Jitter and Jitter Breakdown Analysis

"Advanced Measurements …not only Signal Integrity " *- July2009*

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Agenda

- **Jitter concept**
  - 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**
  - Rj, DDj,
- **Jitter breakdown model methods**
  - **Spectrum based vs. NQ-scale**
  - **Crosstalk measurements**
- **Measurement processing flow on the oscilloscope**

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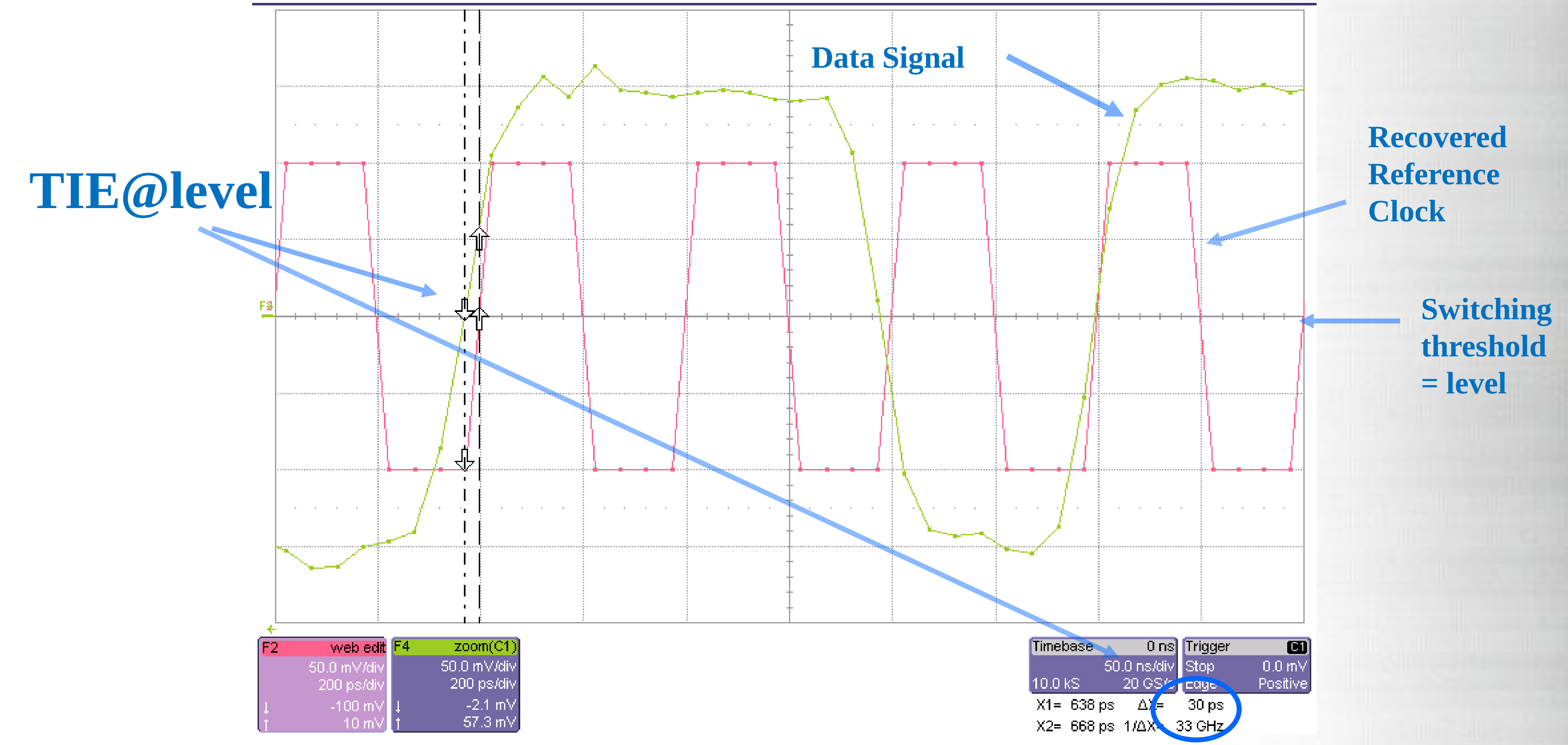
Jitter concept

- ***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.***

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

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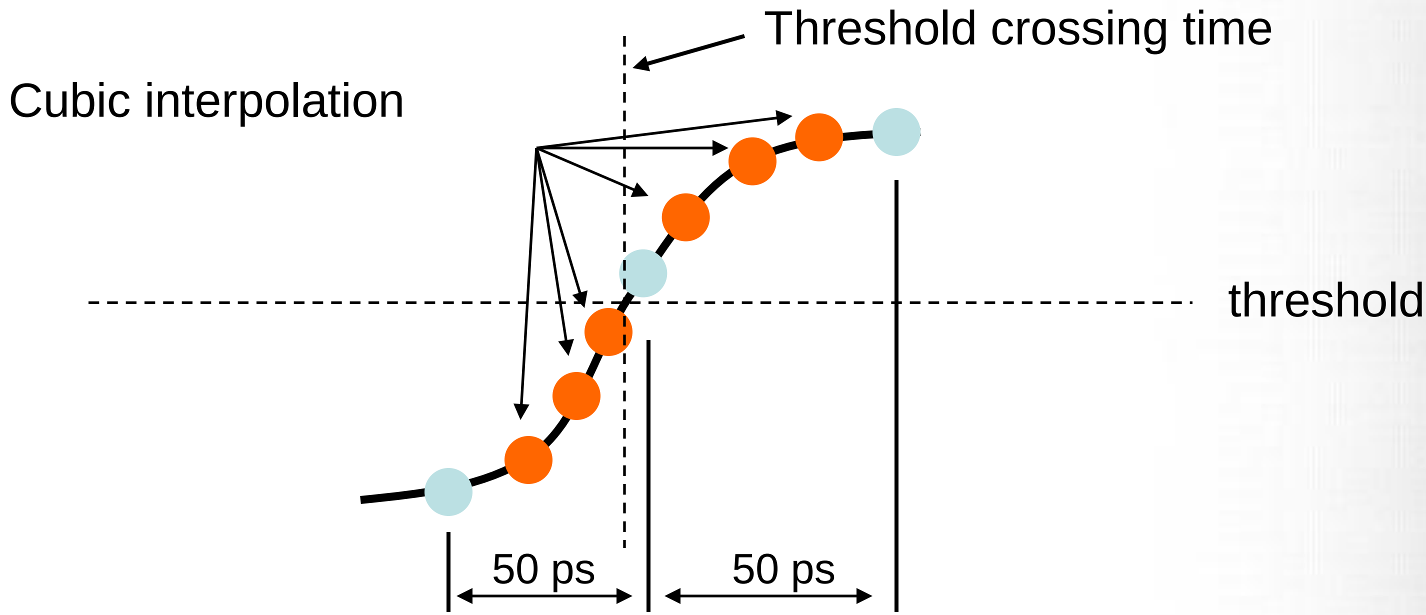
Timing Measurement in Oscilloscopes



