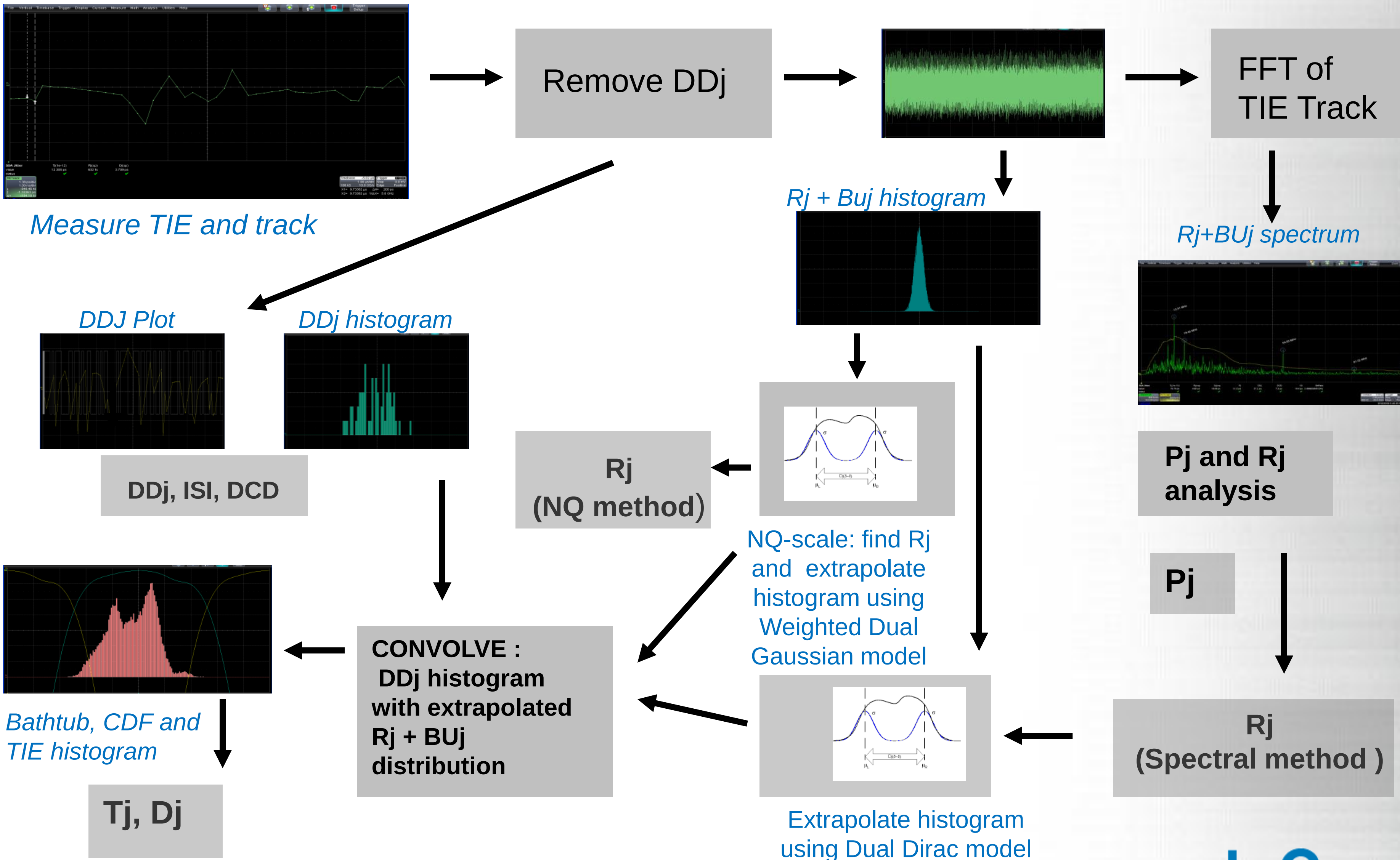
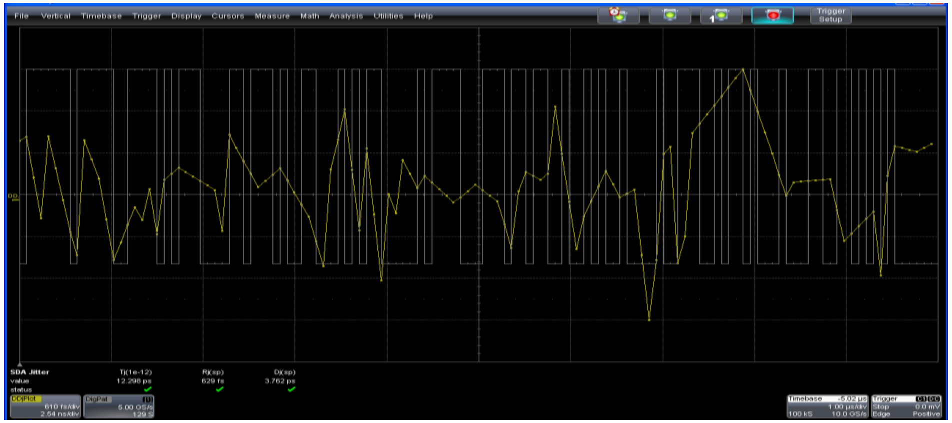
Jitter Measurements Processing Flow
on SDA Platform



