Understanding SDAIII Jitter Calculation Methods

WHITE PAPER

Dr. Alan Blankman
September 2012, v 2.01

Summary

The SDAIII-CompleteLinQ toolset calculates total, random and deterministic jitter (Tj, Rj and Dj), periodic jitter (Pj) and data-dependent jitter (DDj), which includes inter-symbol interference (ISI) and duty cycle distortion (DCD). The toolset includes three algorithmic methods based on dual-Dirac models for calculating and decomposing Tj, Rj and Dj. The document describes the three methods and explains the similarities and differences.

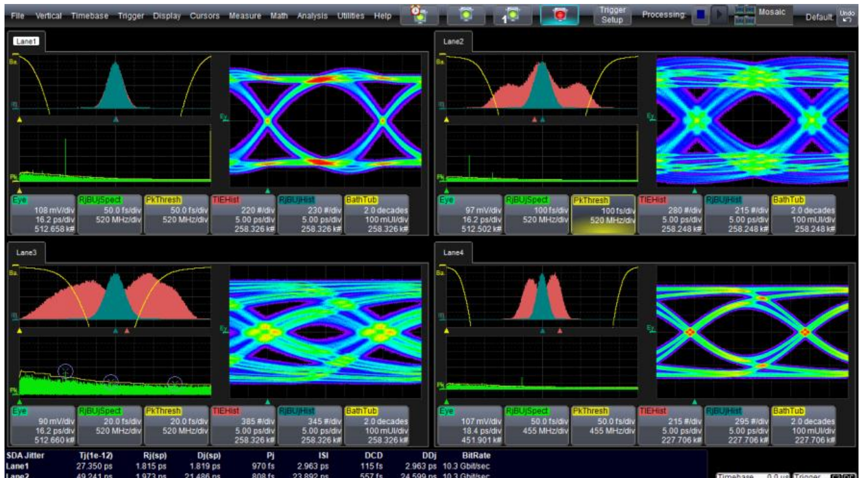


Figure 1: Example SDAIII-CompleteLinQ analysis screenshot showing the simultaneous analysis of four lanes of high-speed serial data signals.

Introduction

Calculating jitter on high-speed serial waveforms is a key feature of the SDAIII-CompleteLinQ Serial Data and Crosstalk Analysis family of software options. This white paper explains the algorithms used to transform the measurement of time interval error (TIE) measurements into jitter results, and describes the views of jitter available for display. Seven jitter values are determined: total, random and deterministic jitter (Tj, Rj, Dj), Periodic jitter (Pj), data-dependent jitter (DDJ), intersymbol interference (ISI) and duty cycle distortion (DCD).Three of these results (Tj, Rj and Dj) are determined via models that use extrapolation. The other four (DDj, ISI, DCD and Pj) are determined directly from an analysis of time interval error measurements and are not model-based.

Three calculation methods based on the dual-Dirac jitter model can be selected by the user to calculate Tj and decompose it into Rj and Dj. Of these methods, two are versions of the industry-standard spectral method. The third is the LeCroy NQ-Scale method, which returns better results when the jitter distribution is a poor fit to the spectral method, such as in the case of crosstalk or other bounded uncorrelated jitter.

This document references steps and includes screenshots from a companion animation available for download from www.lecroy.com.

Introduction to Jitter Calculation and the Dual-Dirac Jitter Model

Rising bitrates result in smaller unit intervals and increasingly tighter timing budgets, such that even picoseconds can now make a difference. Engineers naturally want jitter estimates to be accurate, consistent from one instrument to another, and, of course, as low as possible. The past 10 years have seen an evolution in the techniques used to characterize jitter in high-speed serial data channels. The goal of all this hard work is to estimate the probability of bit errors and the extent of jitter in the presence of very small bit error ratios (BER), such as 10^{-12}.

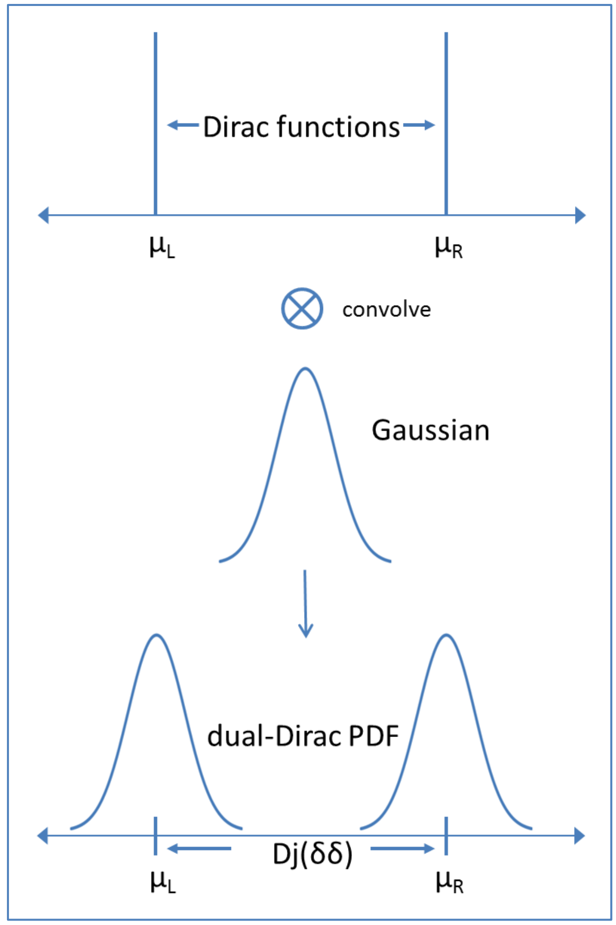


Figure 2: Illustration of the dual-Dirac model, which convolves a Gaussian with two Dirac functions.