- *Time is measured at the point where the waveform amplitude crosses a predefined threshold*
- *Samples are spaced at the sample interval (25 ps at 40 GS/s for example)*
- *Cubic interpolation is used on the waveform transition followed by linear interpolation of the points nearest the crossing to find the exact time*

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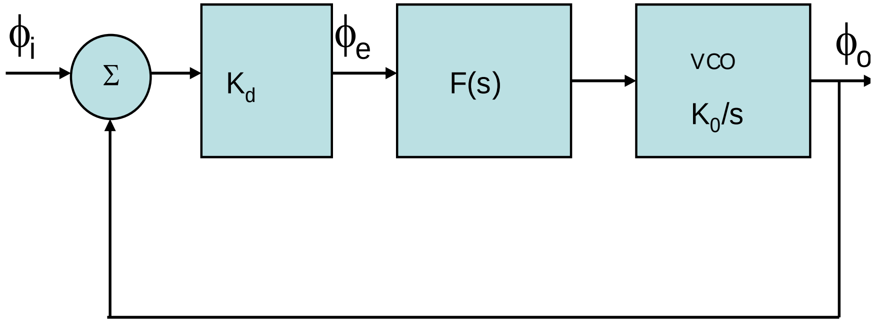
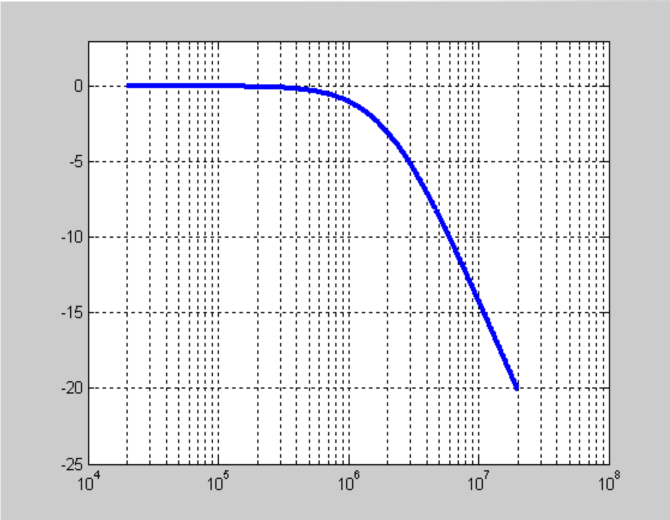
Reference Clock Reconstruction

- ***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.*



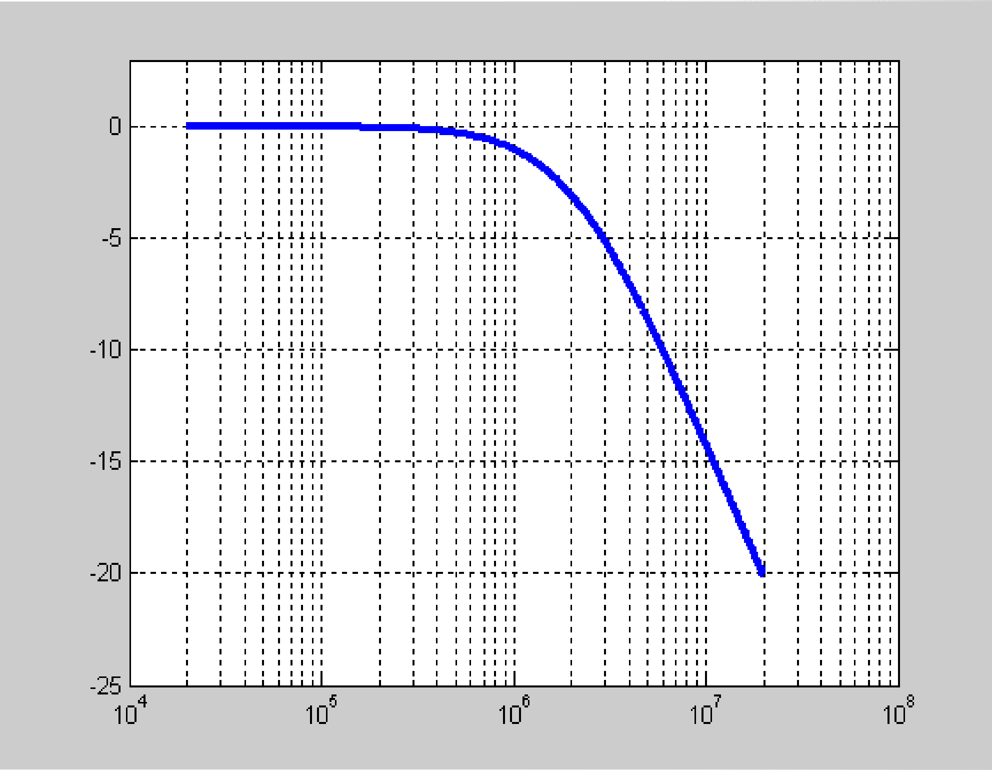


Closed Loop Phase-Locked Loop Response

Closed loop PLL response

$$H(s) = \frac{\phi_o}{\phi_i} = \frac{K_0 K_d F(s)}{(s + F(s) K_0 K_d)}$$

- ✓ **The closed loop PLL response gives the phase tracking as a function of frequency. Jitter present at the phase input of the PLL will appear at the output of the VCO with an amplitude defined by the open loop response**

