Applications of Known Pattern with Marker Tool

- Analyze a data pattern and decompose or separate the various jitter components to better understand and improve system performance
- Measure the Deterministic Jitter (DJ) components: Duty-Cycle Distortion and Intersymbol Interference (DCD+ISI), Periodic Jitter (PJ)
- Measure the Gaussian—or Random Jitter (RJ) component
- View DCD+ISI relative to pattern transition density
- Compliance testing Fibre Channel, Gigabit Ethernet, Infiniband and XAUI devices
- Advanced (not covered in this guide): View jitter data and model the signal as seen by the receiver, filtering RJ and PJ or altering acquisition configuration

Introduction

The use of a known, repeating pattern provides the fastest and most accurate analysis of a data signal. This tool separates jitter into components of DCD+ISI, PJ and RJ as well as calculates TJ for specification compliance testing. TailFit™ is used to accurately separate RJ from PJ.

The focus of this paper is to describe the dataCOM Known Pattern with Marker (KPWM) tool including making a measurement, understanding results, menu descriptions and appendices including measurement theory. Refer to the SIA-4000 User's Guide and the Online Help files for a more in-depth description.

This paper is divided into 6 major sections:

1. Making a measurement
2. Understanding Views, Plots or Results
3. Dialog Bars (instrument settings)
4. Appendix I: Theory of operation
5. Appendix II: RJ calculation methodology

dataCOM Panel

Dialog Bar
Contains tool setting menus.

Plot area
Zoom in—hold down left mouse button, expand zoom box over area of interest.
Zoom out—double click left mouse.

Status area
Cursor coordinates - Displayed in the box at lower right portion of the VISI Panel. Units are same as those in plot.

Statistics View
Shows data from the most recent run.

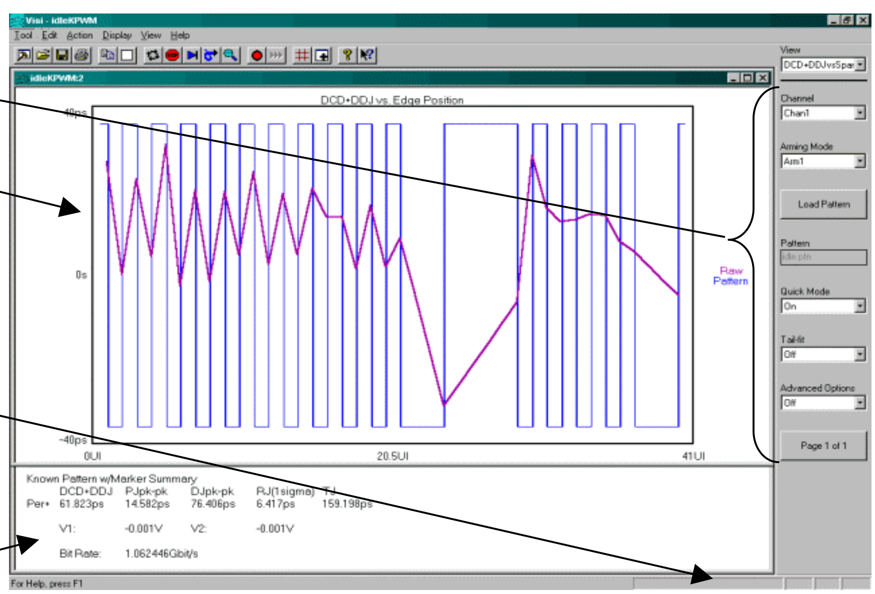


Figure 1 -- Example DataCom Plot

Making a Measurement—Initial setup

This tool requires the signal under test to be a repeating pattern. Internally, the tool creates a “Pattern Trigger” or “Pattern Sync” for analysis. In some cases, a unique pattern is used that is not in the SIA-4000 library, or the pattern is longer than what the SIA will automatically detect. These unique cases are described later in the document.

- Connect a repeating data signal to Channel 1.
- From the main KPWM menu, press Acquire Options.
- Press Arm Number. A Dialog Box will open. Ensure Channel 1 is selected and Pattern Marker is checked.
- Press Add/Del Channel and ensure Channel 1 is checked.
- The –3dB corner frequency default is the bit rate/1667. This is the PLL characteristic of many Serdes devices. To enter a manual corner frequency choose User Defined and enter the corner frequency
- Press Pulse Find.  It is important to perform pulse find. This sets the voltage threshold at which jitter is measured.
- Press Pattern Options.

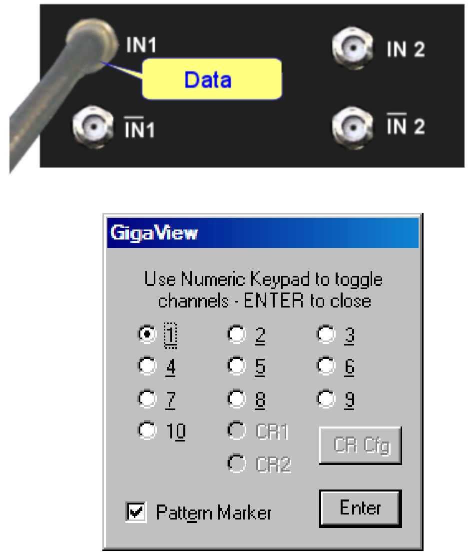


Figure 2 - Connection and Arm Number

- Press Detect Pattern. This will detect the pattern present. Patterns longer than 2048 edges cannot be automatically detected. An example would be a PRBS 2^15-1 pattern. For these patterns, you must load it from the library on the SIA-4000. Press Load Pattern to load the *.ptn file. If your pattern is not preloaded, it is possible to learn it; see details on page 7.
- Now you can make your Measurement: Press Acquire  or Single/Stop on the front panel.

This tool acquires a number of different measurements. There are different views of the results that can be seen by changing the current view in the upper right of the menu bar. Views can be added so that all are present on the screen at the same time. When clear is pressed all results are cleared and pressing Acquire will reacquire all of the measurements at one time. See Section 2 that describes the views.

Possible Errors and solutions

“Failed bit rate calc – bad pattern or signal” or *“Failed DCD+ISI Measure – bad pattern or signal”*
This error generally indicates that the pattern that the SIA-4000 is measuring at the input channel is not the same as the pattern chosen. Check that the signal is present and the input pattern matches the chosen pattern. Press “Perform Placement” in the “Arm Setup” selection to place the marker again.

Understanding Views, Plots and Results

Including the summary view, there are six plots or views of the same data set. Each plot gives insight into the measurements of different components of jitter. In this section, the available views are briefly described. To change views, use the pull-down menu at the top of the dialog bar or use the "PageUp" or "PageDn" keys on the keyboard.

DCD+ISI Histogram

This view displays the "normalized accumulation" of all the DCD+ISI measurements taken during each run. The width of this plot is normalized to one Unit Interval of the data period. Ideally, all measurements would fall at zero on the x-axis with no jitter present. In actuality, the measurements show a distribution of measured times. There are two histograms plotted, one for rising and one for falling edges of the data pattern. There is often a difference in the absolute time of rising edges vs. falling edges. An indication of DCD or Duty Cycle Distortion—a difference in the width of a '1' vs. a '0'—can be seen when the two histograms are not over one another but have some distance between them.

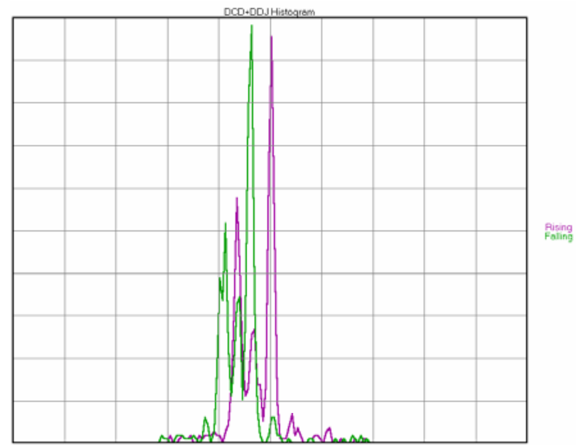


Figure 3 – DCD+ISI Histogram

DCD+ISI vs. Unit Interval

This view plots the DCD+ISI relative to the pattern. The "Pattern" line shows a representation of the entire pattern—zooming in on any edge will show three line that represent the min, mean, and max time measurements from the histogram of each edge. The "Raw" line shows how the measured mean varied from the Ideal UI. The y-axis pk-pk is the value reported for DCD+ISI in the statistics area. This plot also shows how the transition density affects jitter. Bandwidth limiting effects on the signal, as well as reflections, can be identified using this plot.

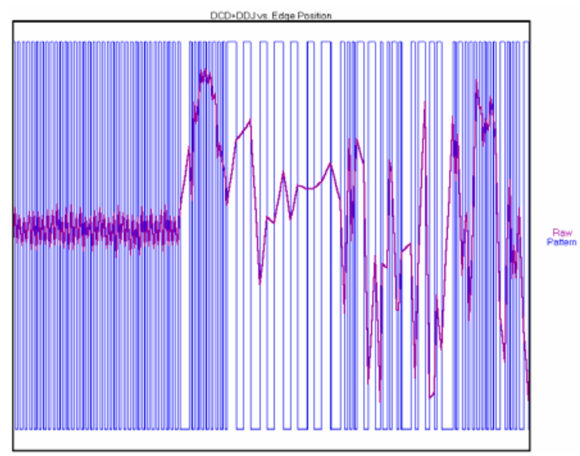


Figure 4 – DCD+ISI vs. Span

1-Sigma vs. Unit Interval

This view shows the 1-sigma values for the histograms of each binned UI measurement, allowing jitter accumulation to be seen. If modulation is present, it shows up as a periodic variation of 1-sigma values. As a default, TailFit is applied across this plot to determine RJ, otherwise PJ would inflate the RJ value. This plot is the basis of the FFT. When there is a PLL imbedded in the device transmitting the data, a characteristic curve is often present. Refer to Appendix II.