Data Dependent Jitter (DDj)



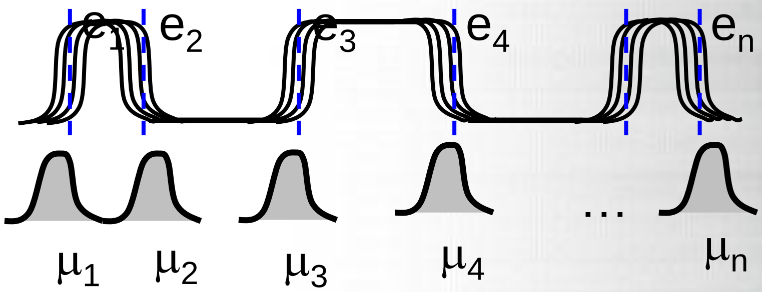
DDj plot vs.bit with digital pattern overlay

- ***Find the pattern length by searching the acquired signal***
  - *Need long enough data record for more than one complete repetition*
  - *Edges must be identifiable (i.e. open eye pattern, proper PLL for tracking SSC, etc.)*
  - *Collect histogram on each of n transitions in data pattern*

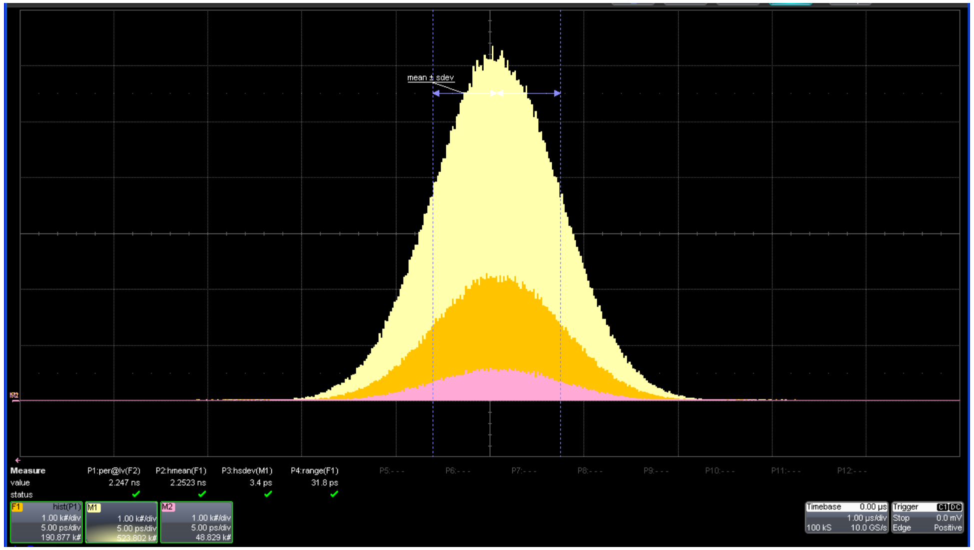
✓ *Removing DDj with a Repeating Data Pattern (Error is removed from each class)*

- *Class is defined as a particular edge in the data pattern*
- *P1..n are the populations of each edge*
- *en is the expected time of arrival of the nth transition*

Class	Population	Error (e-μ)
1	P_1	e_1-μ_1
2	p_2	e_2-μ_2
3	p_3	e_3-μ_3
4	p_4	e_4-μ_4
N	p_n	e_n-μ_n



The Random Component of Jitter (Rj)



# Measurements	Peak-to peak (σ)
100	±2.1
1,000	±2.9
5,000	±3.4
10,000	±3.5
100,000	±4.1
1,000,000	±4.6
5,000,000	±5.1
100,000,000	±6.0
1,000,000,000,000	±7.0

✓ ***Rj is UnBounded and Gaussian in nature***

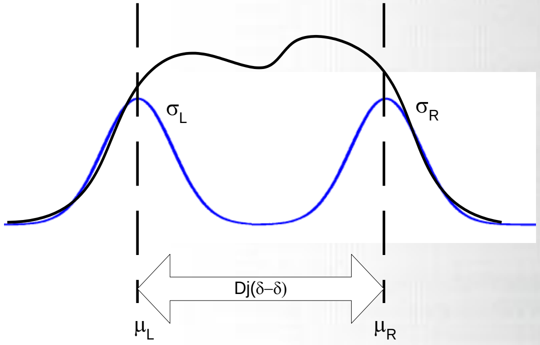
✓ ***Rj is measured as an RMS value , a seemingly small amount of RMS random jitter correspond to a large peak to peak value***

✓***In general Rj peak to peak value of random signal jitter will grow to without bound and a measurement time has to be specified to specify a value.***