Determining jitter at very small bit error ratios on a real-time oscilloscope requires algorithms that extrapolate the measured data rather than by simply calculating peak-to-peak or RMS values directly from the acquired measurements. The reason for requiring extrapolation is simple: to measure total jitter directly rather than via extrapolation requires a data set that could easily take a whole day to acquire. So instead, algorithms utilizing extrapolation are employed.

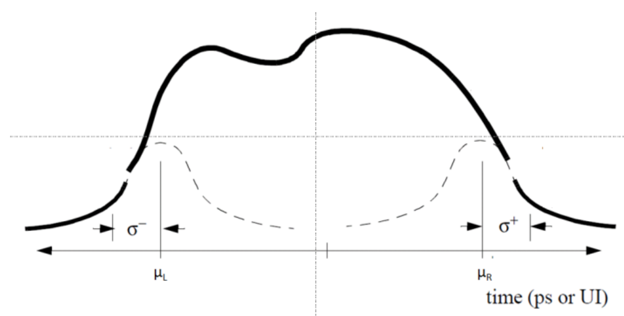


Figure 3: Illustration of a distribution of TIE jitter values overlaid onto the dual-Dirac jitter model. The outer portions beyond the breaks in the curve represent extrapolated values.

To perform this extrapolation accurately, a model of the underlying processes must be used to guide the extrapolated curve. In the engineering of communications channels, the dual-Dirac jitter model used in "MJSQ" ("Methodologies for Jitter and Signal Quality Specification", reference [1]) has become the de-facto industry standard. Figure 2 shows how the dual-Dirac model is formed. First, begin with two Dirac delta functions that sit at times μ_L and μ_R. The delta functions aim to model deterministic jitter. Random jitter is modeled as having a Gaussian distribution, as shown in the center of the figure. Convolving these two distributions results in the dual-Dirac probability density function (PDF) shown at the bottom of Figure 2. It should be noted, however, that deterministic jitter (Dj) does not, in general, follow the dual-Dirac distribution, with the consequence that Dj returned by the MJSQ method will not be the same as peak-to-peak deterministic jitter. This is where the "δδ" in the term Dj(δδ) shown in Figure 2 comes into play. Dj(δδ) is the "model-dependent" deterministic jitter, which is the difference between the μ_L and μ_R values. These values are determined from fitting to the dual-Dirac model. In general Dj(δδ) will be less than Dj(peak-peak).

Figure 3 shows an example histogram of acquired jitter measurements, along with the dual-Dirac Gaussians. The tails of the histogram beyond the breaks in the curve show an extrapolation of the histogram. Determining these extrapolated tails and the positions of μ_L and μ_R is the job of the algorithms discussed below, and requires a determination of the sigma value used for the dual-Dirac Gaussians. In typical MJSQ implementations, the assumption is made that $\sigma- = \sigma+$. The LeCroy NQ-Scale method does not make this assumption.

In MJSQ, total jitter (Tj) is the sum of deterministic jitter (Dj) and random jitter (Rj), with Rj weighted by a multiplier α (alpha) that is determined from the bit error ratio. ($\alpha = 14.07$ for a typical BER value of 10^{-12}):

$$Tj = \alpha(BER)*Rj + Dj(\delta\delta) \quad (1)$$

Lastly, it is important to remember that model-based results are estimates, as opposed to directly measured results like a straight-forward RMS or peak-to-peak value. Total jitter is essentially an estimate of the peak-to-peak jitter at a specific bit error ratio.

Jitter Hierarchy

Total jitter is decomposed into random and deterministic components, where random jitter is defined as unbounded jitter with Gaussian tails. Deterministic jitter is, by definition, bounded, and is composed of jitter that is either uncorrelated or correlated to the data. Two sources of bounded uncorrelated jitter exist: Periodic jitter and “other bounded uncorrelated jitter”, of which crosstalk is a key element. Correlated deterministic jitter is typically referred to as “data dependent jitter”. Tj, Rj and Dj are calculated via a fit to the dual-Dirac model, as explained above. Pj, DDj, ISI and DCD are calculated directly from time interval error measurements. For this reason, it is certainly possible for the components of deterministic jitter to be larger than Dj(δδ), which, as described previously, will be less than Dj(peak-peak).

