LeCroy

WHITE PAPER

SDA, ASDA and SDM
SDA Serial Data Analyzer and SDM Serial Data Mask Package – Theory of Operation

The serial data analyzer is an instrument designed to provide comprehensive measurement capabilities for evaluating serial digital signals. In addition to the WaveShape Analysis features in the standard WaveMaster, the SDA provides eye pattern testing and comprehensive jitter analysis . This includes random and deterministic jitter separation, and direct measurement of periodic jitter (Pj), deterministic jitter (DDj), and duty cycle distortion (DCD). The SDA also provides the capability to directly measure failed bits and to indicate their locations in the bit stream.

SDA Capabilities

In addition to all the standard WaveMaster measurement functions, the SDA provides three main measurements: jitter, eye pattern, and bit error testing. These measurements are displayed together in the Summary screen, but can be viewed individually also.

Note:
- **SDA –** name of the instrument: Serial Data Analyzer
- **ASDA –** Advanced Serial Data Analysis software package available only for the SDA
- **SDM –** Serial Data Mask testing software package available on WaveMaster and WavePro7000 series oscilloscopes. Not available on

Measurements on the SDA are performed on long, continuous acquisitions of the signals under test. Acquisitions are limited only by the available memory of the instrument (up to 100M samples with memory option XXL). Continuous acquisition means that all measurements can be performed without an external trigger. As a result, the measurements are not affected by trigger jitter, a major contributor of errors in both eye pattern and jitter measurements.

The SDA is available in either standard form, which includes mask testing and jitter parameters (Rj, Dj, Tj, DDJ, Pj, and DCD), or with option ASDA. This option adds a major upgrade in capability over the standard instrument. The different measurements available for each configuration are shown in Table 1.

SDM Capabilities

The capabilities of the SDM option are standard in the SDA, so it is not available for the SDA. SDM is only available for the WaveMaster and WavePro7000 series of oscilloscopes. SDM adds eye pattern testing to these oscilloscopes and includes several key components of the basic scope, including JTA2 with its TIE@lvl parameter.

Table 1. Measurements available in SDA, ASDA, and SDM.

Available Measurements			
Single-Signal Measurements	**SDA std.**	**SDA w/ ASDA**	**SDM option**
Data stream			
Mask test w/ golden PLL	**X**	**X**	**X**
Mask violation locator		**X**	
Jitter Rj , Dj, Tj, ISI, DCD (DDj), Pj	**X**	**X**	
Filtered jitter		**X**	
ISI plot		**X**	
N-cycle vs. N plot		**X**	
Bit error test with error map		**X**	
N-cycle jitter (data)	**X**	**X**	
Eye pattern measurements			
Eye height	**X**	**X**	**X**
Eye width	**X**	**X**	**X**
Extinction ratio	**X**	**X**	**X**
Eye amplitude	**X**	**X**	**X**
Eye crossing point	**X**	**X**	**X**
Q factor	**X**	**X**	**X**

TIE@lvl measures the time interval error of the crossing points of the signal under test. SDM also includes a “golden PLL” clock recovery module, which is used for forming the eye pattern without an external trigger. Standard masks are included with option SDM, as indicated in Table 1. Note that not all data rates can be tested with all scope models. The analog bandwidth of the scope limits the upper data rate that can be tested.

ASDA Capabilities

ASDA adds several key capabilities to the SDA. In its standard form, the SDA includes eye pattern testing with mask hit indication, Jitter testing (including jitter “bathtub” computation), and separation of jitter into its random and deterministic components. It also provides a breakdown of deterministic jitter into periodic, data dependent, and duty cycle distortion measurements. ASDA adds the following analysis features.

- Mask violation location –lists and displays the individual bits that violate the selected mask.

- Filtered jitter – processes the time interval error trend vs. time with a user selectable band-pass filter. This feature provides peak-to-peak and rms measurements of the jitter on the filtered waveform.

- ISI plot – generates an eye diagram that includes only those effects from data dependent sources. You can select from 3 to 7 bit patterns for this test and can view the contribution from any individual pattern.

- N-cycle vs. N plot – displays a plot of the average or peak-topeak jitter over the entire acquired waveform for selected bit spacing. The user selects the beginning and ending bit spacing, as well as the step size. The plot shows jitter as a function of bit spacing.