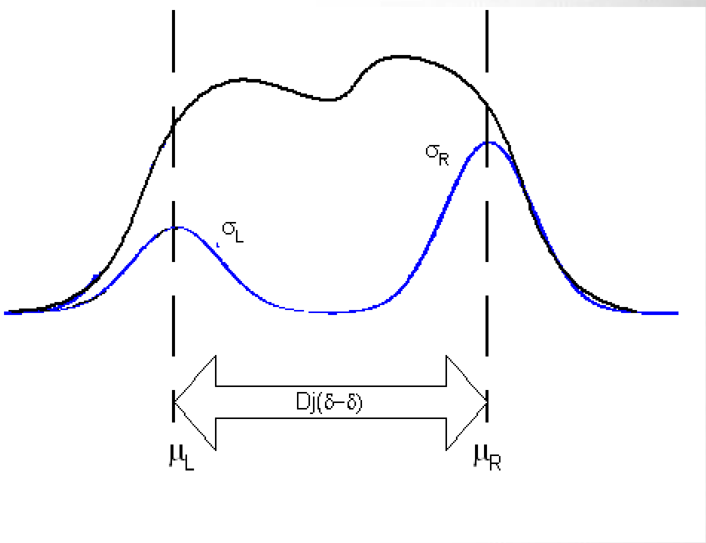
Weighted Dual Gaussian model

- ✓ *Dual Dirac Model*
  - ❖ *One Gaussian*
  - ❖ *2 degree of freedom : the standard deviation and impulse spacing.*
- ✓ *Weighted Dual Gaussian Model*
  - ❖ *Two Gaussians with different weights*
  - ❖ *Different mean values*
- ✓ *2, or 6 degrees of freedom*