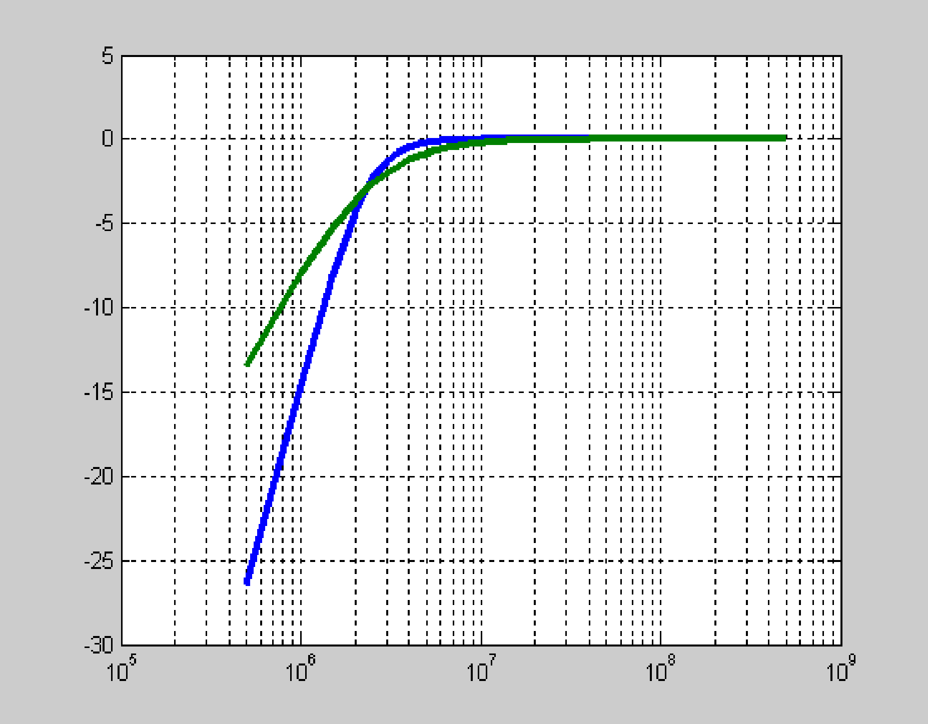


Plot shown for $K_0 = K_d = 1$ and $F(s) = 2\pi * 2e6$

Jitter transfer function (JTF)

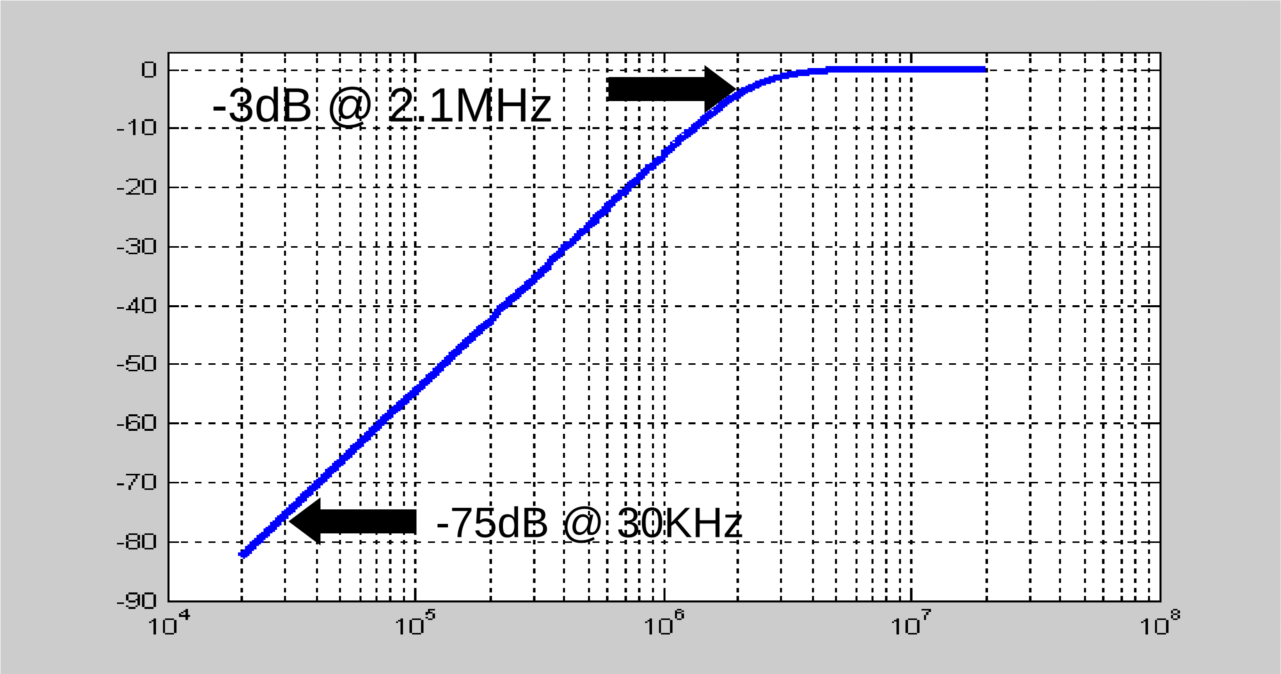
$$J(s) = 1 - H(s) = 1 - \frac{K_0 F(s)}{(s + F(s) K_0 K_d)}$$