- Bit error test with error map – measures the number of bit errors and error rate on the acquired waveform by converting the wave shape to a bit stream and comparing the result to a userdefinable reference pattern. The data can be further divided into frames that can be arranged in a 3-dimensional map with frame number on the Y-axis, bit number on the X-axis, and failed bits shown in a light color.

Table 2. Testing Modes Required

Standard	Mode
1000Base-CX	TX normalized/absolute, RX
1000Base-LX	TX
1000Base-SX	TX
10GBase-LX4	TX normalized
DVI	Transmitter, receiver low, receiver high, cable test low, cable test high
FC2125, FC1063	TX normalized
FC531, FC266, FC133	TX normalized, TX absolute, Receiver
IEEE1394b	400 beta TP2 absolute, 400 beta TP2 normalized, 400 beta receive
Infiniband 2.5 Gb/s	Transmitter
SONET	OC-1, OC-3, OC-12, OC-48, STS-1 eye, STS-3 transmit, STS-3 interface
SDH	STM-1, STM-4, STM-16
PCI-Express	TX transition, TX de-emphasized, RX
Serial ATA 1.5Gb/s	TX connector, RX connector
USB2.0	
XAUI	Driver far, Driver near

Getting Started

Accessing SDA

To start the special SDA measurements, select **Serial Data** from the analysis menu. Alternatively, you can press the **SDA** button on the front panel.

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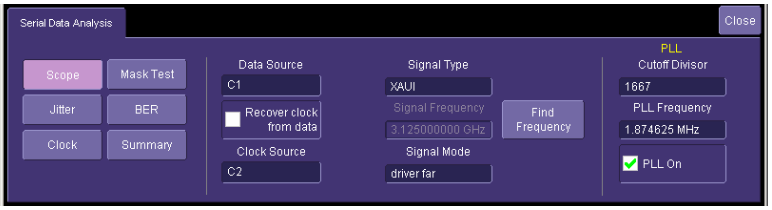
The SDA main dialog shown below will be displayed at the bottom of the screen. The buttons on the left control the display of specific measurements:

- **Scope** returns the scope to normal operation.
- **Mask Test** starts the eye pattern test mode.
- **Jitter** displays the jitter measurement screens.
- **Clock** allows you to designate a signal an actual clock (as opposed to serial data) and displays a bathtub curve, TIE histogram, and Rj, Dj, and Tj.
- **BER** starts the bit error rate test and displays an error map.
- **Summary** enters a display mode that shows jitter, mask testing, and signal parameters in one screen.



Data Source: C1

☐ Recover clock from data

Clock Source: C2

Signal Type: XAUI

Signal Frequency: 3.125000000 GHz

Signal Mode: driver far

PLL

Cutoff Divisor: 1667

PLL Frequency: 1.874625 MHz

☑ PLL On

The signal must first be set up before you enter into any test mode. Select the source in **Data Source** and the clock in **Clock Source.** These can be, and in most cases are, the same. The selections can be active channels as well as math or memory traces.

If you do not check the **Recover clock from data** checkbox, it tells the processing software that the signal should be treated as a clock; that is, one cycle or unit interval is from rising edge to rising edge. This contrasts with the normal selection where a data bit or UI is defined from edge to edge, regardless of whether they are rising or falling. The **Signal Type** control determines the data rate and mask for eye pattern and jitter tests. **Signal Frequency** indicates the data rate for the selected standard, which you can set when **Custom** is selected as the signal type. And **Signal Mode** allows the selection of specific modes (such as Transmitter or Receiver), depending on the selected signal type. For example, some standards define separate transmit and receive masks.

The **PLL** section at the right of the dialog consists of two interlocked controls: one for the **Cutoff Divisor** and the other for the **PLL Frequency.** The cutoff divisor is the number by which the data rate is divided to determine the PLL loop bandwidth filter. This bandwidth can also be set directly using the PLL frequency control.

The default value for the cutoff divisor is 1667, which is the defined value for a golden PLL. The PLL recovers a clock from the channel selected in the **Data Source** control and uses this as a reference clock for jitter (TIE) measurement, eye pattern generation, and bit error testing. The **PLL On** checkbox, when left unchecked, disables the PLL and reverts to a reference clock that operates at a fixed rate equal to the value in the **Signal Frequency** control. **Find Frequency** causes the instrument to search for the actual frequency of the signal in case it differs from the specified value. The resulting frequency from this search is displayed in the **Signal Frequency** control.