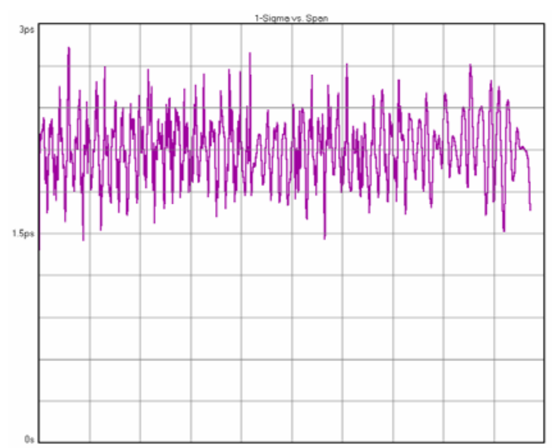


Figure 5 – 1-Sigma vs. Span

FFT

This is the FFT of the autocorrelation of the variance from the 1-sigma vs. UI view. The plot shows the spectral power density of the uncorrelated jitter frequencies from the corner frequency specified to the Nyquist of the bit rate. The largest peak is displayed as the Periodic Jitter (PJ) number in the statistics area.

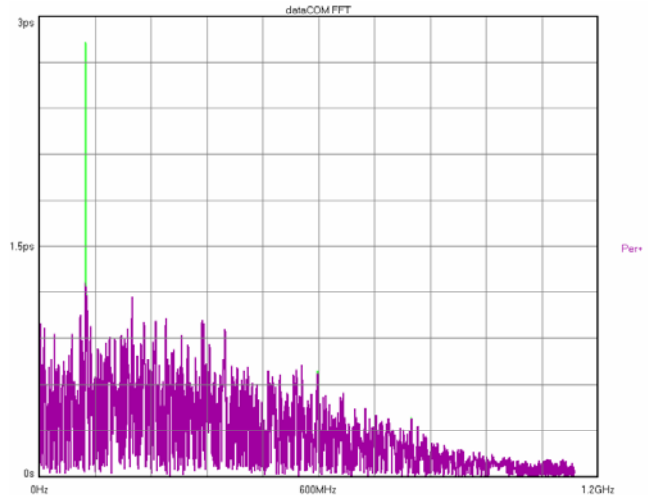


Figure 6 – FFT view

Bathtub Curve

Show the "error probability density plot" of a data signal. The plot is normalized to one UI and the Total Jitter (TJ) number in the statistics area is derived from this view. The thick part of the line represents actual measurements. The thin part indicates extrapolated information based on RJ and DJ values. The color stops at the BER that TJ is determined.

Summary

The summary page shows the jitter results that were measured. It is helpful to look at all of the views associated with the measurement. Jitter is complex, and cannot easily be understood with one number.

- TJ results correspond to the Bathtub curve.
- DCD+ISI results correspond to the DCD+ISI Histogram and DCD+ISI vs. Span.
- PJ is shown in the FFT view.
- DJ and RJ are related to the FFT and 1-sigma vs. span views. For more information on understanding RJ see Appendix II.

It is often helpful to display all views at the same time on the screen. To do this, run the tool once. Then press the add view button or "Add View" on the front panel. This will display a copy of the same view. Use the View dropdown menu to change the display. Results are already present because the SIA-4000 acquires all of the views when "acquire" is pressed. By adding views, you can make your display look like Figure 9. This greatly facilitates understanding the results. All too often users only view the summary page and miss important information that is vital to understanding the data signal.

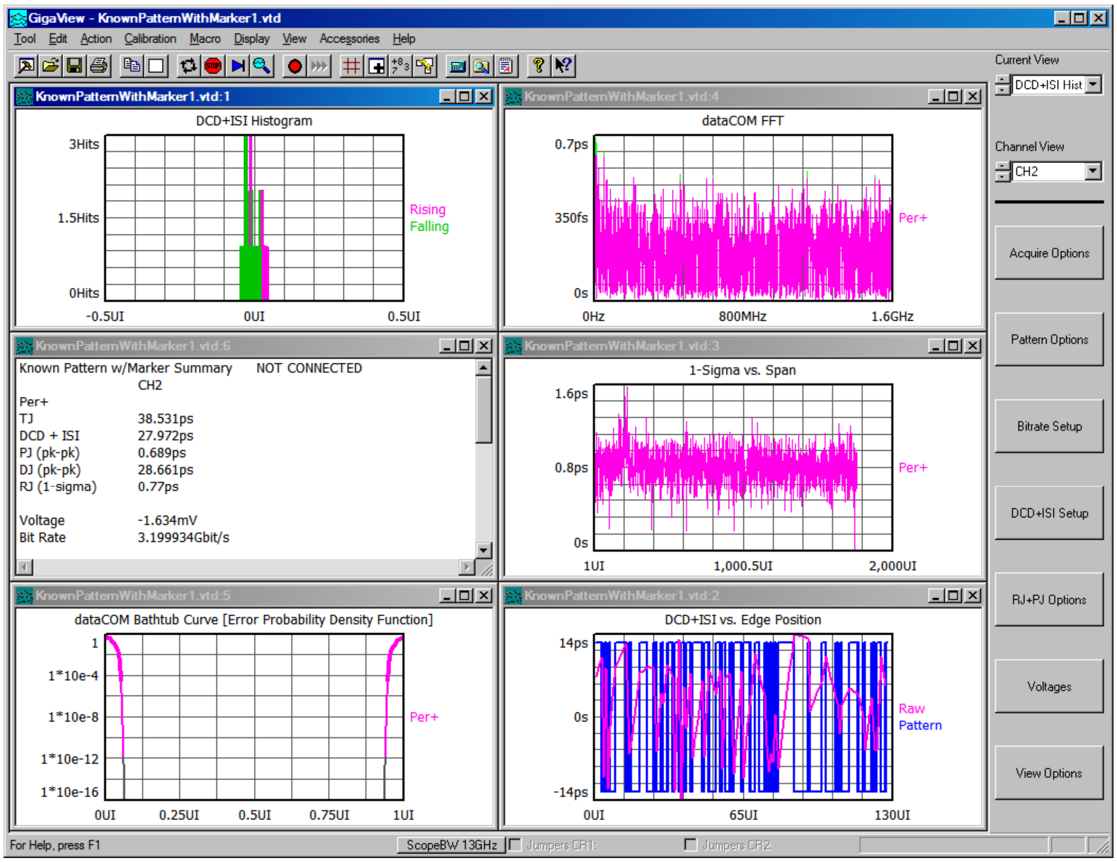
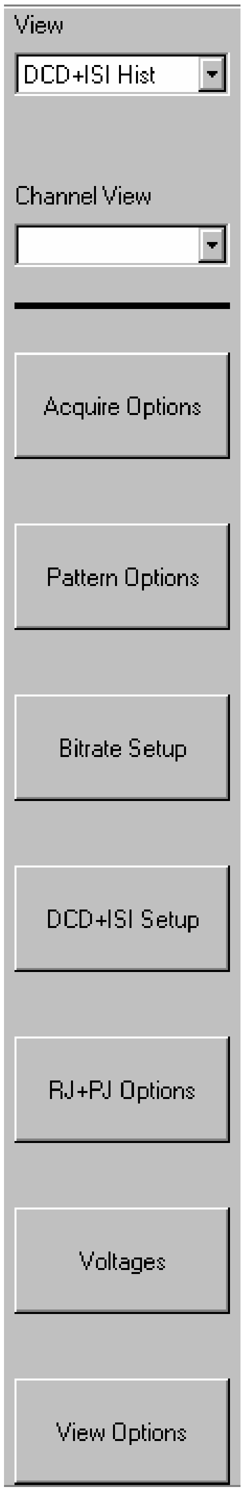


Figure 9 – Shows a number of views displayed simultaneously. When 'clear' or 'acquire' is pressed.

Dialog Bars—Menus and Instrument Settings

Main Dialog Bar



View
The 'view' pull-down menu will show the different available graphical results such as DCD+ISI Histogram, FFT, DCD+ISI vs. Span, 1-Sigma, Bathtub Curve and Summary results. By pressing 'Add View' addition views from the same tool can be added. All six views can be displayed simultaneously and will all update when 'Single/Stop' is pressed.

Channel View
Select a specific channel to view signal measurements.

Acquire Options
Open the Acquire Options menu.

Pattern Options
Open the Pattern Options menu.

Bitrate Setup
Open the Bitrate Setup menu.

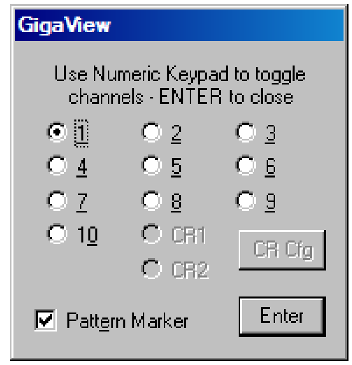
DCD+ISI Setup
Open the DCD+ISI Setup menu.

RJ+PJ Options
Open the RJ+PJ Options menu.

Voltages
Open the Voltages menu.

View Options
Open the View Options menu.

Acquire Options



Arm Number
Use the keypad to select one channel to be used to create the marker. This is usually the same as the measurement channel. Check "Pattern Marker".

Add/Del Channel
Opens Add/Delete channel menu to allow selection of the measurement channel.

Corner Frequency Mode
This is the 3dB corner of a high pass filter function that affects the frequency band that will be measured and displayed. Default is the bitrate/1667 that is the PLL characteristic common to many Serdes. For diagnostics you may choose 'User Defined' to enter a value. This allows you to view PJ at lower frequencies. The Corner Frequency is the Frequency of the Half Power Point (or -3dB Point), so the choice of this frequency will determine the low frequencies visible on the FFT. It determines the maximum measurement interval to be used in sampling and is entered in kHz. A low corner frequency extends the time required to acquire the measurement set because histograms over many more periods must be acquired. Below the corner frequency, a natural roll-off of approximately 20dB per decade is observed.

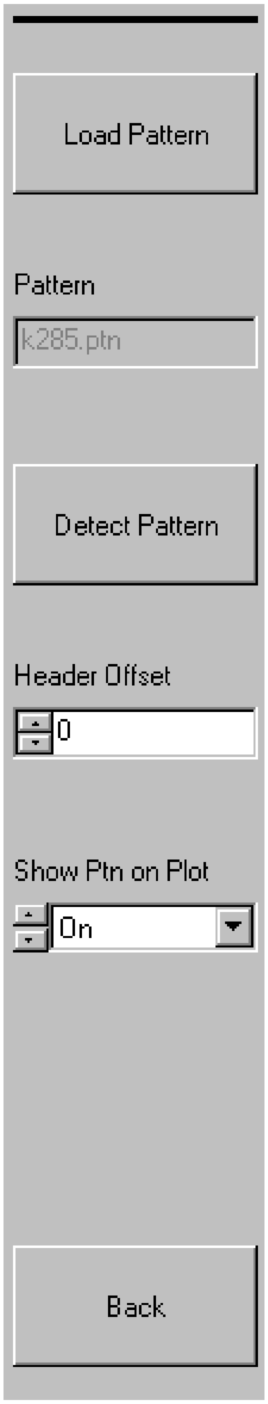
Corner Freq (kHz)
Display the corner frequency. When bitrate/1667 is chosen, the calculated value is shown. If 'User Defined' is chosen, this becomes the data entry field.