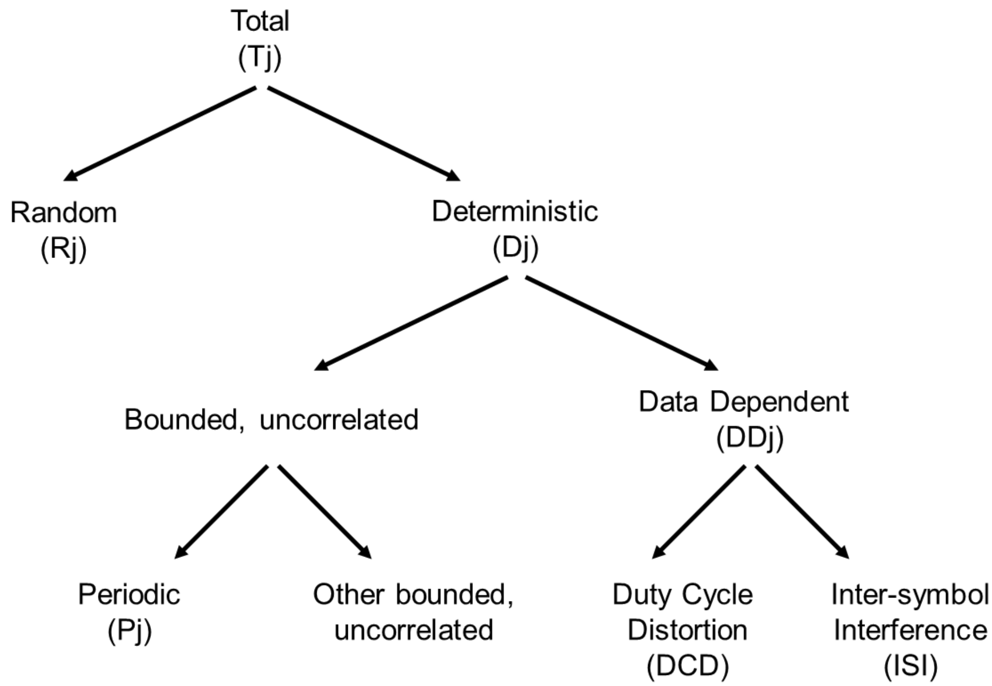


Figure 4: Jitter hierarchy used in SDAIII-CompleteLinQ. The results shown in the jitter measurement table are shown in parentheses.

Overview of SDAIII Calculation Methods for Tj, Rj and Dj

SDAIII includes three methods to calculate Tj, Rj and Dj. All three methods are based on the dual-Dirac model, but with different implementations. Users select which method to use via the Jitter Parameters dialog, and can easily change from one method to another to compare the methods' results. Here are short descriptions of each method; additional information is provided later in the document.

Dual-Dirac Spectral Rj Direct Method:
The standard dual-Dirac model is used, with the σ (sigma) value of the Gaussians being derived from a spectral analysis of the jitter. The tails of the jitter distribution are extrapolated using σ, but the final value for Rj is set to be equal to σ. Tj is the width of the final cumulative distribution function (CDF) at the user's selected BER level.

Dual-Dirac Spectral RJ+Dj CDF Fit:
As with the dual-Dirac Spectral Rj Direct method, the standard dual-Dirac model is used, with the σ (sigma) value of the Gaussians being derived from a spectral analysis of the jitter. However, the tails of the jitter distribution are extrapolated using σ with Tj equal to the width of the final cumulative distribution function (CDF) at the user's selected BER level, and Rj and Dj determined by fitting to equation (1) in the vicinity of the selected BER value. This method most closely follows MJSQ, and is the default selection.

Dual-Dirac NQ-Scale:
"NQ-Scale" stands for "Normalized Q-Scale". This is a variant of the dual-Dirac model that includes six degrees of freedom: the Gaussians can have different σ (sigma) values, populations and means. The NQ-Scale method is performed by transforming to the "Q-scale", in which a Gaussian has a linear slope. Tj is the width of the final cumulative distribution function (CDF) at the user's selected BER level, and Rj and Dj are determined by fitting to equation (1) in the vicinity of the selected BER value. Since the NQ-Scale method does not use spectral methods to determine σ, and since it includes additional degrees of freedom, the estimates of jitter in the presence of high crosstalk or other bounded, uncorrelated jitter may be more realistic than returned by the spectral methods.

Jitter Calculation Methodology, Step-by-Step

Although this paper includes many details about how the jitter calculation is performed, it is not a "how-to" guide for setting up the oscilloscope to make a measurement. Instead, this document aims to provide a high-level description of how the oscilloscope calculates and decomposes jitter into Tj, Rj and Dj, and then further calculates deterministic jitter components. See the LeCroy website for a thirty-minute tutorial, **Jitter Basics Lab Using SDAIII & Jitter Sim,** along with the oscilloscope online help for information on setting up your oscilloscope.

Analysis Starting Point

The algorithms all begin with the acquisition of a "long" NRZ serial data waveform. "Long", in this sense, means that the input waveform or waveforms include a sufficient number of unit intervals and transitions so that 1) the software clock recovery algorithm, which optionally includes applying a PLL, can accurately determine the expected arrival time of the edges, and 2) the jitter calculation, which includes extrapolation, can have the best statistical significance. We recommend acquiring waveforms with a length of several hundred thousand unit intervals and at least 100 iterations of a repeating pattern. (Note: this isn't feasible for very long patterns, such as PRBS23, in which case multiple acquisitions will be necessary to accumulate enough iterations.) For example, a LeCroy SDA845Zi-A oscilloscope configured to acquire 1.6 MSamples at 80 GSamples/sec will acquire 206K unit intervals of a 10.3125 Gbps serial data pattern. (203K unit intervals are retained after ensuring a PLL lock.) Figure 5, taken from the companion animation, shows a zoom of a typical waveform.

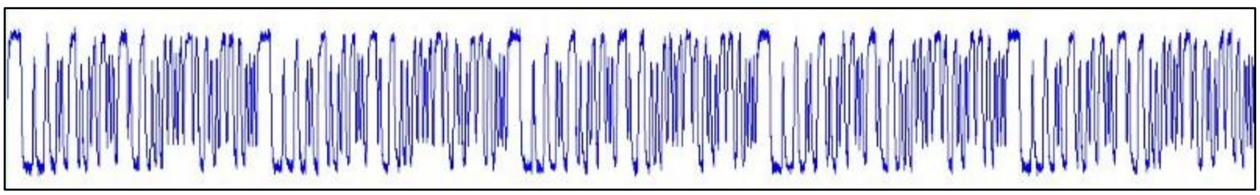


Figure 5: Several iterations of a NRZ high-speed serial data pattern to be input to the jitter calculation algorithms of SDAIII-CompleteLinQ. The actual pattern includes several hundred thousand unit intervals.

Tip: Follow best practices to set the vertical scale of the input signal(s), and when using (+) and (–) inputs, deskew the signals. Neglecting to do so will lead to incorrect jitter results.