SDA Acquisition Settings

The SDA measures eye pattern and jitter parameters by processing a long record in order to recover the clock and to measure the jitter statistics. This same record is also divided into segments, using the recovered clock to form the eye pattern. The record length and sample rate have a dramatic impact on the accuracy of these measurements.

The sampling rate sets the time resolution for both the clock recovery and jitter measurements, while the record length allows for PLL settling and statistical accuracy. It is important that the sampling rate be set to its maximum value for the best performance. This value is 20 Gs/s for all standards with rise times faster than 300 ps. A minimum of 3000 data edges is required for PLL settling in all cases. So for a signal consisting of 12 samples per bit, for example, a minimum record length of 50k samples is needed. In practice, 400k samples is the minimum practical record size to produce acceptable results.

Theory of operation

The SDA operates by processing a long signal acquisition. Processes include clock recovery, eye pattern computation, jitter measurement, and bit error testing ? all performed on the same data record. The processes will be described in detail in this section.

Clock Recovery

An accurate reference clock is central to all of the measurements performed by the SDA. The recovered clock is defined by the locations of its crossing points in time. Starting with zero, the clock edges are computed at specific time intervals relative to each other. A 2.5 GHz clock, for example, will have edges separated in time by 400 ps. The first step in creating a clock signal is the creation of a digital phase detector.

This is simply a software component that measures the location in time at which the signal crosses a given threshold value. Given the maximum sampling rate available, 20 GHz, interpolation is necessary in most cases. Interpolation is automatically performed in the SDA when three or fewer samples exist on any given edge. Interpolation is not performed on the entire waveform. Rather, only the points surrounding the threshold crossing are interpolated for the measurement. To find the crossing point, a cubic interpolation is used, followed by a linear fit to the interpolated data. This is shown in Figure 1.

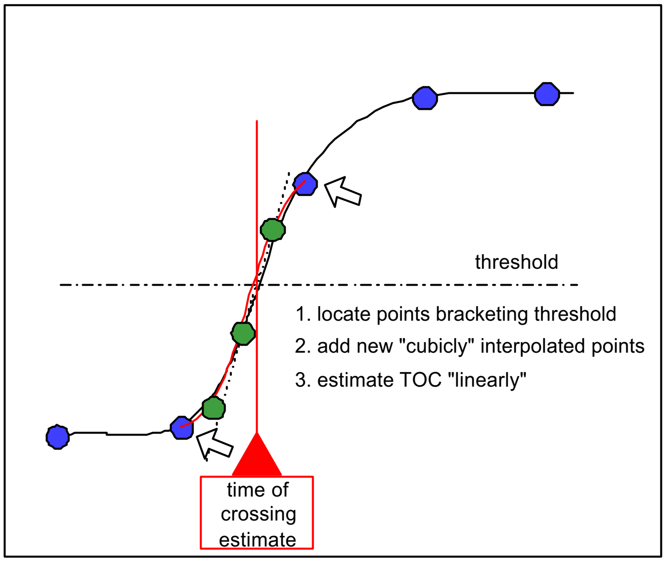


Figure 1. SDA Threshold Crossing Algorithm

The clock recovery implementation in the SDA is shown in Figure 2. The algorithm generates time values corresponding to a clock at the data rate. The computation follows variations in the data stream being tested through the use of a feedback control loop that corrects each period of the clock by adding a portion of the error between the recovered clock edge and the nearest data edge.