Dual Dirac model

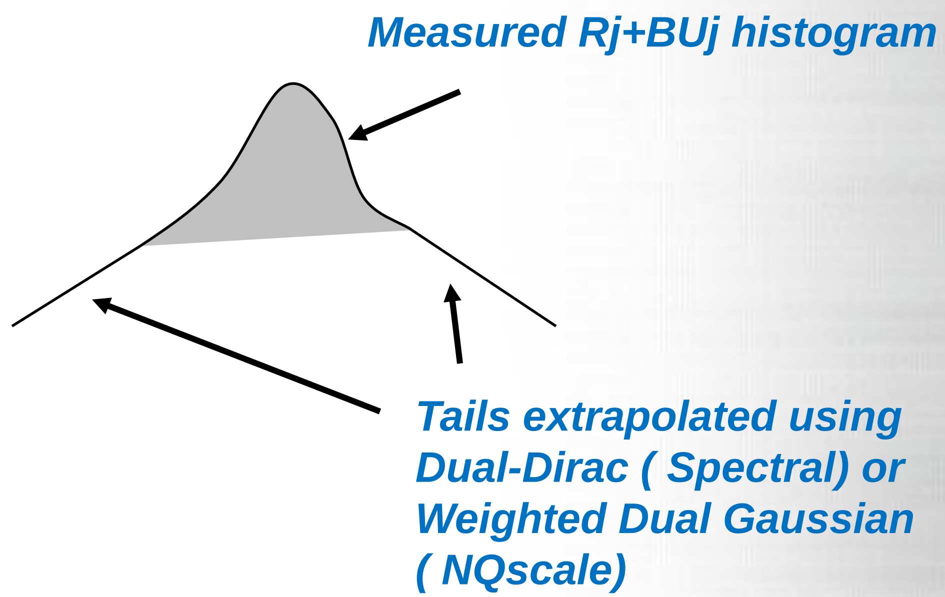


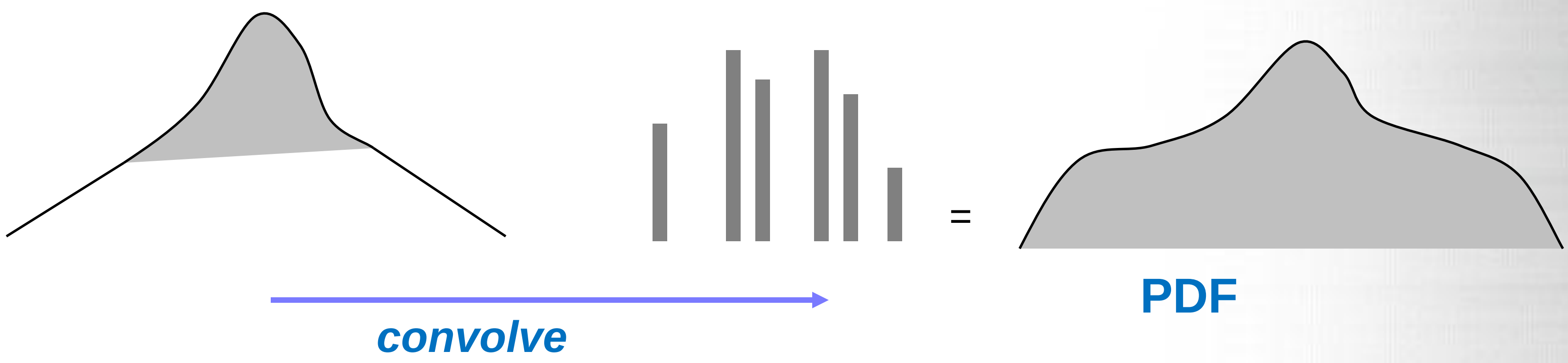
Weighted Dual Gaussian model



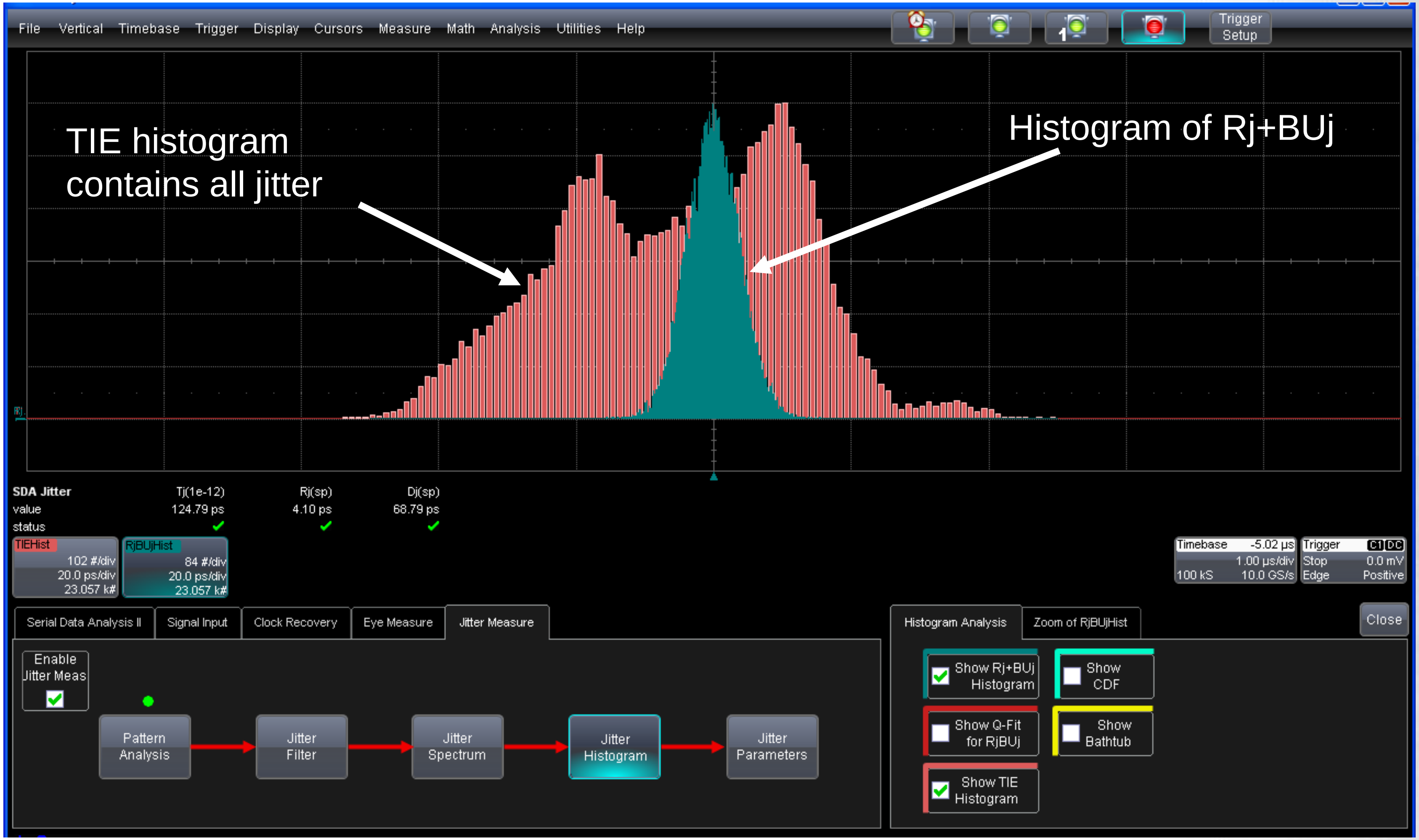
Computing the Jitter PDF

PDF is “built” by combining the measured histogram of Rj+BUj with its tails extrapolated using the selected jitter PDF model