- JTF is the difference between the input phase and the VCO phase as a function of the jitter frequency on the phase reference.
- Complement of the open loop PLL response



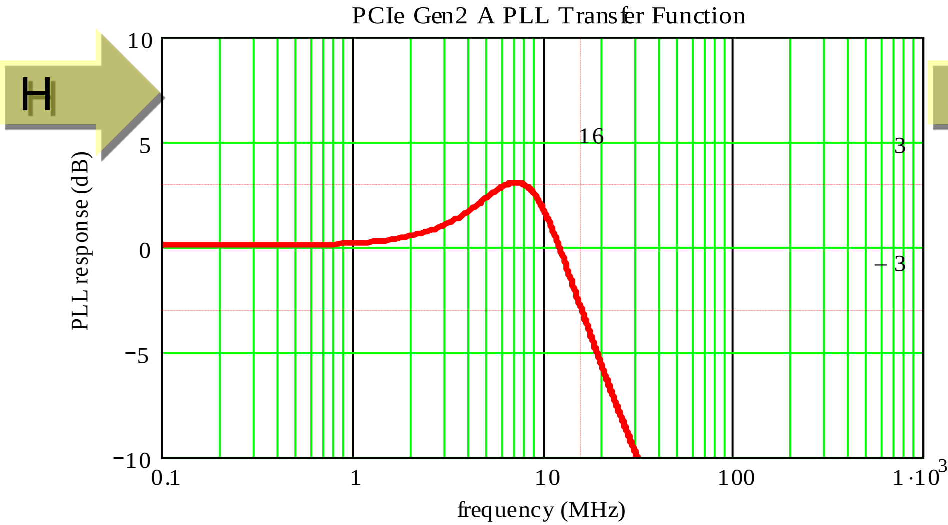
JTF for 1 and 2 pole PLL

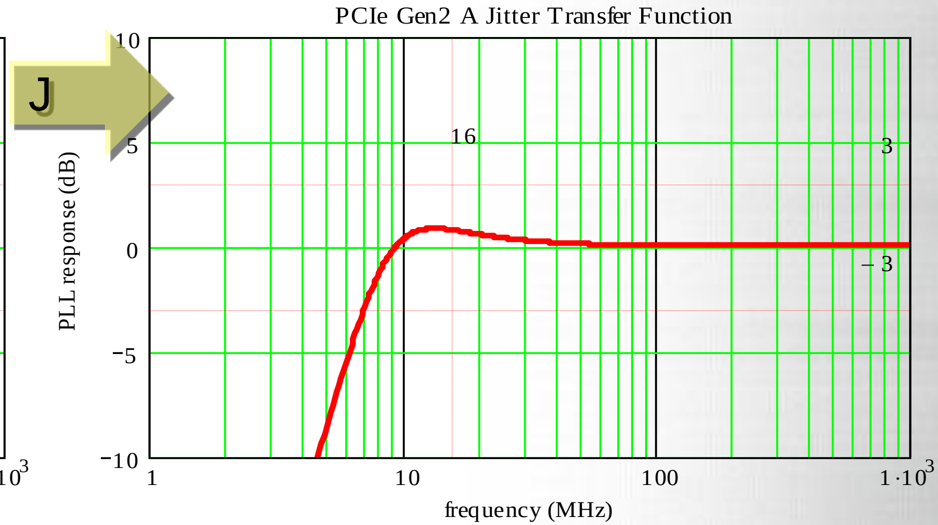
Example Jitter Transfer Function

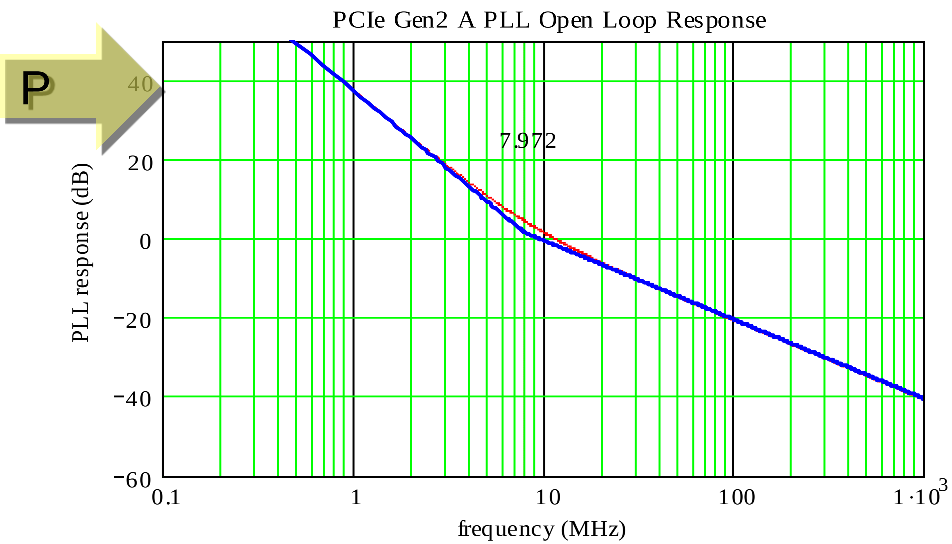


- ✓ **SATA Generation 2 - SSC at 30 KHz rate**
- ✓ **Specified JTF: -72 dB @ 30 KHz, -3 dB at 2.1 MHz**
- ✓ **Use 2nd order PLL with natural frequency of 2.3 MHz and damping factor of 0.707**