Quick Mode
This option enables a sparse sampling protocol for RJ+PJ data acquisition, which reduces the time required to obtain data. This method is appropriate for use only when there is insignificant higher-frequency jitter present. In the presence of high frequency jitter, the standard sampling protocol will reduce the amount of harmonic distortion, which can occur.

Arm Setup
Open Arm Setup menu that contains advanced options for the pattern marker.

Back
Return to the previous menu.

Pattern Options



Load Pattern
Open a browser window to load previously saved patterns.

Pattern
Display the current pattern being used.

Detect Pattern
This feature will detect a pattern with up to 2048 edges. It compares the data to patterns existing in the pattern library. Press this before acquiring results for the first time to load the data pattern. For patterns not loaded in the library you must create a binary file or use the Learn Pattern feature.

Learn Pattern
A pattern may be "learned" if it is not already stored as a .ptn file or too long to be manually entered in Edit Pattern. The number of bits in the pattern must be known and the Bit Rate must be entered as precisely as possible*. The data stream must be relatively jitter free and a suitable pattern marker must be available to connect to CH2*. If there are errors trying to "learn" at a high bit rate and it is possible to have a slower, clean pattern (from a pattern generator), the pattern may be learned at this slower rate (adjusting Bit Rate accordingly). The reason the signal should be relatively jitter free is to ensure that the correct pattern is learned. Once the pattern is stored, analysis of a signal with jitter can then be made.

Header Offset
The measurement will skip a given number of edges after the external pattern marker and before sampling. This is an infrequently used, advanced setting. This can be helpful in applications such as Hard Drives where a header precedes a repetitive data sequence in the data stream. This option is only available when using external arming and applies to all dataCOM sampling, including Learn Pattern.

Show Pattern on Plot
Toggle the pattern on/off for the display on the DCD+ISI vs. Span plot.

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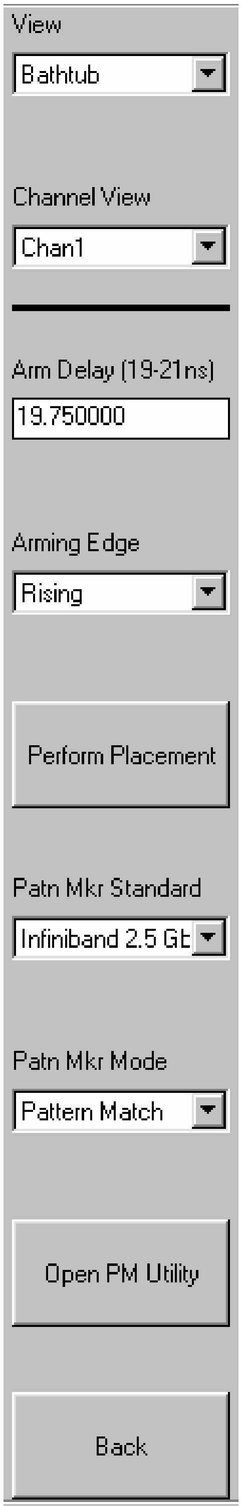
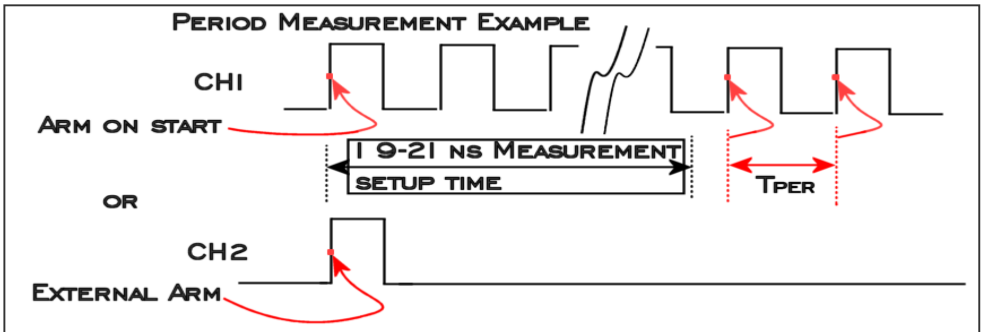
Arm Setup



The settings in this menu are advanced and not needed for typical measurements.

Arm Delay (19-21ns)

The arm delay sets the minimum time from an arm event to the first measurement edge. As Figure 7 shows, there is a user selectable 19 to 21 ns delay from the Arm event to the first measurement.



Arming Edge

Choose rising or falling. This will select which edge types from the Arm Channel will be used to arm a measurement on the Measurement Channel.

Perform Placement

After the Pattern Marker has been selected and configured, and the proper pattern is chosen, this button will optimize the placement of the marker with respect to the data. An improperly placed marker can cause errors such as "Bit Rate Measure Fail—Bad Pattern or signal" or "DCD+ISI Measure Fail—Bad Pattern or Marker."

Patn Mkr Standard

The Following Speeds can be selected in Pattern Match Mode:

1X FC	1.0625Gb/s	Infiniband	2.5Gb/s
GBE	1.25Gb/s	2X SATA	3.0Gb/s
SATA	1.5Gb/s	XAUI	3.125 Gb/s
2X FC	2.125Gb/s	3X FC	3.1875Gb/s

Patn Mkr Mode

Select Pattern Match or Edge Count Mode. In Pattern Match mode, the Pattern Marker card (PM50) will generate a Pattern Marker when matching a unique 40-bit sequence of a pattern. The "Patn Mkr Standard" needs to be selected accordingly. In Edge Count mode, the pattern marker card will generate a pattern marker upon repetition of a user-specified number of positive or negative edges (frequency agile from x MHz to 5GHz). For PRBS patterns use Edge Count mode only.

Open PM Utility

This will open the Pattern Marker Utility window (if a PM50 is installed).

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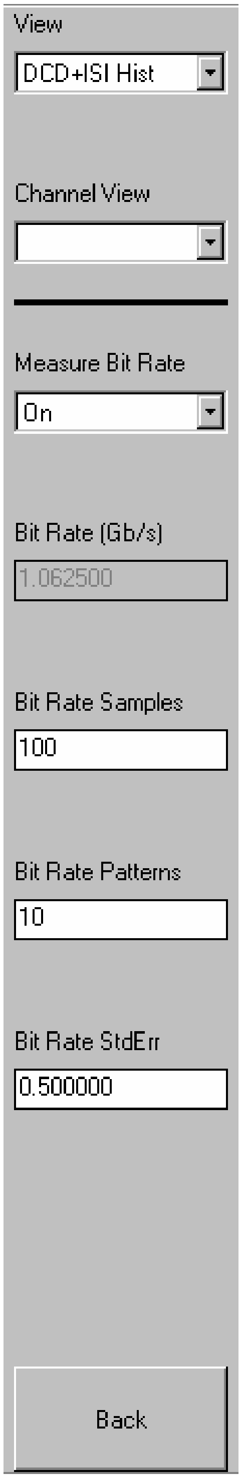
Bitrate Setup



Measure Bit Rate
Measures the Bit Rate based on a correctly defined pattern. The bit rate is derived by measuring the total time over a number of pattern repeats and calculating an ideal unit interval.

Bit Rate (Gb/s)
The average data rate of the signal, entered in GigaBits per second. An accurate Bit Rate is crucial as it is used in the calculation of the various jitter components. The default is 1.0625 Gbit/s, which is the standard 1x Fibre Channel speed. Because the pattern and total number of UI is known, the Bit Rate that is reported is an average value derived from the total time across a number of patterns (defined by Bit Rate Patterns) divided by the total number of UI contained in the patterns times the number of Bit Rate Patterns. A good rule of thumb is the Bit Rate Patterns times the pattern length should be > ~1000 UI for an accurate bit rate calculation.

Bit Rate Samples
Determines the total number of time samples acquired for the single time measurement.
Because the pattern and total number of UI is known, the Bit Rate that is reported is an average value derived from the total time across a number of patterns (defined by Bit Rate Patterns) divided by the total number of UI contained in that many patterns times the number of Bit Rate Patterns.

Bit Rate Patterns
Determines the number of patterns over which a single time measurement is made.
Because the pattern and total number of UI is known, the Bit Rate that is reported is an average value derived from the total time across a number of patterns (defined by Bit Rate Patterns) divided by the total number of UI contained in that many patterns times the number of Bit Rate Patterns.

Bit Rate Standard Error
Value used to determine error limits for Bit Rate calculation. An error message such as "Failed Bit Rate calculation" indicates when suspect measurements have been taken and is usually as a result of improper pattern selection.

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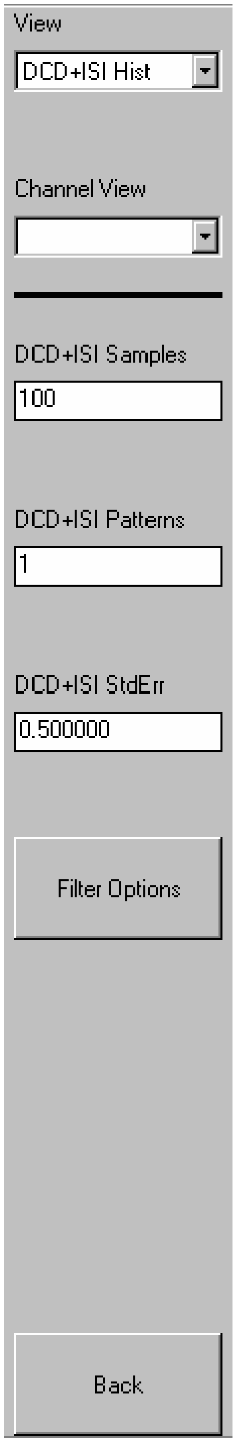
DCD+ISI Setup



DCD + ISI Samples
This is the number of time samples in each histogram for each edge of the pattern. The histogram MIN, MEAN and MAX times can be seen in the DCD + ISI vs. Edge view. It is the mean value of the histogram, which is compared to an ideal unit interval for each edge.