TIE and Rj+BUj Histograms



Back-up slides

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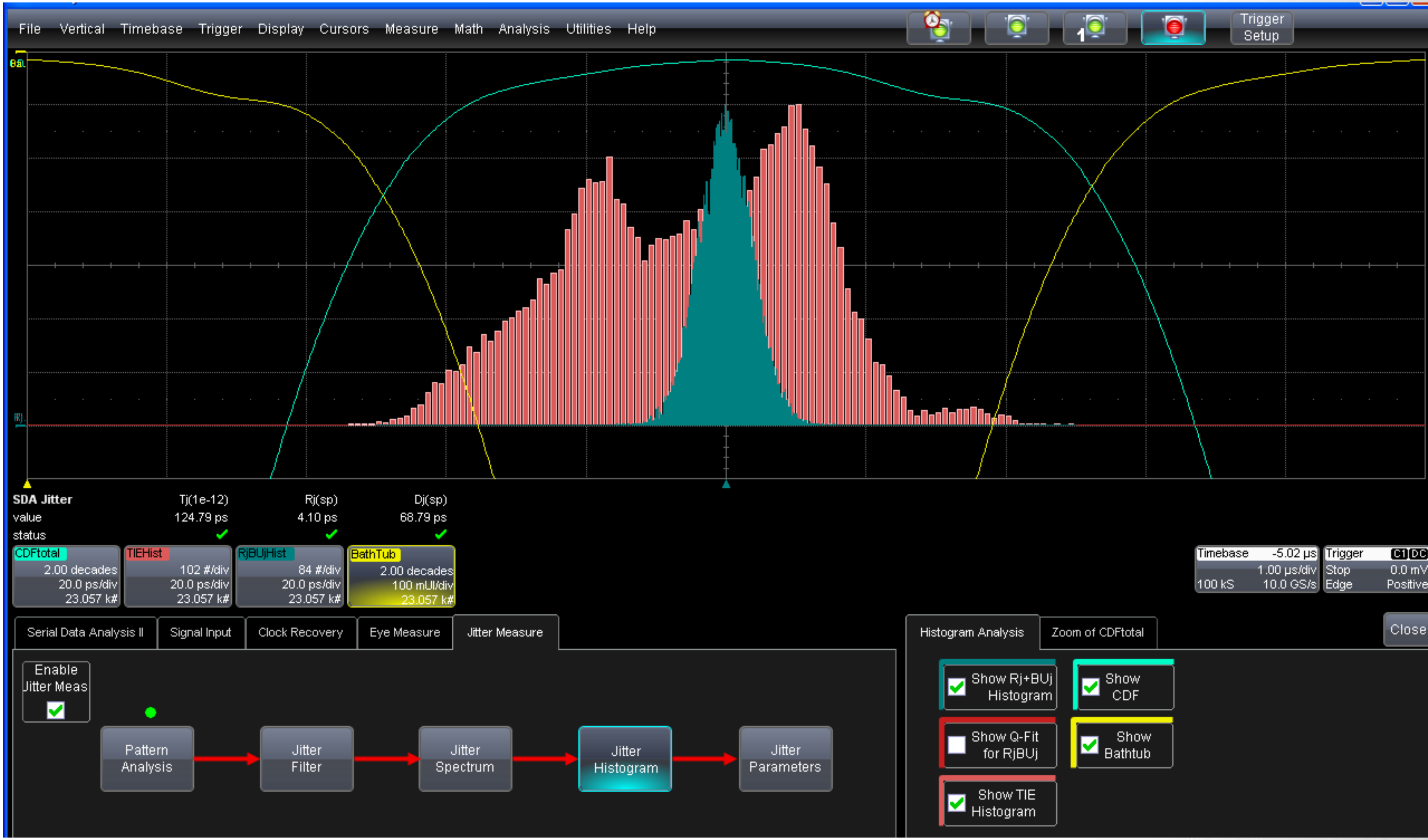
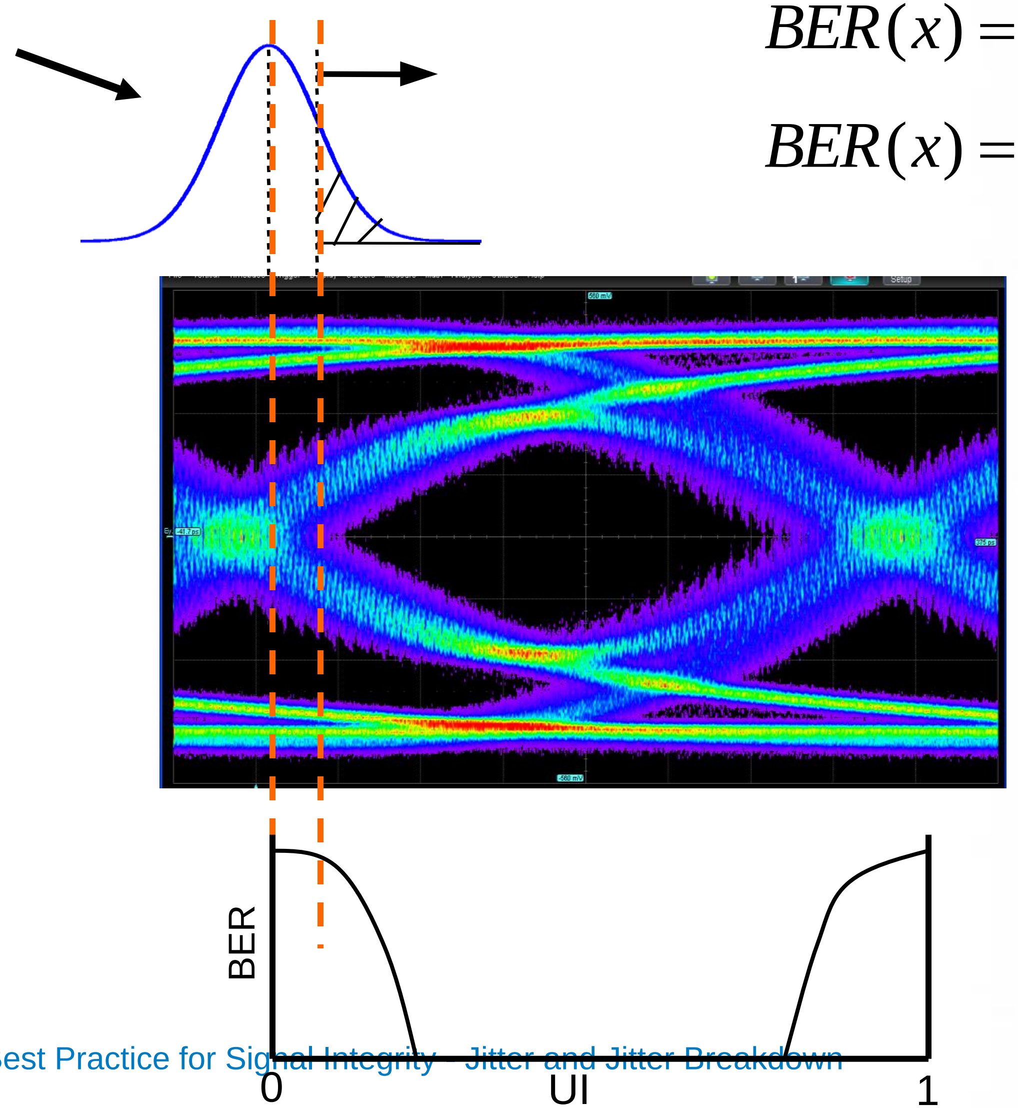
CDF and Bathtub Curve