PLL Open-Loop, Closed-Loop and Jitter Transfer Functions Summarized



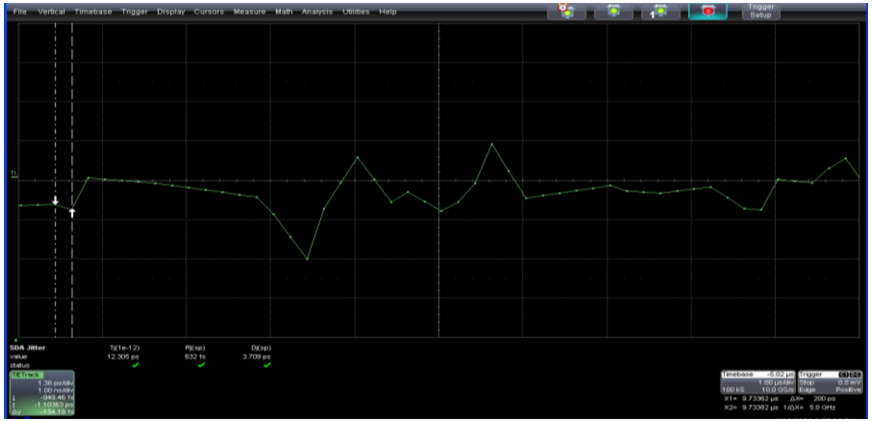




	H	P	J
H	1	$\frac{P}{1+P}$	$1-J$
P	$\frac{H}{1-H}$	1	$\frac{1-J}{J}$
J	$1-H$	$\frac{1}{1+P}$	1

$$P = \frac{K_d K_0}{s} F(s)$$

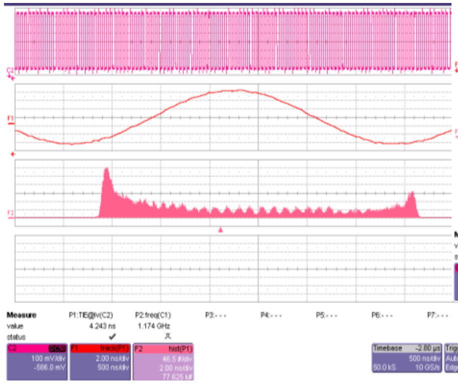
TIE is the fundamental measurement for all the jitter measurements



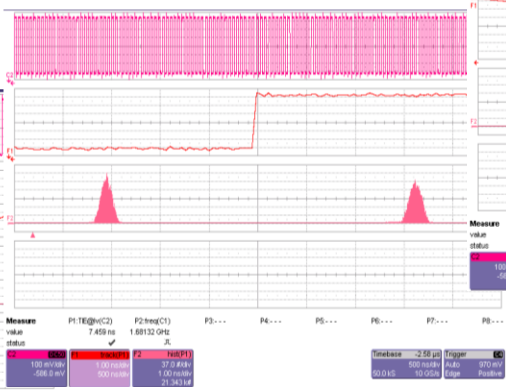
- ✓ ***The sequence of TIE measurements is collected in a track***
  - *One measurement on each transition of the signal*
  - *"virtual" transitions are added where no transition occurs*
  - *"virtual" transitions are needed to maintain time information*

- ✓ ***Jitter TIE histogram analysis***

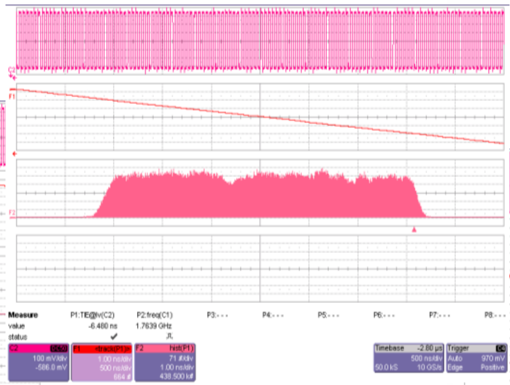
Sinusoidal Jitter



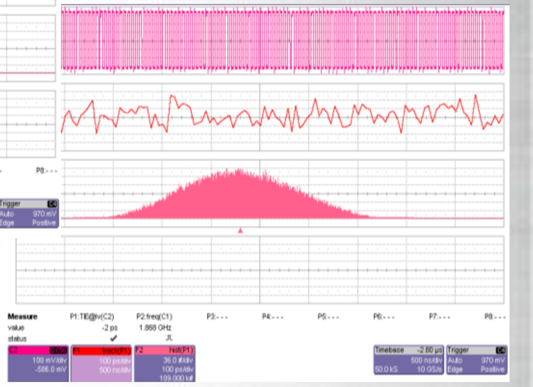
Bi-modal Jitter



Uniform Jitter



Random Jitter – Thermal Noise



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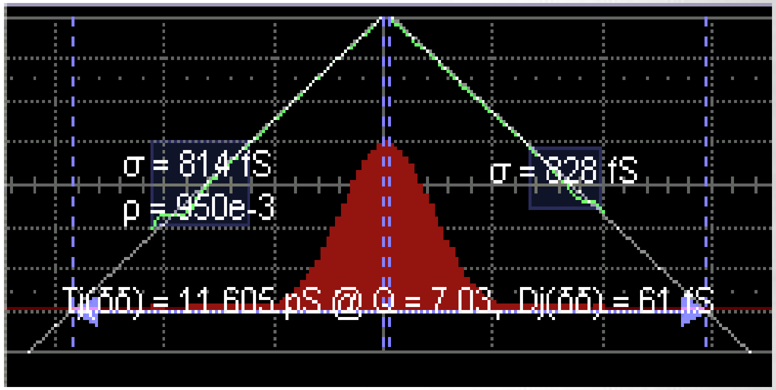
The two types of Jitter

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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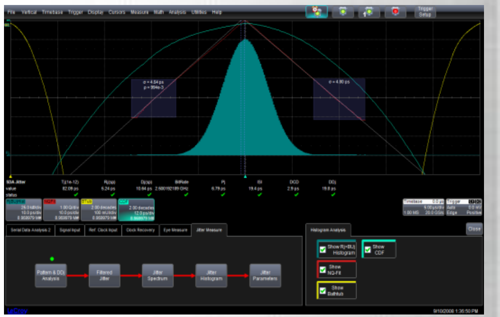
Jitter breakdown

Total Jitter (Tj)