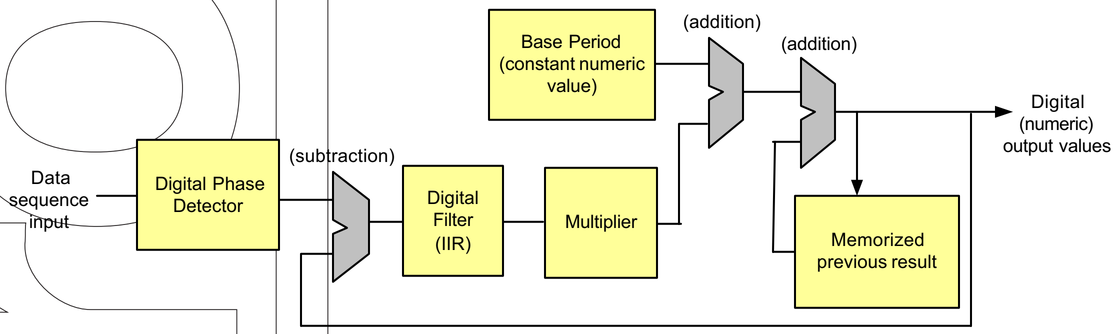


Figure 2. SDA Clock Recovery Algorithm

In Figure 2, the initial value of the output and the digital phase detector are set to zero. The next time value output is equal to the nominal data rate. This value is fed back to the comparator on the far left, which compares this time value to the measured time of the next data edge from the digital phase detector. The difference is the error between the data rate and the recovered clock. This difference is filtered and added to the initial base period to generate the corrected clock period. The filter controls the rate of this correction by scaling the amount of error that is fed back to the clock period computation. This filter is implemented in the SDA as a single-pole infinite impulse response (IIR) low-pass filter, whose equation is:

$$y_k = \frac{1}{n} x_k + \left(1 - \frac{1}{n}\right) y_{k-1}$$

The value of y_k is the correction value for the k^{th} iteration of the computation, and x_k is the error between the k^{th} data edge and the corresponding clock edge. Note that the current correction factor is equal to the weighted sum of the current error and all previous correction values. The multiplier value is set to 1 in the SDA. The value of *n* is the PLL cutoff divisor that is set from the SDA main dialog. The cutoff frequency is Fd/n where Fd is the data rate. This filter is related to its analog counterpart through a design process known as impulse invariance and is only valid for cutoff frequencies much lower than the data rate. For this reason, the minimum PLL cutoff divisor setting is 20 in the SDA.

The factor *n* determines the number of previous values of the correction value y that are used in the computation of the current correction value. This is theoretically infinite; however, practically there is a limit to the number of past values included. One can define a “sliding window” equivalent to a number of UI of the data signal for a given value of *n*. This is useful for measuring signals such as serial ATA and PCIExpress where the specifications call for clock recovery over a finite window.

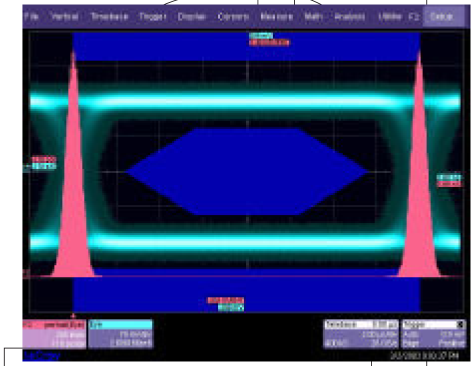
The equivalent bandwidth of the sliding window is given by a sin(x)/x function. The first null of this function occurs at $x = \pi$ or 1/2 the bit rate (the digital equivalent of the frequency of a signal at the sampling rate is 2π and the sampling rate for clock recovery is the data rate). This is scaled by the window size to be $2\pi/N$ where N is the window in UI. The 3 dB point of the sin(x)/x function is at $0.6\pi/N$ or 0.3Fd/N for a window length of N. This gives us a relationship between N and n:

$$Fd/n = 0.3Fd/N \text{ or } n = N/0.3$$

For a sliding window size of 250, the equivalent value of *n* would be 833.

Eye Pattern Measurement

An eye diagram shows all values that a digital signal takes on during a bit period. A bit period or UI (unit interval) is defined by the data clock so some sort of data clock is needed in order to measure the eye pattern. The traditional method of generating an eye pattern involves acquiring data on an oscilloscope using the data clock as a trigger. One or more samples are taken on each trigger. The samples are stored in a persistence map with the vertical dimension equal to the signal level and the horizontal position equal to the sample position relative to the trigger (or data clock). As many data points are collected, the eye pattern fills in with multiple occurrences of time and amplitude values counted by incrementing counters in each x,y “bin.” Timing jitter is indicated by the horizontal distribution of the points around the data crossings. The histogram of the bins around the crossing points gives the distribution of jitter amplitude.



Histogram of Zero Crossing in Eye Pattern Showing Jitter Distribution

A recovered clock is used if there is no access to a data clock. The recovered clock is normally a hardware PLL designed to operate at specific data rates and with a cutoff frequency of Fd/1667. One of the major drawbacks of a hardware clock recovery circuit is that jitter associated with the trigger circuit adds to the measured jitter by creating uncertainty in the horizontal positioning of the eye pattern samples.