Step 1: Timing Measurement

The input signal is analyzed to determine the actual arrival time of each edge. This is done by identifying the time each edge traverses a **crossing level** selected by the user. Figure 6 shows an example of how the edge timing is determined, which includes cubic interpolation of the samples, and linear interpolation to find the exact time the signal traverses the crossing level. The complete set of crossing times (i.e. the **actual edge arrival times**) comprise the set of data to be analyzed.

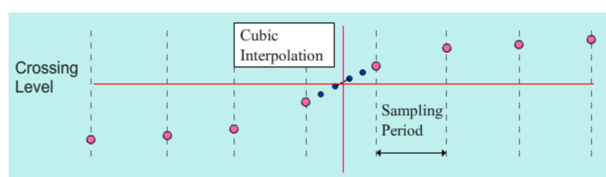


Figure 6: Each edge in the NRZ pattern is analyzed to determine the time it traverses a user-configurable crossing level.

The next step is to compare these actual arrival times to expected arrival times. To do this, a reference clock that provides the expected arrival times is required. Either an external reference clock can be used, or preferentially, a clock calculated by the oscilloscope from the signal using a "software clock recovery algorithm". The software recovery algorithm functions similarly to a hardware clock recovery system or module that generates a clock signal. This is the technique historically used for triggering sampling scopes for eye diagram creation.

When recovering the clock from the data, the arrival times of the edges are input to a software clock recovery algorithm that determines the underlying clock (and therefore the bitrate) of the input data stream. This algorithm optionally applies a PLL that allows the oscilloscope to simulate the behavior of a receiver. Users can select from a set of PLLs specific to a variety of serial data standards, or apply custom values. The output of this step is a clock signal, as shown in Figure 7. The time of the clock edge closest to a specific data edge is the **expected arrival time** for that data edge.

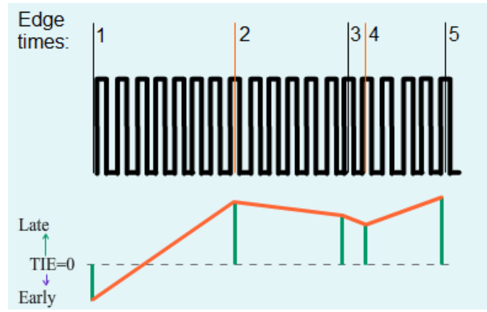


Figure 7: Illustration showing arrival times of several edges and the recovered clock. Time interval error (TIE) measurements are the difference between actual and expected arrival times.

Once the clock arrival times are known, the expected arrival times are subtracted from the actual arrival times to output a list of **time interval error** (**TIE**) measurements. When viewed as a waveform, this is the initial "TIE track". (Note: At this point in the algorithm, the TIE measurements are a list of values that are usually referred to as a "trend" rather than a "track". The animation does not make this distinction. Also, the "TIE Trend" is not shown on the oscilloscope.) Figure 7 shows TIE measurements for 5 example edges. One negative TIE value is shown (edge #1), indicating an edge arriving early; the other four are positive, indicating a late arrival.

The TIE values are direct measurements of jitter, and the distribution of TIE measurements is used to determine total, random and deterministic jitter after extrapolating the tails of the distribution in order to estimate jitter at low BER levels.

Step 2: Pattern Dependent Extraction

The first step in characterizing data-dependent jitter (including intersymbol interference and duty cycle distortion) is to look for a repeating pattern in the signal. When no repeating pattern is present, a non-repeating method can be used to look for repetition of bit sequences of a user-defined length. (The non-repeating method is not described in this paper.) Once the repeating pattern is found, the TIE measurements are analyzed to determine an average TIE value for each bit in the repeating pattern. Figure 8 shows this analysis. Corresponding TIE measurements of each iteration of the pattern are averaged resulting in a waveform that contains only data-dependent jitter.

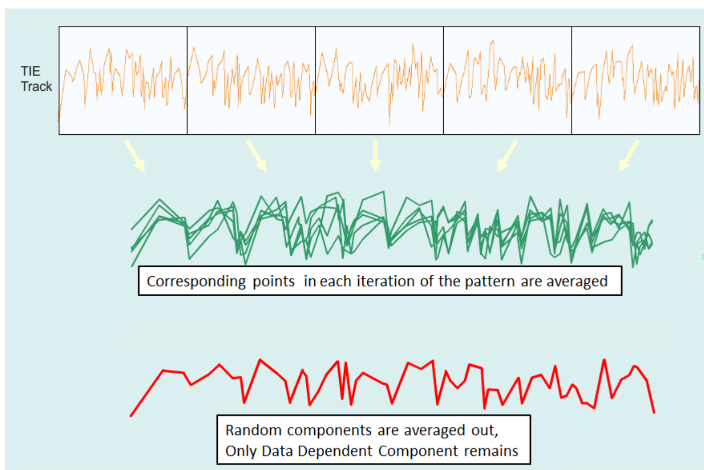


Figure 8: The process of determining data-dependent jitter begins with finding the average TIE value for each edge in the pattern. The result is the DDjPlot.

This results in an "average TIE trend" waveform, called the **DDjPlot**. Figure 8 shows this process. The digital pattern found (**DigPatt**) and the **DDjPlot** views of jitter can be selected for display from the **Pattern Analysis** dialog.