DCD + ISI Patterns
Enter number of pattern intervals for which measurements will be taken.
Default is 1 for compliance testing. Increase this value to see more pattern repeats on the dataCOM with Marker, DCD + ISI vs. Edge View. Note: Bit Rate Patterns should be set greater than or equal to DCD + ISI Patterns because an accurate bit rate is important for calculating the ideal unit interval; DCD + ISI is calculated as a deviation from this ideal UI.

DCD + ISI Standard Error
Indicates when suspect measurements have been taken, usually as a result of improper pattern selection. Default is 0.5 UI. Any measurements deviating from the ideal by more than this value will produce an error message and the test will stop. This value may need to be increased if the signal has more than 0.5 UI of jitter (such as tolerance testing).

Filter Options
Open the Filter Options menu.

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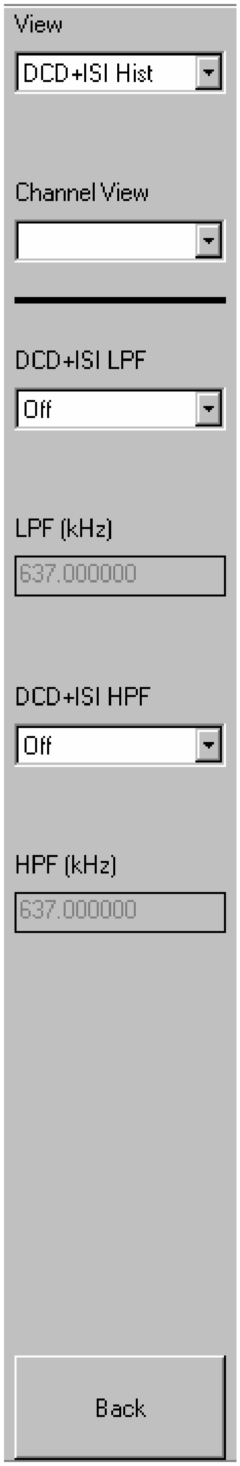
Filter Options



DCD + ISI LPF
This option applies a Low Pass Filter to the DCD+ISI data. The resulting, filtered data is plotted on top of the raw DCD+ISI data in the DCD+ISI vs. Edge plot window. This feature allows the modeling of receiver performance given the measured (transmitted) data pattern if the characteristics of the receiver are known. The filter characteristics are applied after the measurement is acquired and does not affect the acquisition.

LPF (kHz)
User defined Low Pass Filter corner frequency, in kHz, when the DCD + ISI LPF (Low Pass Filter) option is "on". Default is 637 kHz.

DCD + ISI HPF
This option applies to a High Pass Filter to the DCD+ISI data. The resulting, filtered data is plotted on top of the raw DCD+ISI data in the DCD+ISI vs. Edge plot window. This feature allows the modeling of receiver performance given the measured (transmitted) data pattern if the characteristics of the receiver are known. The filter characteristics are applied after the measurement is acquired and does not affect the acquisition.

HPF (kHz)
User defined High Pass Filter corner frequency, in kHz, when the DCD + ISI HPF (High Pass Filter) option is "on". Default is 637 kHz.

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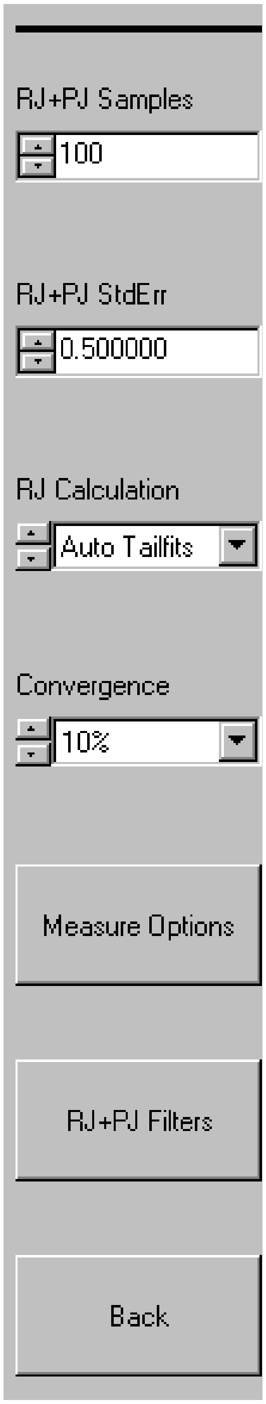
RJ+PJ Options



RJ + PJ Samples
This is the number of samples in each histogram. The 1-sigma values used to create the 1-sigma vs. Span plot come from these histograms.

RJ + PJ Standard Error
Indicates when suspect measurements have been taken, usually as a result of improper pattern selection. Default is 0.5 UI. Any measurements deviating from the ideal by more than this value will produce an error message and the test will stop. This value may need to be increased if the signal has more than 0.5 UI of jitter (such as tolerance testing).

RJ Calculation
Default is 'Auto TailFits'. This applies a TailFit at a select span on the "1-sigma vs. span" results. The algorithm starts with three TailFits: left, center, and right of the results on the plot. These three TailFit-derived RJ values must not vary more than the "Convergence" value (below). TailFitting prevents PJ from affecting the RJ values. The pull-down menu list allows RJ to be derived from a number of methods. To understand the reasons for different RJ calculations, refer to Appendix II.

Convergence
Determines the percentage within which consecutive Auto Tail-Fits must comply in order to insure reasonable frequency coverage from the corner frequency. The default setting is 10%.

Measure Options
Open the Measure Options menu.

RJ+PJ Filters
Open the RJ+PJ Filters menu.

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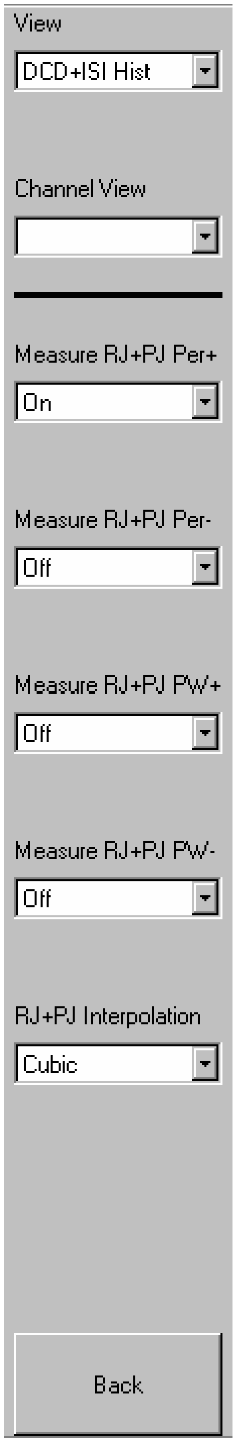
Measure Options



Measure RJ + PJ Per+
Plot the RJ+PJ time measurements for Period + (rising edges to rising edges). See Measure RJ + PJ Per-.

Measure RJ + PJ Per-
Plot the RJ + PJ time measurements for Period - (falling edges to falling edges). See Measure RJ + PJ Per+.

Measure RJ + PJ PW+
Plots RJ + PJ time measurements for PW+ (pulse width rising edges to falling edges).

Measure RJ + PJ PW-
Plot the RJ + PJ time measurements for PW- (pulse width falling edges to rising edges).

RJ + PJ Interpolation
This option selects the means of filling the gaps in the autocorrelation function that naturally occur in a pattern. Generally, the "cubic" interpolation will produce the best results in the presence of periodic jitter. Selection of "linear" interpolation may be preferred in the presence of purely random jitter. In which case, the presumption of a smooth autocorrelation function cannot be made.

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RJ+PJ Filters

RJ + PJ High Pass Filter (HPF)
This is a post-processing filter that is applied to the data after acquisition. The filter affects the determination of what are considered peaks in the FFT views. The highlighted peaks are then reported among the values displayed in the Summary View. Choices are Natural Rolloff and Brickwall. User can enter value in box labeled Min Filter (MHz) only when the Brickwall selection is enabled. The values shown when options are deselected are not used.
Natural Rolloff – When selected, does not add any filtering but refers to the natural –3db rolloff, or high pass corner frequency, determined by how much data the tool is allowed to acquire. The corresponding user entry box is deselected and the value in the box is not used.
Brickwall – is a high pass filter. It does not allow the RJ or PJ to be calculated below this user-selected value. A user entry box allows entering a frequency value. Any value entered MUST be above the frequency that is set for the –3db freq. The –3db frequency setting controls how much data is acquired and the Brickwall filter value is applied to that data.

High Pass Freq (MHz)
Lower frequency limit for the window over which RJ and PJ is calculated. Default is Corner Frequency. This setting cannot be set lower than the corner frequency.

RJ + PJ Low Pass Filter (LPF)
This is a post-processing filter that is applied to the data after acquisition. The filter affects the determination of what are considered peaks in the FFT views. The highlighted peaks are then reported among the values displayed in the Summary View. Choices are Nyquist and First Order. User entry is possible in box labeled Low Pass Freq Filter (MHz) only when First Order selection is enabled.
Nyquist – when selected, it does not add any filtering but refers to the highest possible frequency component that will be displayed by the FFT and used for data calculations. This value normally is the measured clock frequency/2.
First Order – is a low pass filter, it does not allow the RJ or PJ to be calculated above this user-selected value. The Low Pass Freq (MHz) field allows entry of the filter rolloff frequency.
The displayed values are not used when options are deselected.

Low Pass Freq (MHz)
Upper frequency limit for the window over which RJ and PJ is calculated. Default is Nyquist. See RJ + PJ max filter.

+/- 0.5 UI Filter
The filter is available when a pattern marker is being used and quick-mode is not enabled. It eliminates stray errors due to insertion of extra IDLE characters compensating for device re-clocking, which disrupts standard Fibre Channel test patterns. Filters are automatically calculated and applied to throw away any measurements, which are more then +/- 0.5 UI away from their expected positions. If more than 5% of the edges are filtered, an error will be reported.