Deterministic Jitter (Dj)
Bounded Jitter

Random Jitter (Rj)
UnBounded Jitter
Gaussian in Nature

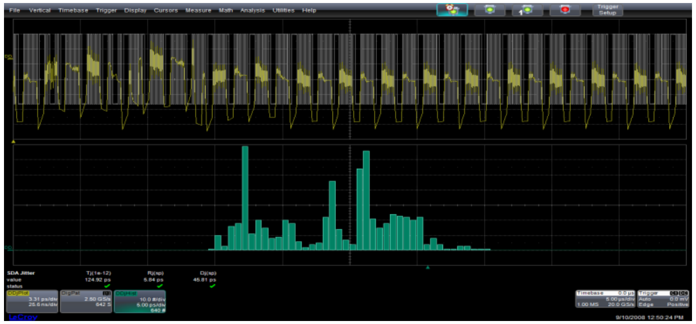


Data Dependent Jitter (DDj)
Correlated to Data Pattern

Bounded Uncorrelated Jitter (BUj)
Independent of Data Pattern

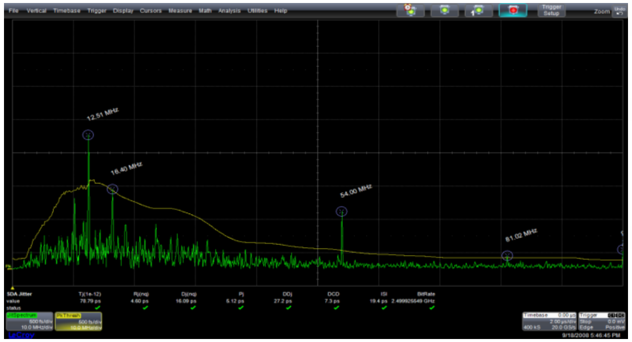
Duty Cycle Distortion DCD

Inter-Symbolic Interference ISI

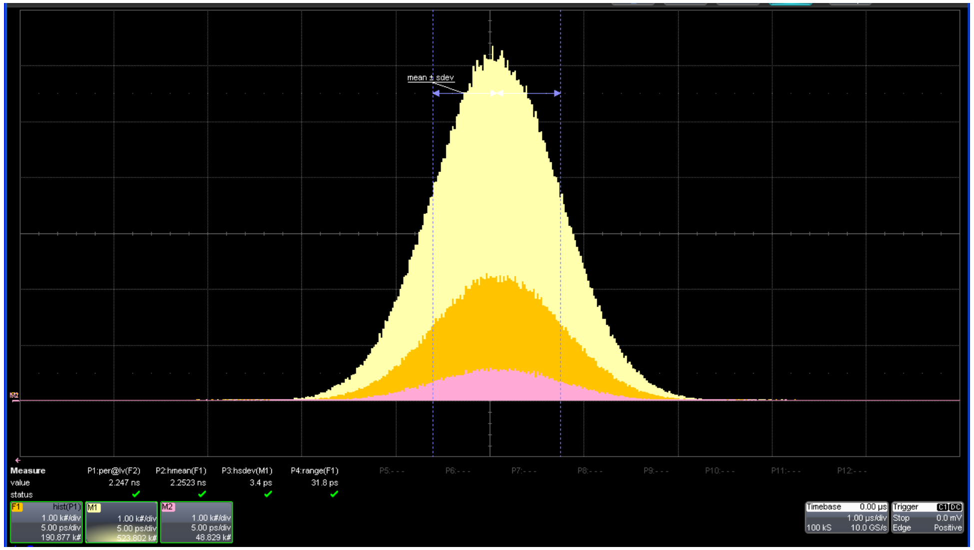


Periodic Jitter (Pj)

Other BUj



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.*

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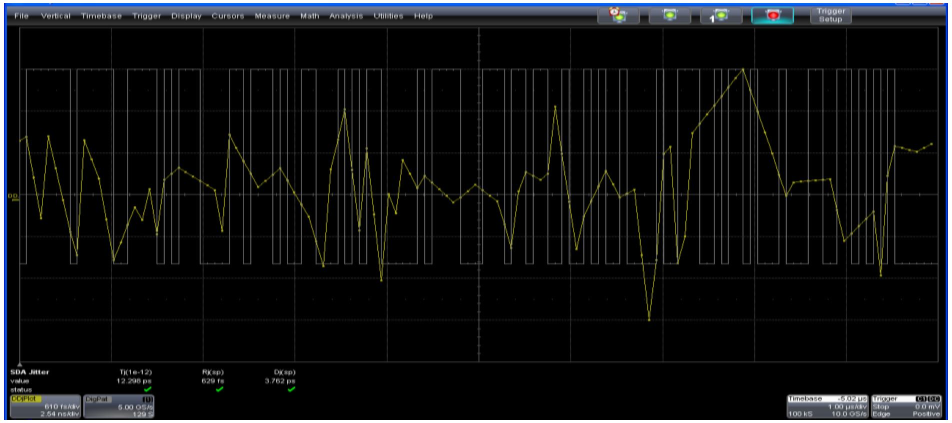
Data Dependent Jitter (DDj)



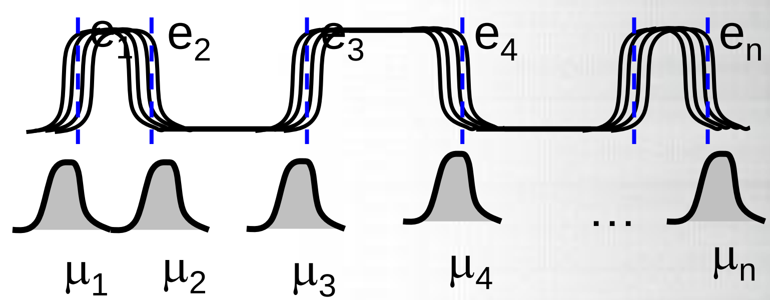
DDj plot vs.bit with digital pattern overlay