Step 3: Pattern Dependent Measurement

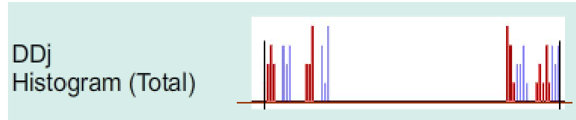
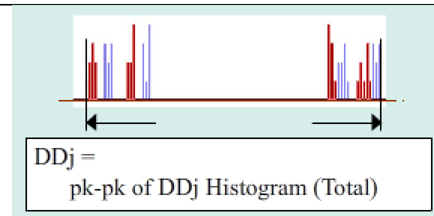
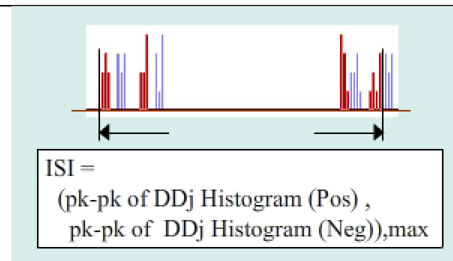
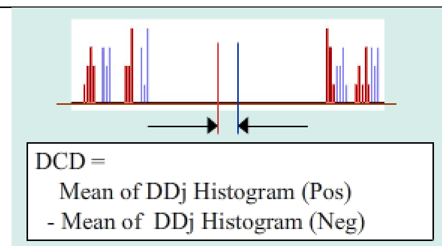


Figure 9: The DDjPlot is histogrammed for both positive (red) and negative (blue) edges to determine ISI, DCD and DDj parameters

The average TIE values are histogrammed for positive and negative edges, forming the DDj histogram. Figure 9 shows an example. The **DDjHist** view of jitter can be selected for display via the Pattern Analysis tab. Users can optionally limit **DDjHist** to include data from only the positive or negative edges in order to improve their understanding of the data-dependent jitter. DDj, ISI and DCD are determined as follows:

DDj	Range (max-min) of the complete DDj distribution, including both positive and negative edges. The DDj parameter includes the DCD effect as well.	
ISI	The larger of the range (max-min) of the individual histograms formed from the DDjPlot measurements of positive and negative edges. (In the example image, the peak-to-peak of the histogram for positive edges is larger, so the arrows denote the full width of the red histogram.)	
DCD	The difference in the means of the histograms for positive and negative edges.	

Step 4: Pattern Uncorrelated Extraction

The DDjPlot is extended to include as many iterations of the pattern as are present in the TIE trend, and is then subtracted from the full TIE trend. Via this subtraction, the data dependent jitter is removed, or "stripped," such that only random jitter (Rj) and bounded uncorrelated jitter (BUj) remain. Our next step is to convert this data set (which is a still a list of jitter values for the edges in the input data signal) into a waveform that includes one value per unit interval. This is done by creating TIE values for edges that are not present in the waveform (i.e. "virtual edges"). This process is not shown in the companion animation. The resulting waveform is the **RjBUjTrack**. Virtual edges are also created for the full TIE trend (which is the list of TIE measurements prior to the removal of DDj), yielding **TIETrack**. Both **RjBUjTrack** and **TIETrack** views of jitter can be selected for display via the Jitter Track dialog.

Jitter Filter (Not shown in animation)

The next step is to optionally filter the RjBUjTrack. Users can select to use a low, high or bandpass filter. This step is not included in the animation.

Step 5: Periodic Jitter (Pj) Measurement

A spectral analysis of the RjBUjTrack (optionally filtered as described above) is performed via simple FFT methods. The spectrum is called **RjBUjSpect**. Peaks in **RjBUjSpect** that exceed a threshold are identified as periodic jitter contributors, and information below this threshold is removed from the FFT leaving only the Pj peaks. Then an inverse FFT (iFFT) is calculated from these isolated Pj peaks. The value for Pj displayed in the jitter measurement table is the peak-to-peak value of the inverse FFT. Figure 10 shows this analysis. The Pj Inverse FFT has a tapered shape due to the windowing function used in the iFFT algorithm.

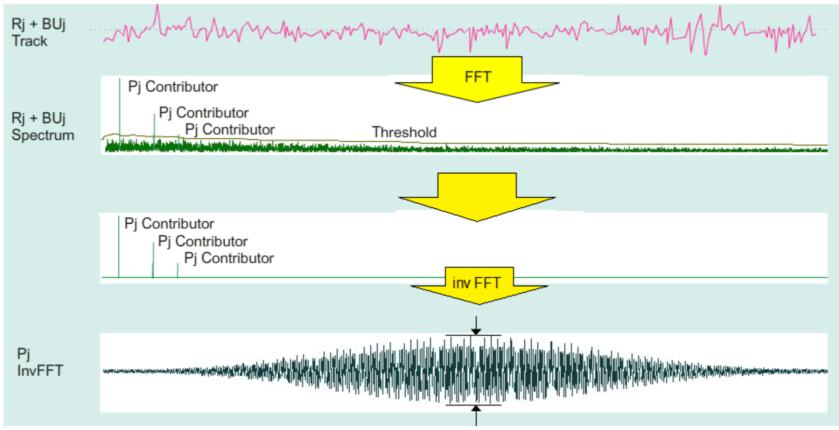


Figure 10: The process to determine Pj from the RjBUj Track

RjBUjSpect, along with the threshold (**PkThresh**), peak values (**Show Peaks** checkbox) and the Pj inverse FFT (**PjInvFFT**) of can be selected for display via the Jitter Spectrum dialog.