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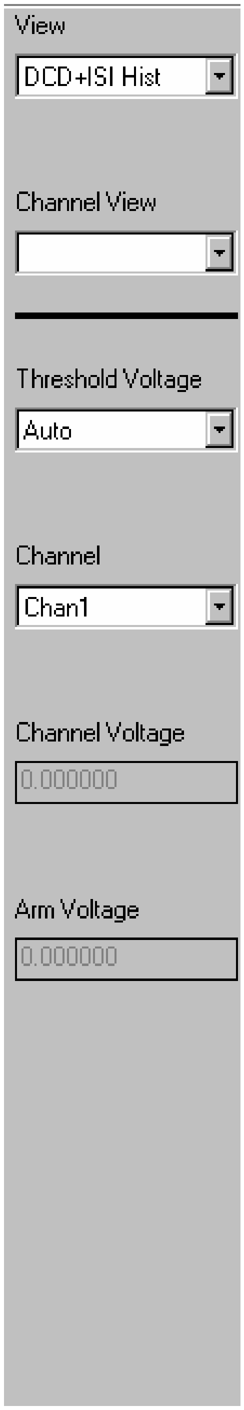
Voltage Options



Threshold Voltage
When set to “AUTO”, the start and stop threshold reference voltages are based on the 50% point of minimum and maximum voltage level found on each channel.
The voltages are shown in the voltage display boxes after a pulsefind is completed.
Select "USER VOLTS" to manually enter threshold voltages in the voltage display boxes. A pulsefind cannot be performed when User Volts is selected.

Channel
When "Threshold Voltage" is set to AUTO, you can use the "channel" control to view the threshold voltages derived from PULSEFIND to be used by that channel for a measurement. Voltages are displayed under "Start Voltage", "Stop Voltage", and "Arm Voltage".
When "Threshold Voltage" is set to USER VOLTS, use the "channel" control to select a channel and specify or fix the threshold voltages to be used for the measurement on that channel.

Channel Voltage
Enter channel voltage trigger level.

Arm Voltage
This is the voltage threshold used to Arm the chosen measurement. This value is derived from PULSEFIND when "Threshold Voltage" is in AUTO. If "Threshold Voltage" is in USER VOLTS, you can enter a fixed value to be used. In USER VOLTS, PULSEFIND will have no effect on the threshold voltages.

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View Options

X-axis
Select the horizontal plot axis unit of measure.
Delay Time - Shows time from Arm
Delay Periods - Shows number of periods from Arm
Elapsed Time - Shows elapsed acquisition time
Event - Take a measurement for each event from START event to STOP event and plot these values versus the count.
Hit Number - Low Frequency Modulation: Hit number is integer value assigned to each measurement as it is made.
Measurement - Shows number of total measurements
Span Periods - Shows number of periods measured
Span Time - Shows units of time measured
Time - Take a measurement and plot the value versus time.
UI Spans - Shows number of UI spans measured

Summary Units
Select unit of measure.

Effective Jitter
Several Bit Error Rate Testers (BERT) offer the ability to derive Deterministic Jitter and Random Jitter from a Bathtub Curve. Since this method is based on a pure DCD+ISI jitter model, it tends to generate lower DJ and higher RJ values. This option is offered in the event values are desired that are determined on a comparable basis to a BERT.
The "Effective Jitter" algorithm uses a total jitter (TJ) value to derive both DJ and RJ. This is opposite of the Tail-Fit algorithm which determines DJ and RJ to derive TJ.

High Limit
Upper limit of Bit Error Range over which the Effective Jitter is derived.

Low Limit
Lower limit of Bit Error Range over which the Effective Jitter is derived.

Bit Error Rate
Determine the Bit Error Rate to be used when extracting total jitter from the Bathtub Curve. The default value is 1e-12. This setting has a direct effect on the TJ value that is calculated. For example, TJ at 1e-6 will be lower (smaller) than TJ at 1e-12.

Back
Return to the previous menu.

Appendix I: Theory of Operation

This section will give a basic overview of the methodology behind the measurement. In addition to the data signal, this tool uses a pattern marker. Each channel in the SIA-4000 has the capability of producing this internal reference signal from a repeating pattern. The Marker signal has an edge relative to the same bit of the pattern each time the marker occurs. No bit-clock is used so analysis of jitter is independent of clock-jitter effects. The pattern marker is an arming signal, not a trigger, and any jitter on the marker will not transfer to the measurement of the data jitter.

The following steps are performed automatically when a measurement is acquired using this tool. The first step is to accurately measure the unit interval (UI). This is done by making a series of pattern length measurements, calculating the mean and dividing that time by the length of the pattern in UI. This results in the average or ideal UI and an accurate bit rate. Subsequent measurements and analysis will compare to this ideal UI and the jitter is displayed as the deviation from this ideal bit time.

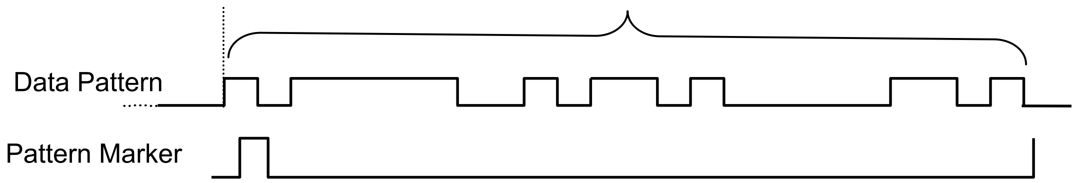


Figure 10 – Calculating UI and Bit rate

After the UI measurement, a pattern match of the data must be done to identify the measured data stream relative to the expected bit sequence as well as the phase relationship to the pattern marker. This eliminates the need to have the pattern marker at the beginning of the expected pattern. The expected pattern is rotated against the measured pattern until it matches. See Figure 11.

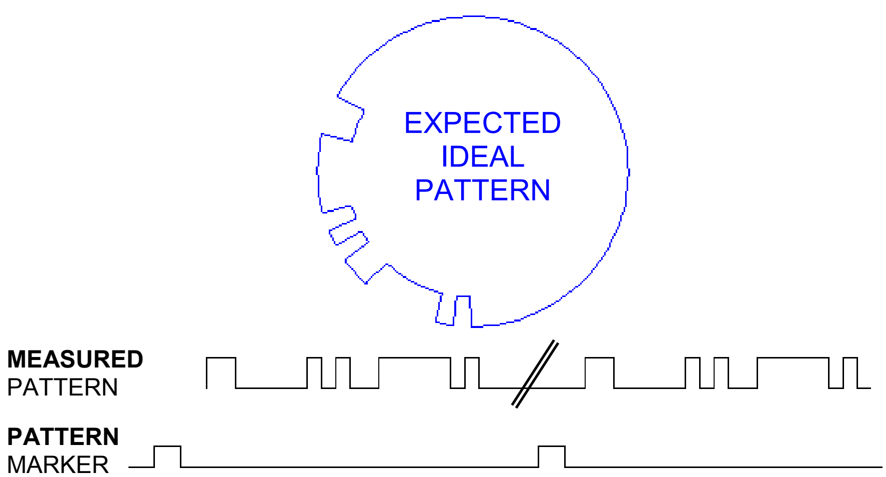


Figure 11 – Performing pattern match (K285)

Next, the total DCD + ISI is calculated. Histograms are made of every edge in the pattern. The mean values of these histograms are compared to the ideal edge locations. The measured mean location is subtracted from the calculated ideal edge location. The worst-case positive edge location is added to the worst-case negative edge location giving the total DCD+ISI. This can also be thought of as comparing the earliest edge to the latest edge. See Figure 12.

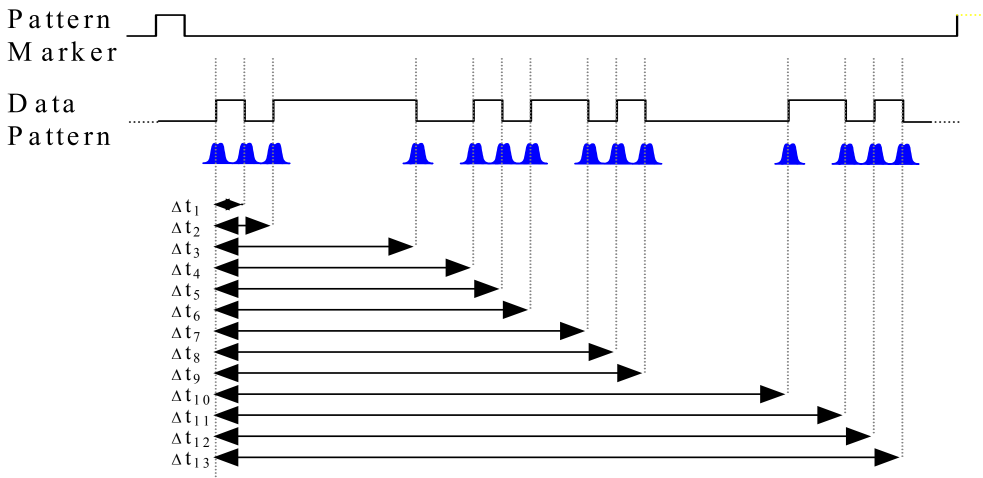


Figure 12 – DCD+ISI Measurement

Lastly, data is gathered to show PJ and RJ frequency components. PJ and RJ components are determined by taking the variance of timing measurements from the histogram at each UI. The variance is the square of the standard deviation of the histogram at each UI. If any "holes" in the variance record exist, they will be interpolated by either a cubic or linear fit. The plot of the 1-sigma values versus UI (1-Sigma view) shows if modulation is present. Refer to the "High Frequency Modulation" Getting Started Guide for further information about this concept.

An FFT of the autocorrelation function is used to determine the periodic components. The Fast Fourier transform of the autocorrelation function is commonly referred to as the power spectral density or power spectrum. The largest magnitude periodic component represents the PJ contribution to TJ. The RJ component is determined by subtracting the spectral components, summing the background then taking the square root to provide a 1-sigma value.