- ***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



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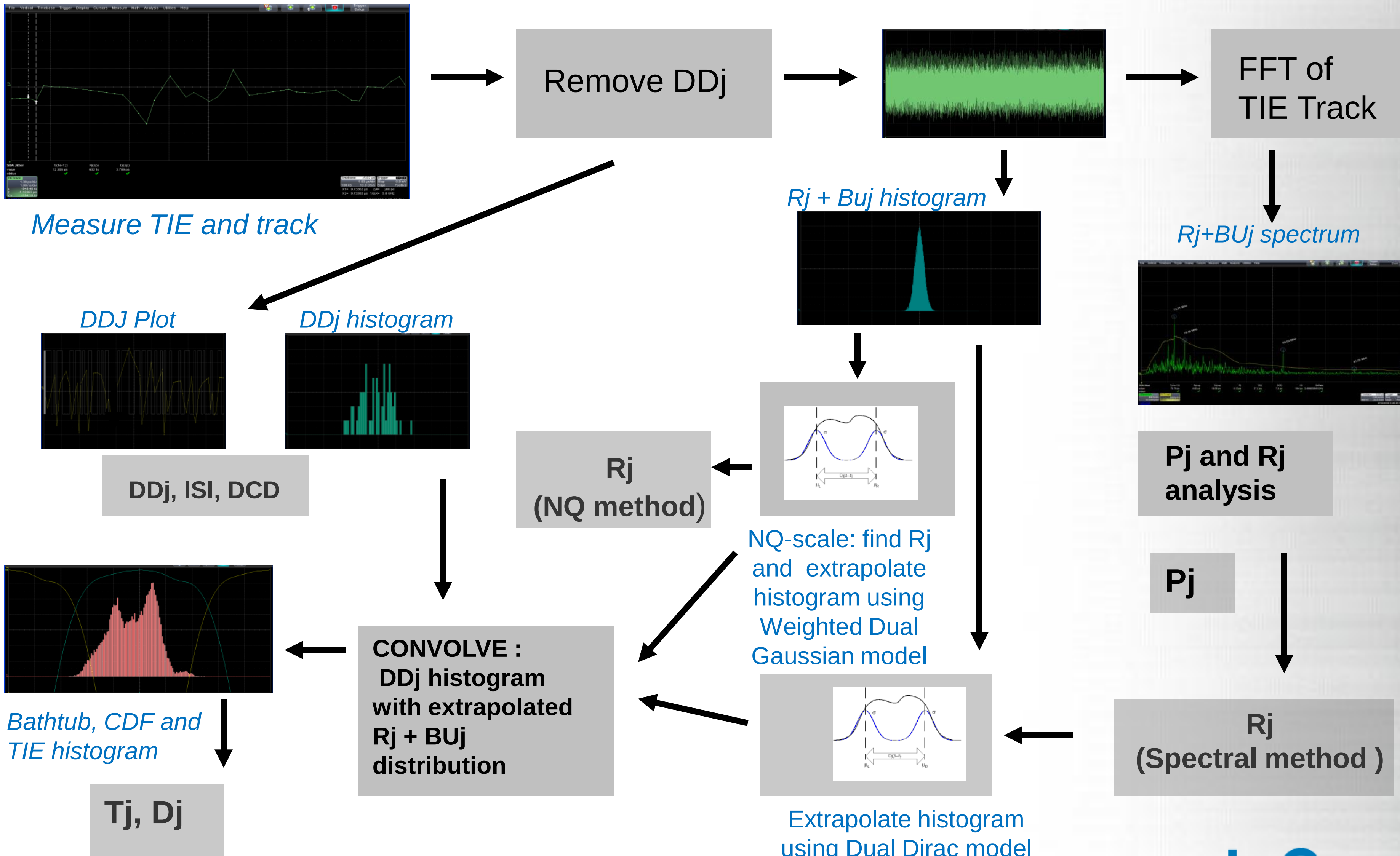
Jitter Measurements Processing Flow

on SDA Platform



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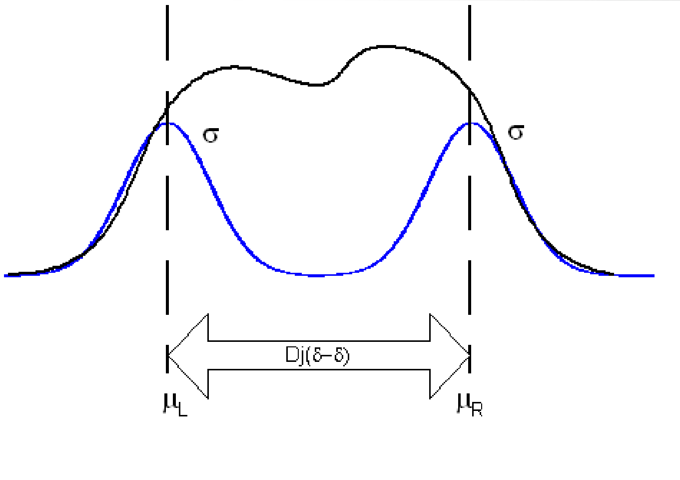
Methods for estimating random jitter

- ✓ **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)*

The Dual Dirac Jitter Model

- Fit Gaussian curves to the left and right sides of estimated jitter PDF (i.e. the measured histogram)
- Separation of the mean values gives Dj(d-d)
- Standard deviation gives Rj
- Dj(d-d) is chosen to best fit the measured histogram in the tails
- Model Predicts jitter for low bit error rates
- Note that the model does not fit the central part of the measured distribution