Step 6: Determination of Sigma (Spectral Methods)

The two spectral jitter calculation methods analyze the RjBUj spectrum. As described above, the periodic jitter contributions to the spectrum are removed, such that the remaining spectrum is associated with random and other bounded uncorrelated jitter. The remaining spectrum is integrated and becomes the σ (sigma) value of the Gaussian distributions of the dual-Dirac model. Figure 11 shows this analysis. However, it is important to note that the σ result will also include the effects of bounded, correlated jitter (apart from periodic jitter), including crosstalk. In cases where there is high crosstalk or other bounded uncorrelated jitter, the crosstalk will manifest itself as broadband spectral energy over the frequency range and masquerade as Rj when separated using the spectral method. Therefore, when there is crosstalk or other bounded uncorrelated jitter that raises the jitter spectrum's noise floor, the spectral method can fail to give an accurate result. Rj will be overestimated, and the fit to determine Rj and Dj may fail. In this scenario, the NQ-Scale method should be used instead.

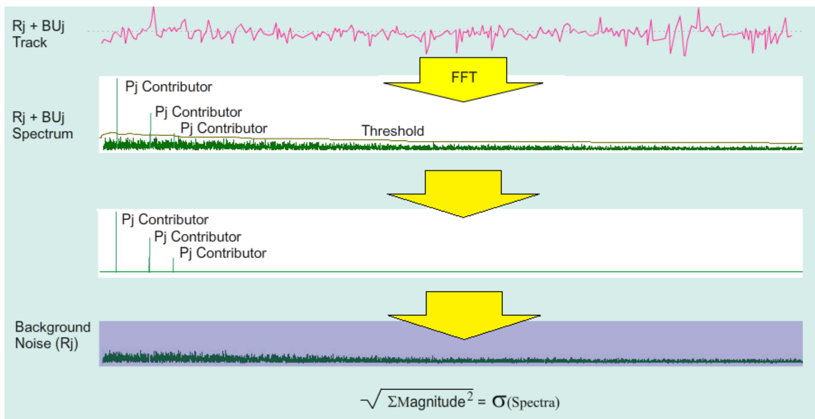


Figure 11: The sigma value for the Gaussians is determined through spectral analysis. Periodic jitter contributors are removed, leaving a spectral background that is associated with random noise and other bounded uncorrelated jitter.

The σ value is used as follows:

- For the **Spectral Rj Direct** method, σ becomes the final Rj value.
- For the **Spectral Rj+Dj CDF Fit** method, σ is used to extrapolate the RjBUj distribution (see below).

Step 6, continued: Tail Extrapolation

The next step in the process is the extrapolation of the tails of the jitter distribution. This extrapolation allows for the estimation of jitter beyond the acquired TIE data, and out to BER values such as 10^{-12}. The ability to perform this extrapolation accurately depends on the accuracy of the steps described above.

A. Spectral Methods

In the two spectral jitter calculation methods, **RjBUjTrack** is histogrammed to form the **RjBUjHist** histogram. The tails of this histogram are extrapolated using the σ value found from the spectral analysis. Figure 12 shows a depiction of the extrapolation.

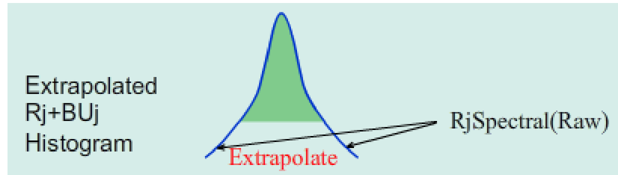


Figure 12: Depiction of the extrapolation of the tails of the RjBUj histogram. (Note that the tails really asymptotically reach zero.)

RjBUjHist and the complete TIE histogram **(TIEHist)** can be selected for display via the Jitter Histogram dialog.

B. NQ-Scale Method

The NQ-Scale method, or "Normalized Q-Scale", extrapolates and fits the Gaussian distributions of the dual-Dirac model, but with a key difference in the model: the σ and population for each Gaussian can be different, and are **not** determined from a spectral analysis. The NQ-scale procedure is performed by transforming to the "Q-scale", in which a Gaussian has a linear slope, and a normalization algorithm finds the best-fit weighting. By allowing different sigmas and populations, additional degrees of freedom are available as compared to the spectral methods, resulting in a more flexible model. For detailed information and comparisons to other methods, see reference [4].

Step 7: Total Jitter Reconstruction

In this step, we convolve in the data-dependent jitter that was extracted in step two, and form the overall cumulative jitter distribution function in order that we can determine Tj:

A. Convolution with the DDj Distribution

After the Gaussian(s) have been extrapolated, (one Gaussian for the spectral methods, and two for NQ-Scale), the DDj distribution is added back via convolution. The resulting distribution is the overall jitter probability density function (PDF), which looks similar to the TIE Histogram (**TIEHist** trace), but with extrapolated tails as described above. Figure 13 shows an example PDF.

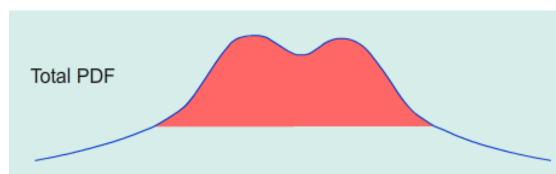


Figure 13: The extrapolated RjBUj and DDj histograms from Figure 9 and Figure 12 are combined via convolution to form the probability density function (PDF).

B. Integration to form the CDF

The PDF formed is integrated from the outsides to the center to form the cumulative distribution function (CDF). The CDF is plotted with time on the X-axis, and probability on the Y-axis; the width of the CDF at a particular Y-value (or BER) is the Tj at that BER value. The CDF, and a bathtub curve derived from the CDF, can be selected for display from the Jitter Histogram dialog. Figure 14 shows an example CDF resulting from the integration of a PDF.

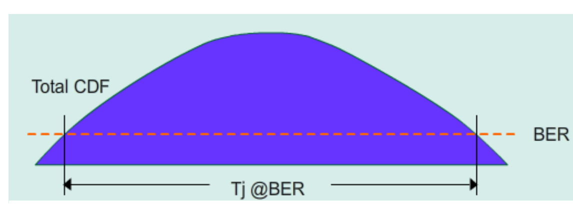


Figure 14: The PDF is integrated from the outside to the median to form the cumulative distribution function (CDF).