Jitter and Bit Error Rate

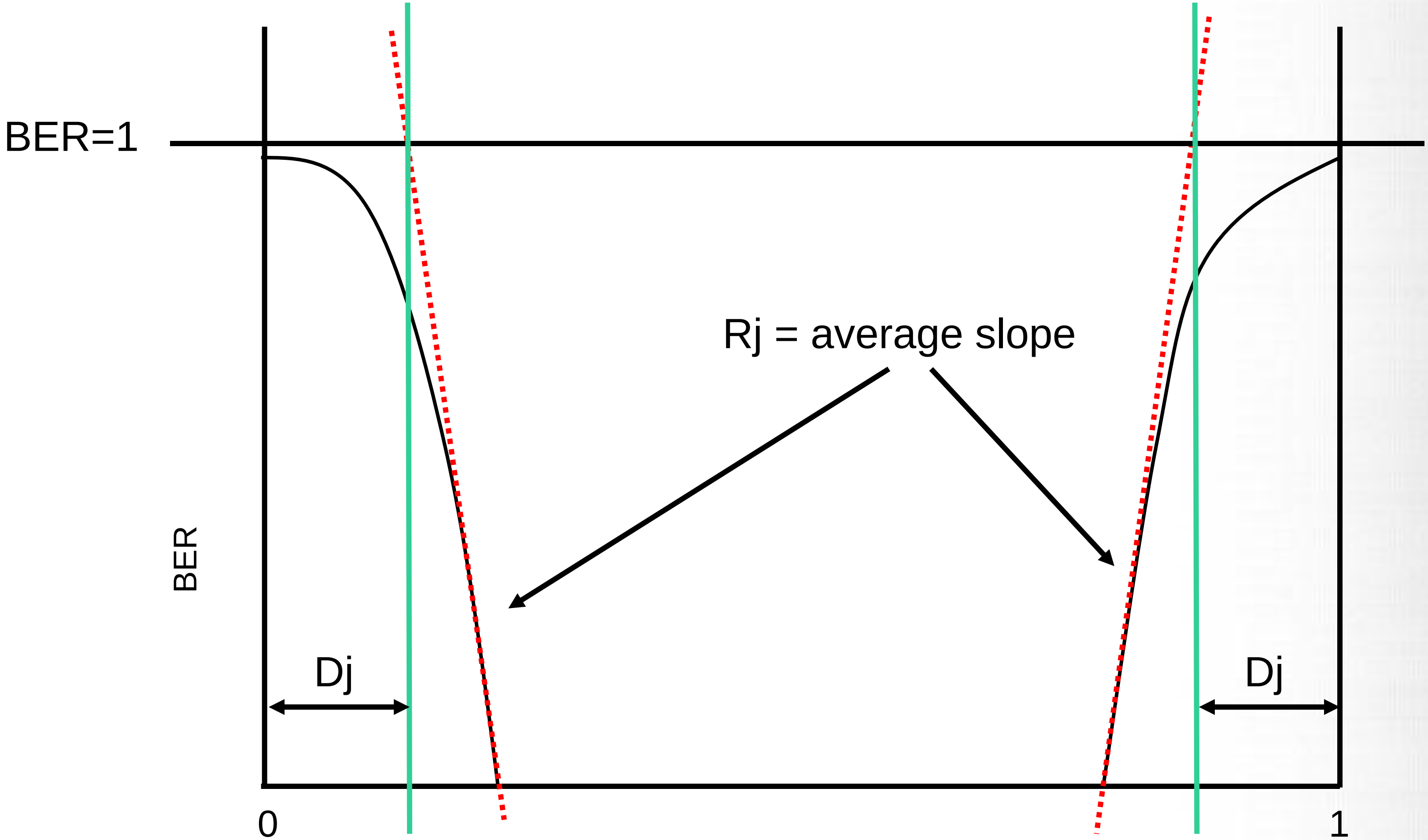
Modeled PDF (e.g. dual dirac)