$$Tj = Q_G(BER) * Rj + Dj(\delta - \delta)$$

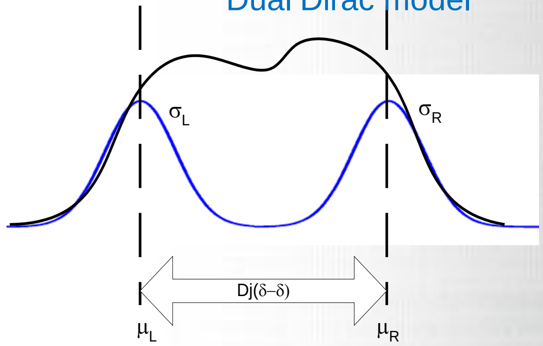
$$Rj = \sigma$$

$$Dj(\delta - \delta) = \mu_R - \mu_L$$

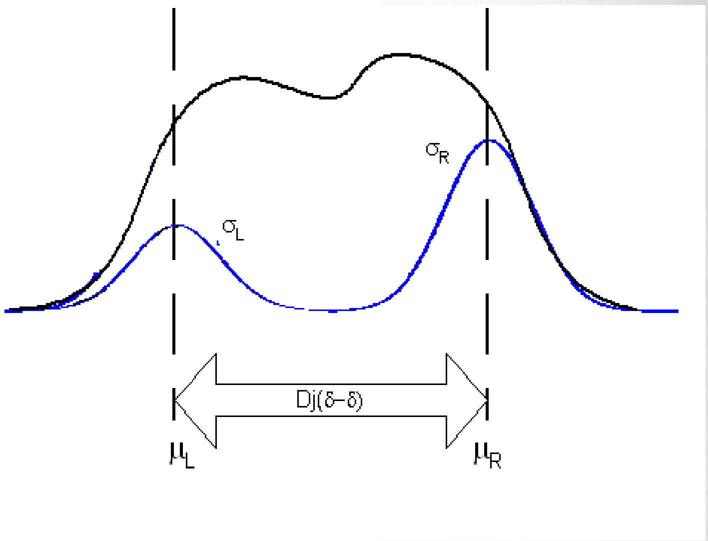
Weighted Dual Gaussian model

- Dual Dirac Model
  - One Gaussian
  - 2 degree of freedom : the standard deviation and impulse spacing.
- Dual Gaussian Model
  - Two Gaussians
  - Different mean values
- Weighted Dual Gaussian Model
  - Two Gaussians with different weights
  - Different mean values
- 2, 4, or 6 degrees of freedom

Dual Dirac model



Weighted Dual Gaussian model



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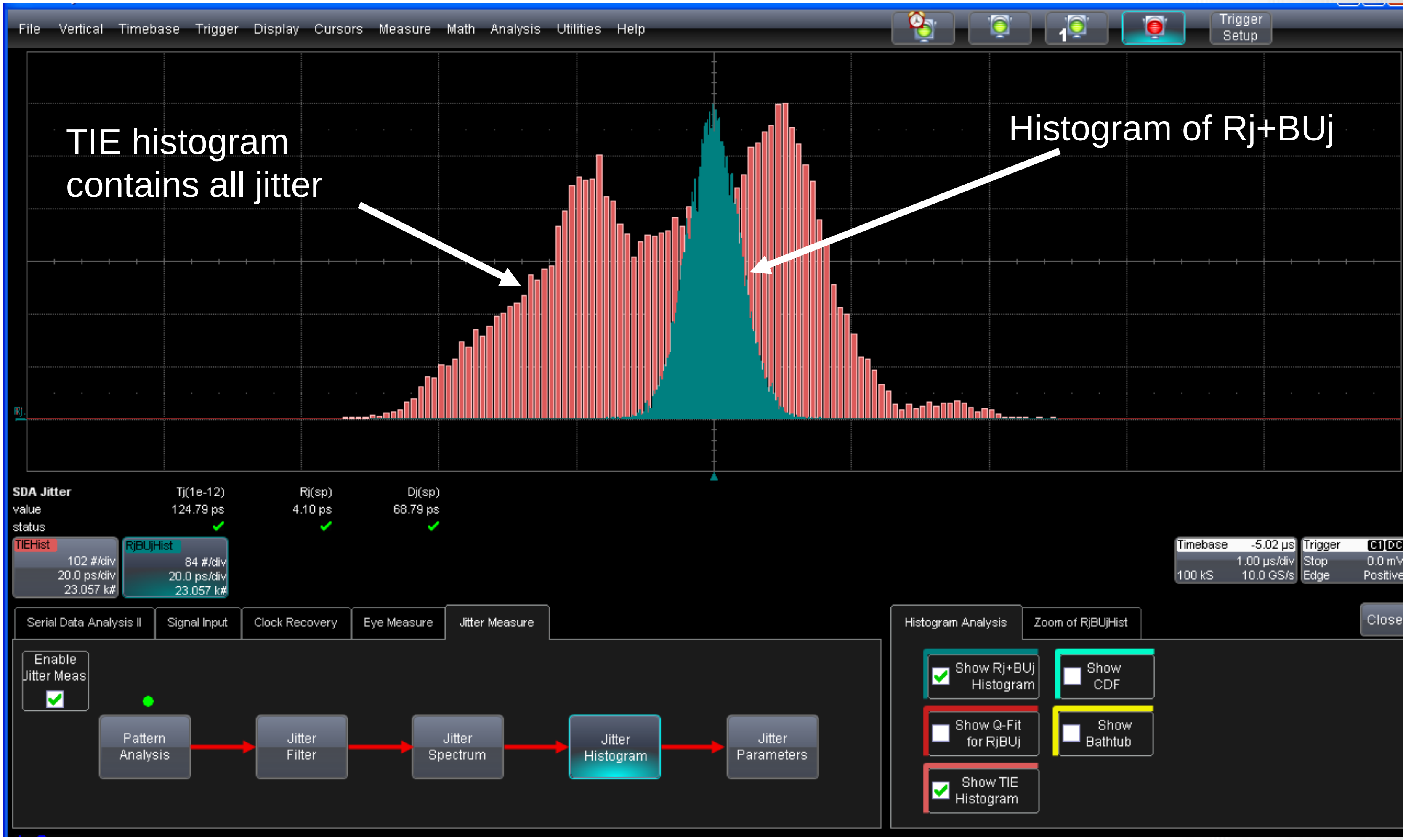
TIE and Rj+BUj Histograms



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