Step 8: Tj, Rj, Dj Calculation

Tj Determination

For all methods, Tj is the width of the CDF at the user's selection for BER. Note that the CDF for NQ-scale is determined differently than the two spectral methods.

Rj and Dj Determination:
(Spectral Rj+Dj CDF Fit Method)

To determine Rj and Dj when using the Rj+Dj CDF Fit method, the CDF is fitted to the Dual Dirac model equation Tj = α(BER)*Rj + Dj(δδ), where α(BER) is the confidence interval at a confidence level of 1-BER for a single "normal" Gaussian. (For example, α ~= 14.07 for BER = 10^{-12}). The points on the CDF that are used in the fit include the selected BER, 1 point above, and two below. For example, for a selected BER of 10^{-12}, the CDF points used for the fit are BER=10^{-11}, 10^{-12}, 10^{-13} and 10^{-14}.) See Figure 15.

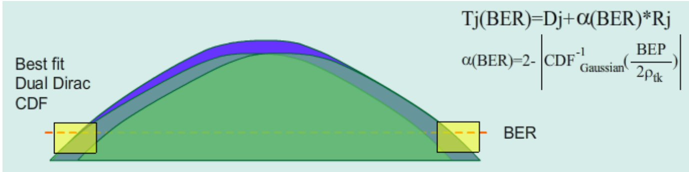


*Figure 15: In the Spectral Rj+Dj CDF Fit and NQ-Scale methods, Rj and Dj are determined by fitting to Tj(BER) = α(BER)*Rj + Dj*

Rj and Dj (Spectral Rj Direct Method)

In the **Spectral Rj Direct** method, Rj is determined directly from the jitter spectrum. Dj is then determined by fitting the CDF with the constraint that Rj = σ. Deriving Rj directly from the spectrum rather than via a fit typically produces lower values of Rj. Limitations of this method are discussed below in the section "Variation of Rj with Pattern Length".

Rj and Dj Determination: (NQ-scale Method)

In the NQ-Scale method, Rj and Dj are determined from the CDF using the same technique as for Rj+Dj CDF Fit, but since the CDF for NQ-scale is determined much differently than for the two spectral methods, the Rj and Dj results will be different. See Step 6B above for more information regarding the CDF calculation for the NQ-Scale method.

Variation of Rj with Pattern Length

This Spectral Rj Direct method typically gives the lowest value of Rj, but at the expense of deviating from the MJSQ jitter calculation methodology, which specifies that Rj and Dj should be derived by fitting to a dual-Dirac jitter model. This method is included in SDAIII to provide a result that closely correlates to jitter calculation methodologies on sampling oscilloscopes that cannot perform Rj and Dj separation using a repeating pattern technique. For a channel that includes even a small amount of intersymbol interference (ISI), a fit to the dual-Dirac jitter model as described in MJSQ should result in Rj that increases with pattern length. This is due to the fact that as pattern lengths grow, the data-dependent jitter (DDj) distribution increasingly takes on a Gaussian shape with growing tails. These tails cause the fit to the equation Tj = α(BER)*Rj + Dj(δδ) to return an Rj value that increases with pattern length. Note that bit error rate testers (BERT) will also return increasing Rj with pattern length. When using Spectral Rj Direct, Rj will not show grow with pattern length, since it is determined directly from the jitter spectrum and not via a fit.

Last Step: Display results

Users can display the jitter measurements in the SDA jitter table, as show in Figure 16. Notice that the table includes a header row: the Tj column header indicates the BER value selected by the user, and the Rj and Dj header indicates which method is in use. For Rj direct: “spD”; for Rj+Dj CDF Fit: “sp”; for NQ-Scale: “nq”.

SDA Jitter	Tj(1e-12)	Rj(sp)	Dj(sp)	Pj	ISI	DCD	DDj	BitRate
Lane1	27.350 ps	1.815 ps	1.819 ps	970 fs	2.963 ps	115 fs	2.963 ps	10.3 Gbit/sec
Lane2	49.241 ps	1.973 ps	21.486 ps	808 fs	23.892 ps	557 fs	24.599 ps	10.3 Gbit/sec
Lane3	68.925 ps	2.426 ps	34.808 ps	155 fs	37.376 ps	1.560 ps	37.376 ps	10.3 Gbit/sec
Lane4	26.286 ps	1.238 ps	8.873 ps	441 fs	10.373 ps	58 fs	10.373 ps	9.10 Gbit/sec

Figure 16: Table showing the jitter measurement results. The column header indicates which method is employed. (In this case, it indicates "sp", which is Rj+Dj CDF Fit.

When using the SDAIII products that include the ability to simultaneously measure jitter on up to four lanes simultaneously (“LinQ” is part of the part number for these products), the views of jitter are shown within a “LaneScape” for each lane. Up to 40 traces can be displayed simultaneously, arranged in a large variety of user-selectable grid modes, with 1, 2 or all lanes displayed at a time. Figure 17 shows a comparison of two lanes in dual LaneScape mode, showing many of the views of jitter discussed in this document.