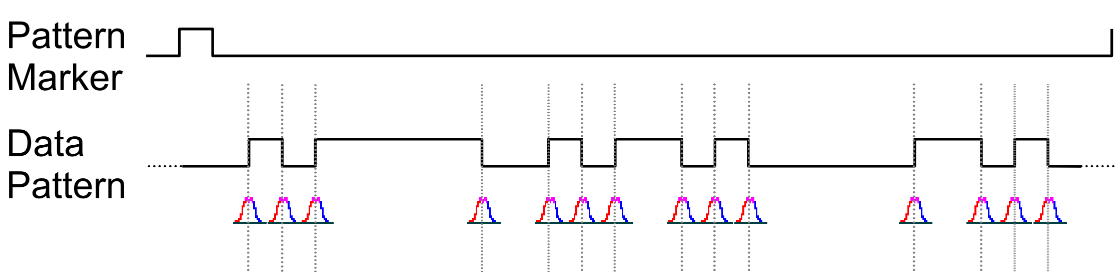


Figure 13 – Using TailFit™ to determine Random Jitter (RJ)

Optionally, Tail-Fit allows the accurate determination of random jitter when there is a significant amount of periodic jitter. Refer to Histogram Getting Started Guide for more about Tail-Fit. For more information regarding the calculation of RJ, see Appendix II.

Appendix II: RJ calculation methodology

This appendix discusses the method of Random Jitter calculation in the Known Pattern with Marker (KPWM) tool. Different settings are available to allow for optimizing test time, or measurement based on the signal under test. Signals have properties that differ based on how they were generated and what jitter is present. Different standards allow for different types of margins, jitter generation, and methodology of signal analysis. For these reasons, different RJ calculations are available.

This appendix will help you understand RJ calculation as it relates to different signals that may be encountered in applications such as Fibre Channel, SATA or other high-speed serial data standards. Because these are fundamentally different applications and allow for different amounts and types of jitter generation, the KPWM tool has different settings and overall test times. The setup that works for Fibre Channel signals may not work for SATA signals because the signal and test conditions are different. This is not a limitation of the tool, in fact this paper will show the flexibility of the tool to provide fast and accurate RJ results under a wide range of very different applications.

RJ Calculation Options

This section describes the options for quantifying RJ in the KPWM tool. A discussion of the algorithms, tool configuration, test times, signal under test and interpreting and understanding results is provided. Before making any conclusions based on results, it is important to understand how this tool makes a measurement and what is used as the basis for the RJ measurement. The first sections provide a description of theory, the second section describes tool configuration, and the last section describes how to interpret and understand results and how those results may lead to a change of tool setup. "Real-world" examples provide a basis for understanding the results.

The ultimate goal for the RJ calculation is to ensure that it is accurately quantified in the presence of Periodic Jitter. Simply running KPWM and looking at the final RJ value is often insufficient to understand the jitter present or if that RJ value is correct. You must look at the results of the 1-sigma vs. span plot to understand which method of RJ calculation is best based on the type of signal under test. Once determined, the appropriate setting can be used for all similar devices with similar outputs.

Various examples show the 1-sigma vs. span plot with different amounts of Random Jitter (RJ) and Periodic Jitter (PJ) and with Tail-fit on and off. The calculation of RJ is described with Tail-fit on and off. Depending on the conditions of the Device Under Test (DUT) and the Noise processes, the use of Tail-Fit may have a significant effect on overall Total Jitter (TJ). These examples are provided to help you determine what is best for you.

Known Pattern with Marker—A General Overview

The core concept to remember is that the SIA-4000 measures time intervals between voltage threshold crossings. These fundamental time measurements form a basis for a complete analysis of serial data signal timing. Histograms of these time intervals form the basis for the signal analysis. The DCD&ISI is determined from the mean displacement of each edge relative to the distribution of all edges in the pattern. The PJ&RJ are obtained in the frequency domain from the 1sigma vs. span record. RJ can also be quantified using the Tail-Fit algorithm.

A Brief Description of the 1-sigma vs. Span Plot

A portion of the test in KPWM measures the PJ components on a repeating pattern. This test utilizes an algorithm developed to determine the PJ from a variance record of 1-sigma values[i]. This plot shows the results of Histograms of measurements acquired over increasing numbers of Unit Interval (UI) combinations. Equal UI times are binned into histograms (figure 1). Likewise, RJ information can also be obtained from this record.

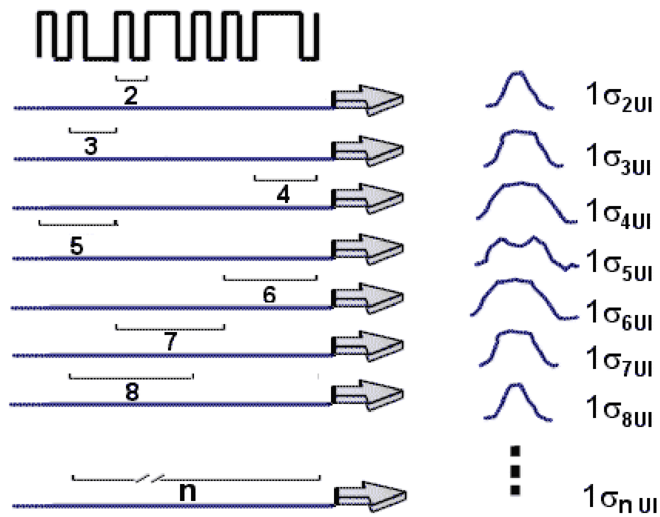


Figure 14 – Shows equal UI time spans binned into histograms

The reason for combining the same spans of UI is that any modulation on the data pattern will then affect these spans. PJ information can then be extracted. The measurement is made from data edge to data edge, but is scaled such that the reference edge is ideal (no jitter). This is in contrast to the general purpose Histogram tool in which the measurement is made between two jittered edges. In the default settings, the histograms that are made for the RJ and PJ measurement is made between rising edges (Period +). Other combinations of edges can be enabled such as Rising to Falling (PW+), Falling to Rising (PW-), and Falling-to-Falling (Period -). These settings are under RJ+PJ Options >> Measure Options menu. The results are displayed as a line for each measurement on the 1-sigma vs span plot and on the FFT plot.

The 1-sigma values from each histogram are plotted relative to the number of UI that the time measurement was acquired over (Figure 15). In the presence of PJ, the 1-sigma values will increase and decrease as a function of the period of the modulation. It is this information that is used to generate an FFT to view the PJ frequency components.

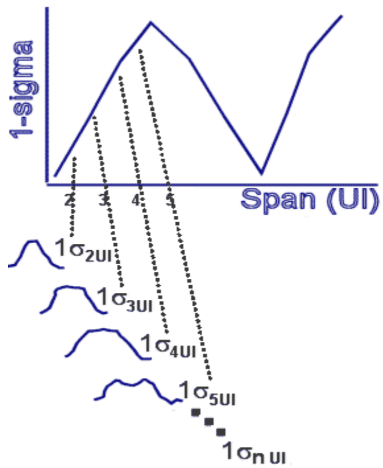


Figure 15 – The 1σ values are plotted with respect to the UI span over which the histogram was made.

Some actual examples of results from different signals under test using this tool are displayed below. The 1-sigma vs. span plot essentially shows accumulation of jitter over a number of UI. Interestingly, plots 1,2 and 3 (in figure below) show characteristics of the PLL in the SERDES under test. Wavecrest has developed algorithms to fit these types of results, and derive PLL characteristics but, only for the direct output of the PLL (not this output of the SERDES). In SERDES applications, this curve is often present, but because of the complex noise processes, these algorithms cannot typically be used to provide information about the SERDES PLL. For more information on PLL analysis, see the Wavecrest Paper[ii], "A New Method For Simultaneously Measuring And Analyzing PLL Transfer Function and Noise Processes".

http://www.wavecrest.com/technical/pdf/pll_noise_designcon_final_sub_120601.pdf

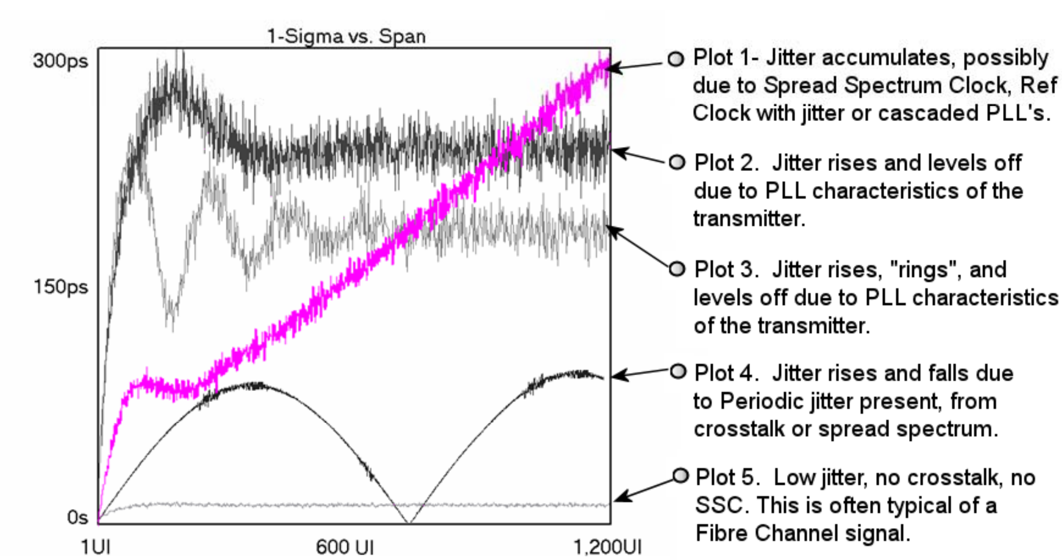


Figure 16 – Shows real-world examples of different RJ accumulation characteristics. This plot shows the importance of relying not just on an RJ value but also viewing the graphical results.

A Brief Description of Tail-Fit

Tail-Fit is a method of separating RJ and DJ components from a histogram (see Figure 17). Separate Gaussian curves are fit to the left and right tail regions. This is necessary because the 1-sigma of the histogram is not equal to the RJ. In the presence of DJ, the 1-sigma value is inflated and cannot be used as an accurate RJ value. It is important to note that the fitted curves may be different on the left and right due to dissimilar noise processes.