$$BER(x) = \int_x^{\infty} pdf(u)du$$

$$BER(x) = 1 - CDF(x)$$

Estimating random jitter from the bit error rate (BERT Scan)



Bounded, uncorrelated jitter

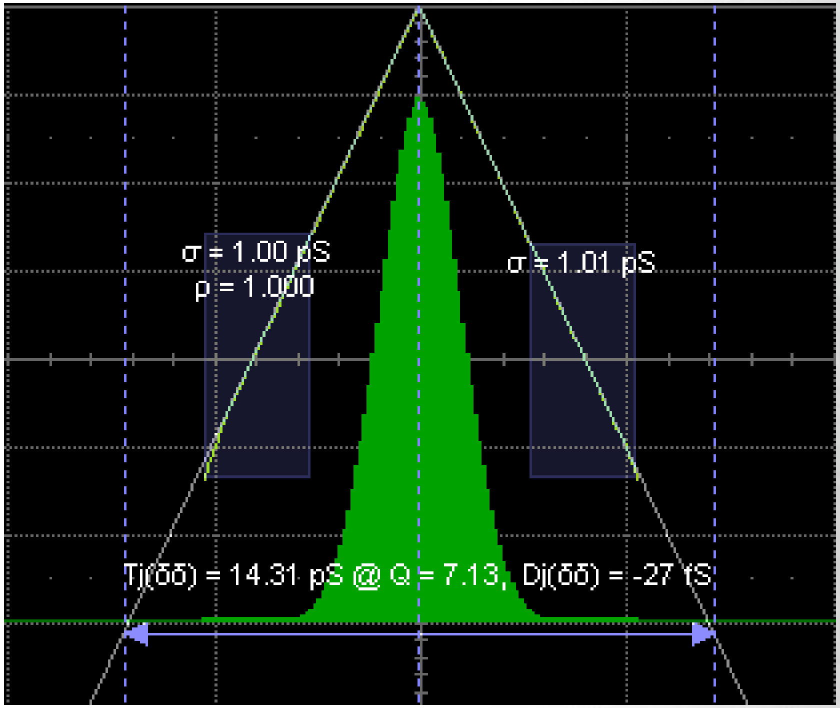
- ***Jitter that is uncorrelated with the data pattern***
  - ***Includes Pj***
  - ***Other sources that are not periodic over the observation time***
- ***OBUj = Other Bounded Uncorrelated Jitter***
  - ***Non-periodic but bounded jitter sources***
  - ***Appears as elevated noise floor in jitter spectrum***
  - ***Must be measured from the jitter histogram (Q-scale)***
- ***Sources of OBUj***
  - ***Crosstalk from long repeating data pattern***
  - ***High rate FM on Pj component***

Q-scale Analysis

$$Q(BER) = \sqrt{2} \bullet erf^{-1}\left(1 - \frac{1}{\rho_t} BER\right)$$

BER(x) is the measured BER as a function of sampling point in the eye (bathtub curve):