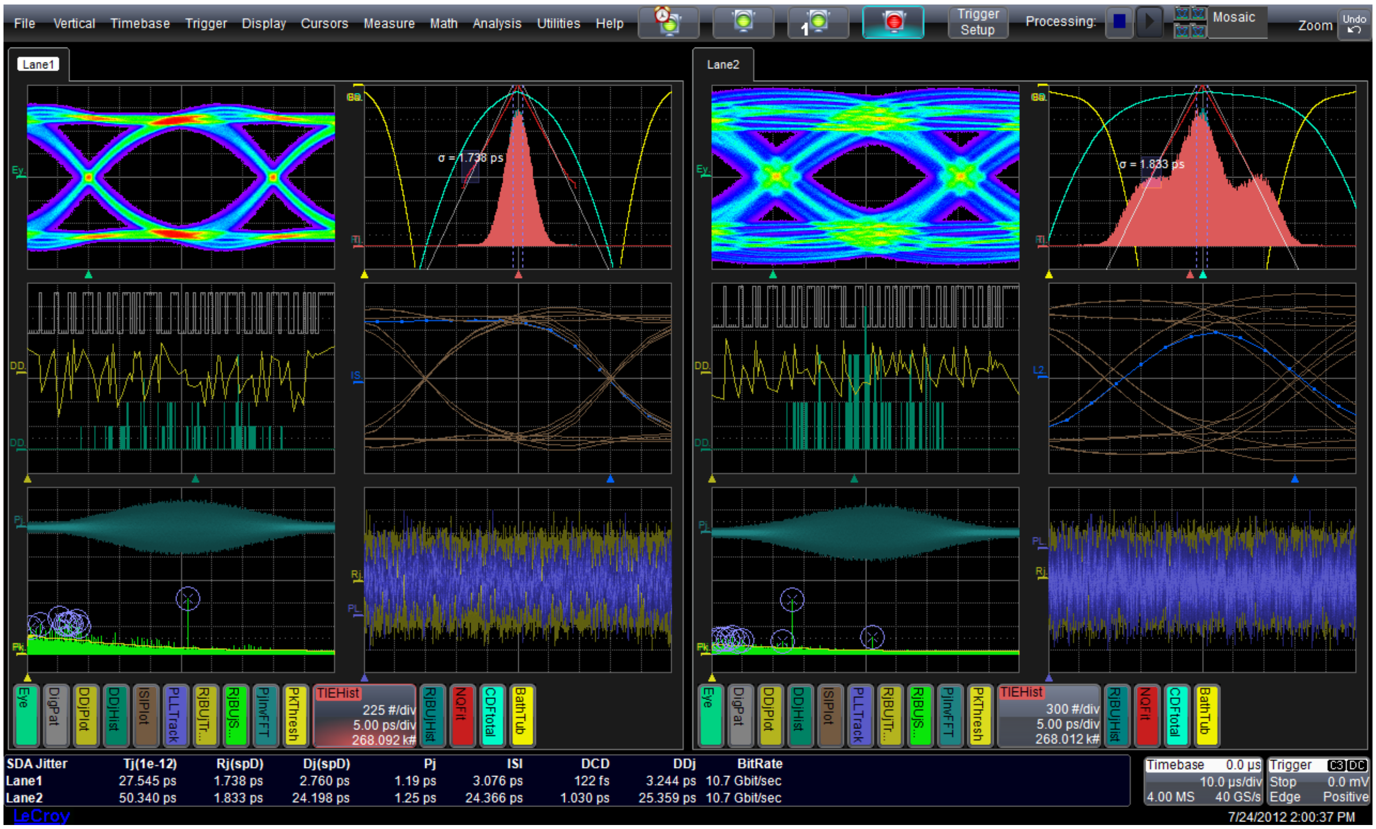


Figure 17: Screenshot showing SDA analysis on four lanes, showing the jitter table along with a wide variety of views.

Conclusions

The SDAIII-CompleteLinQ calculates jitter on long serial data waveforms using one of several dual-Dirac based models, and finds components of data-dependent jitter directly from TIE measurements. Users can choose to display a wide range of jitter results, including summary results, such as Tj, Rj, Dj, DDj, ISI, DCD and Pj, as well as views that provide insight into the sources of jitter quantified in the results listed above. Views include spectra, histograms and jitter tracks that describe jitter in the time, frequency and statistical domains. Users are encouraged to examine the jitter tracks, spectra and histograms in order to understand the nature of jitter aggressors and to determine which method to use for determining final jitter values. Three methods for calculating Tj and decomposition into Rj and Dj have been described, including two spectral methods and LeCroy's NQ-scale method. When crosstalk or other bounded-uncorrelated jitter is present, the NQ-Scale method will give the most realistic jitter estimates.

Questions, comments or suggestions regarding this document are welcomed, and can be emailed to *ideas@lecroy.com.*

Additional Reading

[1] "Fibre Channel - Methodologies for Jitter and Signal Quality Specification- MJSQ". *T11*, 5 June, 2005. http://www.t11.org (t11.org membership required.)

[2] Miller, Marty and Schnecker, Michael. "A Comparison of Methods for Estimating Total Jitter Concerning Precision, Accuracy and Robustness." *DesignCon2007.* <http://cdn.lecroy.com/files/whitepapers/lecroy_jitter_methods_designcon2007.pdf>

[3] Miller, Marty. "6 Tales of Rj and Dj." *LeCroy Corporation Website*, 2005. <http://cdn.lecroy.com/files/whitepapers/wp_techbrief_rj_and_dj.pdf >

[4] Miller, Marty. "Normalized Q-scale Analysis: Theory and Background." *EDN Magazine*. 16 March, 2007. <http://www.edn.com/design/test-and-measurement/4314553/Normalized-Q-scale-analysis-Theory-and-background>

[5] Miller, Marty and Schnecker, Michael. "Quantifying Crosstalk Induced Jitter in Multi-lane Serial Data Systems." *DesignCon2009*. <http://cdn.lecroy.com/files/whitepapers/lecroy_jitter_methods_designcon2007.pdf>