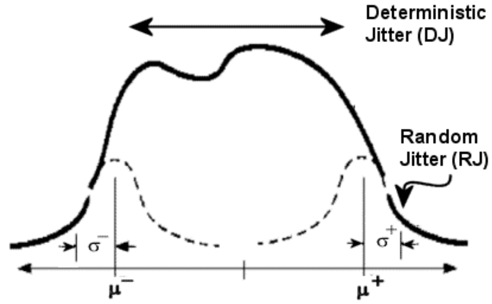


Figure 17 – Example of fitting Gaussian curves to tail regions. [iii]

Different options for RJ calculation

There are essentially 4 ways of calculating RJ:

- FFT based — *Appendix IIa*
- A number of TailFits — *Appendix IIb*
- 1-sigma based — *Appendix IIc*
- All TailFits — *Appendix IId*

As we can see in the preceding real-world example in Figure 16, the variety of possible RJ conditions necessitates the choice of different calculations for an accurate RJ measurement. The benefits and trade-offs of the selections in Figure 18 are detailed in Table 1.

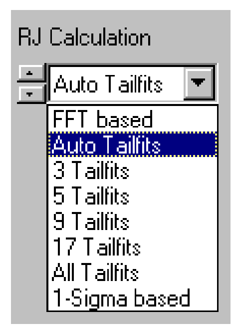


Figure 18 – RJ Calculation selections

RJ Calculation	Test Speed	Can be used with PJ present?		
Number of TailFits: Auto 3,5,9,17	Medium	Yes, preferred method if PJ is unknown.	Yes/No* *Filters only apply to PJ does not affect RJ value.	Time Domain
FFT based	High	No, or only less than about 10ps of PJ.	Yes	Frequency Domain
1-sigma based	High	No	No	Time Domain
All TailFits	Lowest	Yes	Yes	Frequency Domain

Table 1 – shows the benefits and trade-offs of different RJ calculation methods.

APPENDIX IIa:
RJ calculation Default —with Auto TailFits (Auto, 3, 5, 9, 17…)

When PJ is present, Tail-Fit should be enabled. This setting is used as the default. Figure 19a and 19b compare Tail-Fit on and Tail-Fit off. Note the thick flat line on the 1-sigma vs. span plot. This is the result of the Tail-Fit algorithm being performed. Recall from Figure 15 that each point on the plot is the 1-sigma value from a histogram of measurements. By enabling Tail-Fit we can perform RJ and DJ separation from these histograms with the resulting RJ plotted as the thick line. In Figure 19a, RJ is reported as 2.242ps. Compare this value to the overestimated 8.452ps reported in Figure 19b.

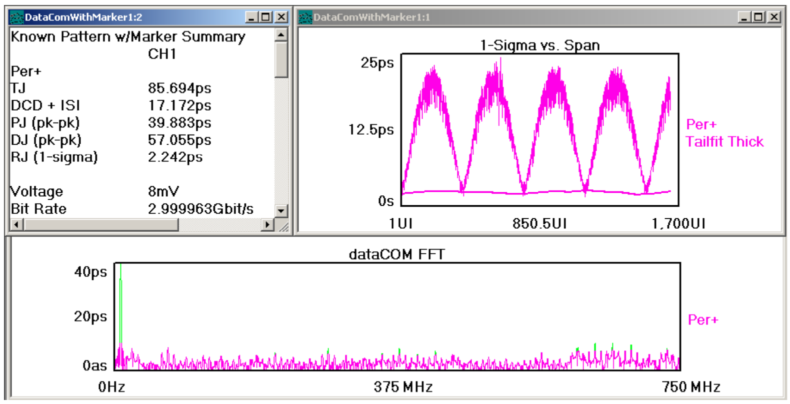


Figure 19a - Shows the measurement with PJ present and TailFit enabled. The RJ reported is calculated from the average of a number of Tail-Fit values (flat line on 1-sigma vs. span plot).

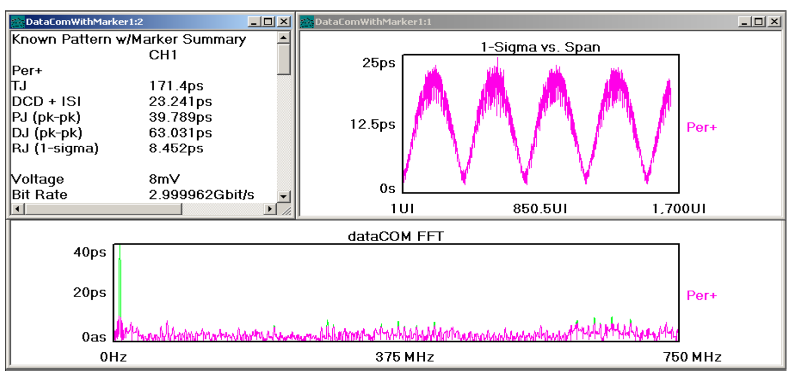


Figure 19b - Shows the measurement with PJ present and RJ calculated from FFT based. The RJ reported (8.452ps) is over-estimated due to PJ. Note that the 1-sigma plot accumulates to almost 25ps, and the FFT has a PJ spike of almost 40ps. FFT based RJ calculation should not be used in this case.

In the presence of Periodic Jitter (PJ) TailFit provides an accurate RJ measurement. (This is in contrast to using the FFT method that uses an RMS value of the entire FFT as the RJ. PJ would artificially inflate the reported RJ.) There are a number of choices for how many Tailfits will be performed. 'All' will produce the longest test times. Usually it is sufficient to use some number of Tailfits (3,5,9,17) or to use 'Auto'. 'Auto' is the default and will generally provide the most accurate, fast and repeatable results.

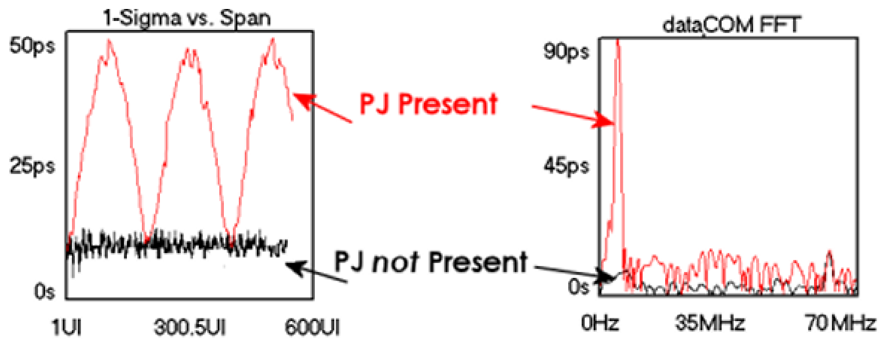


Figure 20 – Shows the differences when PJ is or is not present on the data signal.

The following plot Figure 21 shows TailFit Enabled. RJ from TailFit is an accurate value when PJ is or is not present, in contrast to using RJ from FFT when PJ is present.

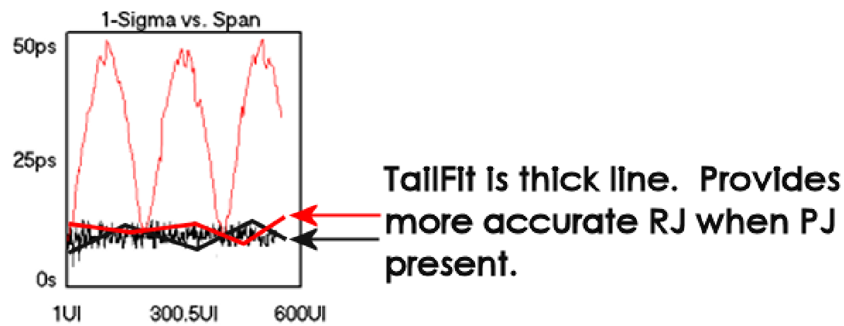


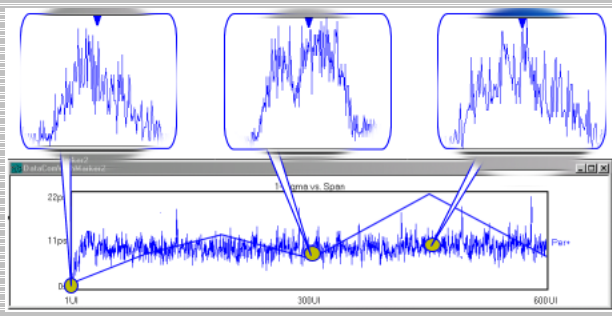
Figure 21 – Shows that the TailFit line follows true RJ. Black flat line shows no PJ added, and TailFit follows the flat trend. When PJ is added in the red, periodic measurements, the red TailFit line remains flat showing no change in RJ when PJ is added.

There are different choices for a number of TailFits: Auto, 3, 5, 9 and 17

1. Choosing 'Auto' will first measure '3' and '5' Tail-Fits. The recorded values must be within X% (as set by the "Convergence" control). If the values vary more than that then '5' and '9', Tail-Fits are compared. This process continues up to '17' Tail-fits at which time the test reports an error if the values do not satisfy the convergence criteria.
2. Choosing 3, 5, 9, or 17 sets the number of TailFits to be performed on that number of histograms from the 1-sigma vs. span plot. The histograms chosen will be equally spaced across the span. For example, choosing '3' would Tail-Fit the histograms on each end of the Span and the one in the center. The Tail-Fit algorithm will run until goodness of fits criteria are achieved, then the next histogram is fitted.

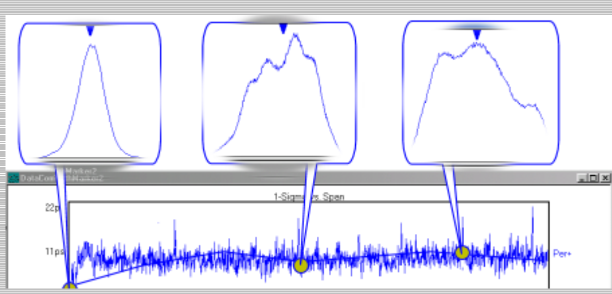
A note on RJ stability when calculating RJ from Auto, 3,5,9, or 17 TailFits

When the RJ calculation is from "TailFit", the TailFit samples will determine the minimum number of samples to be in a histogram before the TailFit is performed. With Tailfit selected as the RJ calculation, refer to the "1-Sigma vs Span" view. This view shows the 1-sigma value of histograms acquired over increasing numbers of Unit Intervals.
The histograms have a sample size set in the RJ+PJ Options menu, "RJ+PJ Samples", but "TailFit Samples" determines how many samples are in each histogram used for TailFits. So for Example, say you have chosen TailFits=3. Three histograms will have TailFit performed. See the Example below:



The "grainy" line on the 1-sigma view indicates the 1-Sigma values from histograms. The thick line indicates values from TailFit. Note that the line jumps up near the end of the plot. This can indicate a poor TailFit. If we could view the histograms that generated each of the 1-sigma values, we might see that not enough samples were acquired to perform a good TailFit. This can cause poor repeatability of RJ values.