$$Q(x) = \sqrt{2} \bullet erf^{-1}\left(1 - \frac{1}{\rho_t} BER(x)\right)$$

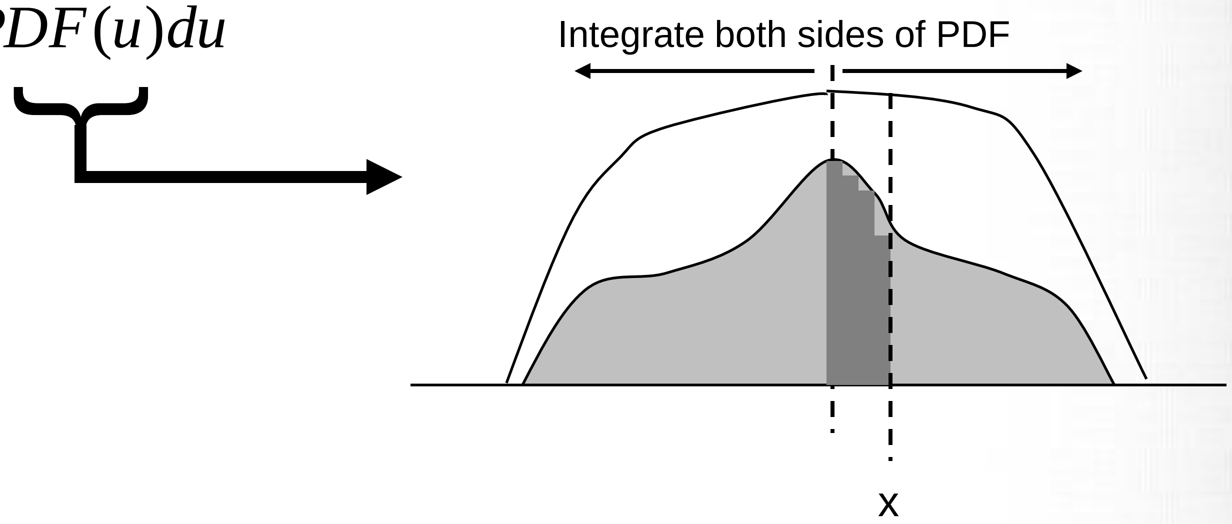


For a Gaussian distribution:

$$BER(x) = \rho_t\left(1 - erf\left(\frac{\mu - x}{\sqrt{2}\sigma}\right)\right) \Rightarrow Q(x) = \frac{\mu - x}{\sigma}$$

Computing the CDF

$$CDF(x) = \int_0^x PDF(u)du$$



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Methods for estimating random jitter

- ✓ **Spectrum-based methods**
  - Measure noise floor of the spectrum of jitter
  - Separate random from deterministic jitter by frequency content
  - Deterministic jitter is contained in the spectral "peaks"
  - Rj (σ) is measured by integrating noise floor
- ✓ **Distribution extrapolation**
  - Measure the distribution of jitter using a histogram
  - Fit Gaussian models to the low probability section of the histogram
  - Standard deviation of best-fit histograms gives Rj

- ✓ *LeCroy offers two jitter methods*
  - ✓ Dual-Dirac (spectral)
  - ✓ Weighted Dual-Gaussian (normalized Q-scale)

Crosstalk and Jitter

- **Crosstalk is caused by a signal called the “aggressor” inducing a voltage or current in an adjacent conductor, the “victim”**
  - Occurs during transitions where dV/dt is high
  - Fast rise time and/or high voltage swing increase crosstalk
  - Differential signaling reduces but does not eliminate crosstalk
  - Primarily affects the amplitude of the victim

Practical Lab

Jitter and Jitter breakdown analysis

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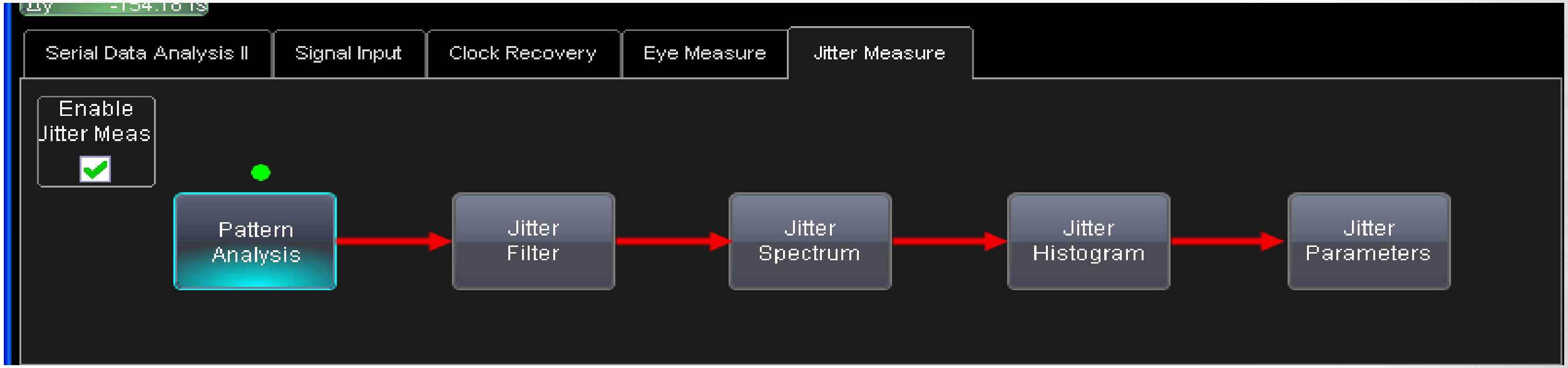
Jitter Measurement in the SDA



- ***Pattern analysis***
- ***Jitter spectrum***
- ***Jitter histogram***
- ***Jitter parameters***
  - ***Spectral (Dual-Dirac)***
  - ***NQ-scale (Weighted Dual Gaussian)***