To improve repeatability of the RJ values, set "Tail fit Samples" higher and reacquire the measurement. The example below shows increased samples, which would provide better statistics for the histogram, and a smoother TailFit line.



APPENDIX IIb: RJ Calculation—'FFT based'

When TailFit is disabled, RJ is calculated from the RMS across the range of frequencies from Nyquist to the set –3dB point. This is sufficient when no PJ is present as in Figure 22. But, as was described in the previous section and Figures 19a and 19b with PJ present the RJ value is inflated due to the additional power in the spectrum when it is integrated to provide the RJ value. The 1-sigma vs. span plot shows the periodicity of the 1-sigma values and the FFT shows the PJ spike in Figure 4b.

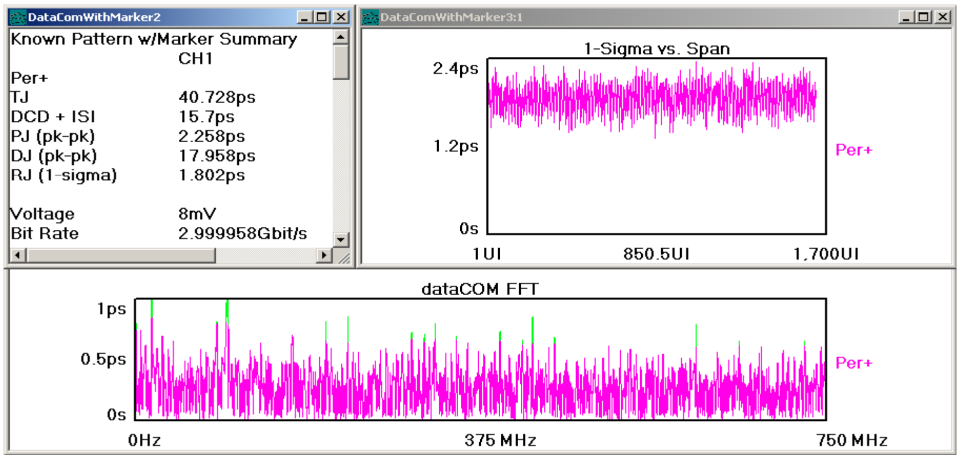


Figure 22 – Shows the measurement with RJ calculated from FFT based. Note that the 1-sigma plot levels off at about 2ps, the FFT shows some spikes that are around 1ps. Compare these results to Figure 19b where PJ is present. FFT based RJ calculation can be used in this case, but would not be appropriate in the example of 19b.

APPENDIX IIc: RJ Calculation—'1-Sigma based'

In some cases there may be a characteristic curve of a PLL on the "1Sigma vs. Span" view. This curve is caused by the PLL in the transmitter. The curve will rise across the span and then level off. In this case applying TailFits will provide a reliable RJ value, but the test time may be high. If you find that the TailFit line tracks the 1-Sigma values—in an effort to improve test time and not loose RJ accuracy—you can choose RJ Calculation "1-Sigma based". This will use the average of all 1-sigma values on the view. This is much faster than computing a TailFit at a few points across the span. Figure 23 below shows a case when "1-sigma based" can be used.

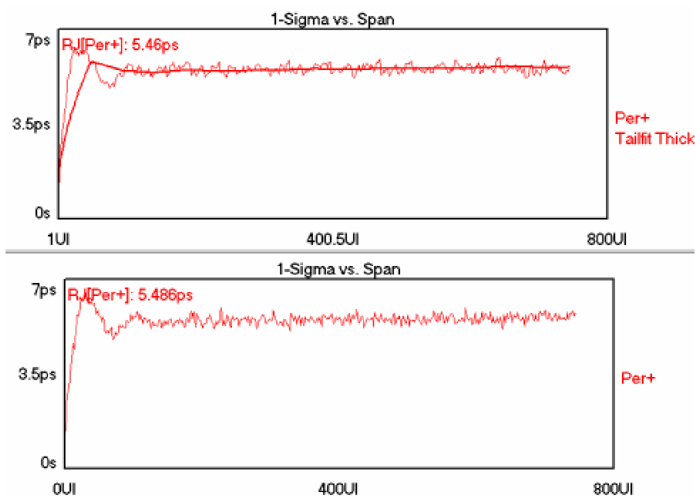


Figure 23 – This example shows the same signal under test. The top shows the RJ calculation from Tailfits. The bottom shows RJ from the "1-sigma based" average of all 1-sigma values across the span. The RJ values do not significantly differ and "1-sigma based" will give a faster test time.

It is possible to have a 1-sigma curve but the TailFit line *does not* track it. In this case you should use "TailFit based" RJ calculation rather than "1-sigma based". The following example shows a 1-sigma curve with TailFits that do not track the 1-sigma values. In this case you should use the TailFit results. Using "1-sigma based" RJ calculation will overestimate the Random Jitter.

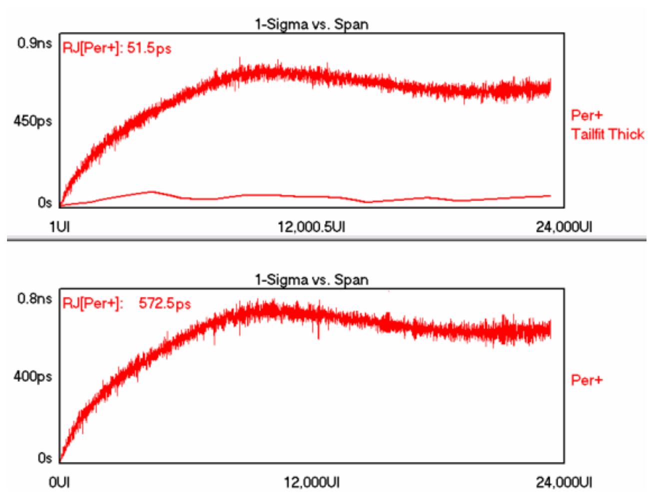


Figure 24 - This example shows that the TailFit is the correct RJ calculation. In this case because the 1-sigma values do not track the TailFit line, it is not possible to decrease test time by using "1-sigma based".

APPENDIX IId: RJ Calculation—'All TailFits'

Choosing 'All' will perform Tail-Fits on all of the histograms across the entire span which may result in longer test times than just using a specified number of TailFits as in Appendix IIa. Using 'All', the histogram sample size is changed to 5,000 samples (irregardless of the default/or user entered values) and the Tail-Fit is "force-fit" to the measured samples. This may not yield optimal results but is done in order to bound the test time which will still be longest with 'All' selected. When 'All TailFits' is chosen, it is possible to derive an FFT from the Tailfit results because it is a continuous record of 1-sigma values. The RJ in this case comes from the FFT of the Tailfit values.

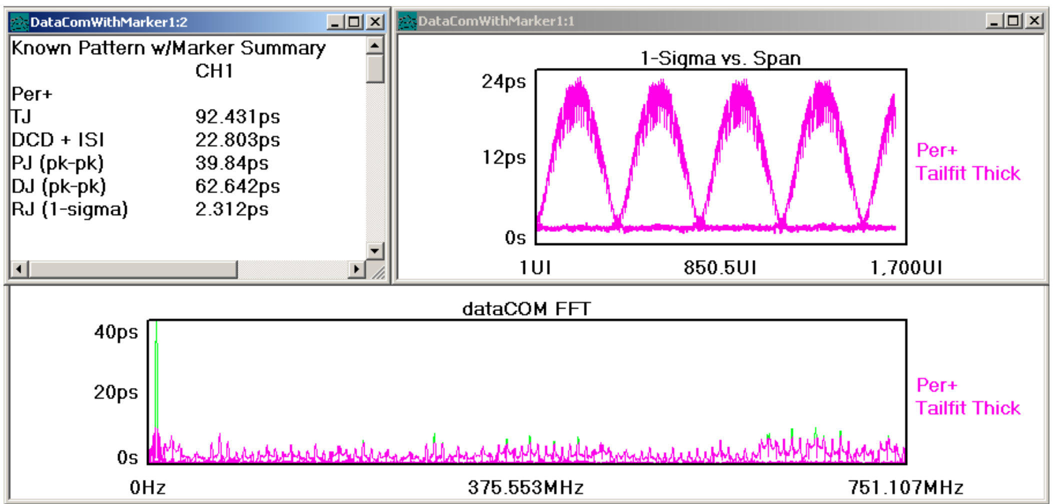


Figure 25. This plot shows a setup similar to Figure 19a. The only difference that 'All TailFits' is enabled as opposed to a specified number.

If post processing RJ+PJ filters are to be used, the 'All Tailfits' setting will allow both RJ and PJ to have the filters applied. This is contrary to using a fixed number of Tailfits as in Appendix IIa, where applying RJ+PJ filters only affects the PJ value, not the RJ value.

A brief discussion of the "rule of thumb" TJ=DJ+14*RJ.

The 'Known Pattern with Marker' tool does not use the above equation. Many studies have been performed that show this is an inaccurate method of calculating Total Jitter. In general, the problem is much more complicated. The KPWM tool makes a measurement in order to construct the actual Probability Density Functions (PDF) for different noise processes such as Data Dependent Jitter (DDJ), PJ, and RJ. By building up these independent PDFs, a convolution and integration can be performed to determine the actual TJ PDF.

For more information contact:

WAVECREST Corporation
7610 Executive Drive
Eden Prairie, MN 55346
www.wavecrest.com
1(952)-646-0111

01.15.07 tag

i J.Wilstrup, "A method of Serial Data Jitter Analysis Using One-Shot Time Interval Measurements", ITC Proceeding, 1998.
Relevant US Patents #6,185,509 , #6,356,850, #6,449,570

ii M. Li, J. Wilstrup, "A New Method for Simultaneously Measuring and Analyzing PLL Transfer Function and Noise Processes", DesignCon, 2002. Patent Pending.

iii M. Li, "A New Method for Jitter Decomposition Through Its Distribution Tail Fitting", ITC Proceeding, 1999.
Relevant US Patent #6,298,315B1