The SDA measures eye patterns without using a tirgger. It does this by using the software clock recovery discussed above to divide the data record into segments along the time values of the clock. For the purposes of dividing the time line into segments, the time resolution in the waveform record is infinite. The samples occur at fixed intervals of 50 ps/pt (for a 20 Gs/s sampling rate). The samples are positioned relative to the recovered clock timing points and the segments delimited by the clock samples are overlayed by aligning the clock samples for each segment. A monochrome or color persistence display is used to show the distributon of the eye pattern data. Jitter added by the measurement system in this case is from the sampling clock, which, for the SDA, is very low: on the order of 1 ps rms.

Eye Violation Locator (ASDA)

The eye pattern is measured by overlaying segments of a continuous acquisition. Since the complete data record is available, the location of individual bits can be determined by comparing each bit interval in the original waveform with the selected mask. The mask is aligned horizontally along the mean bit interval, and vertically along the mean one and zero level in the case of a relative mask. Absolute masks exist for some standards and are defined in the vertical dimension by specific voltage values. Figure 3 below shows this alignment. When mask testing is turned on, the entire waveform is scanned bit-by-bit and compared to the mask. When a mask hit is detected, the bit number is stored and a table of bit values is generated. This table is numbered, starting with the first bit in the waveform, and can be used to index back to the original waveform to display the waveform of the failed bit.

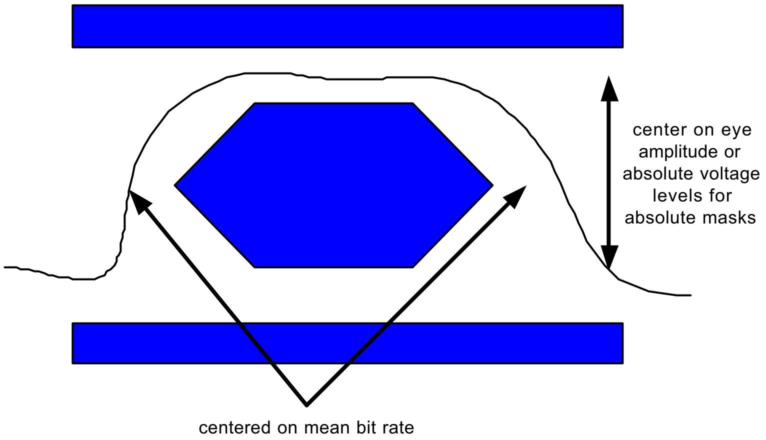


Figure 3. Eye Mask Alignment for Violation Locator

Eye Pattern Measurements

There are several important measurements that are made on eye patterns. These are specified as required tests for many standards. Eye measurements mainly deal with amplitude and timing, which are described next.

Eye Amplitude

Eye amplitude is a measure of the amplitude of the data signal. The measurement is made using the distribution of amplitude values in a region near the center of the eye (normally 20% of the distance between the zero crossing times). The simple mean of the distribution around the ‘0’ level is subtracted from the mean of the distribution around the ‘1’ level. This difference is expressed in units of the signal amplitude (normally voltage).

Eye Height

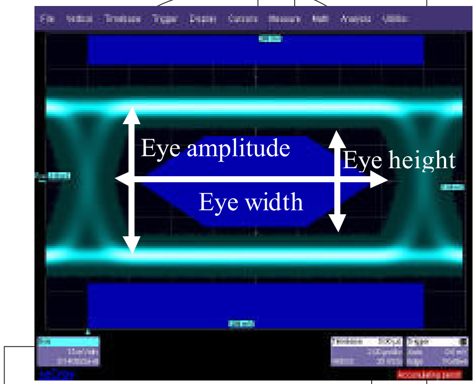
The eye height is a measure of the signal to noise of a signal. The mean of the ‘0’ level is subtracted from the mean of the ‘1’ level as in the eye amplitude measurement. This number is modified by subtracting the standard deviation of both the ‘1’ and ‘0’ levels. The measurement basically gives an indication of the eye opening.

Eye Width

This measurement gives an indication of the total jitter in the signal. The time between the crossing points is computed by measuring the mean of the histograms at the two zero crossings in the signal. The standard deviation of each distribution is subtracted from the difference between these two means.

Extinction Ratio

This measurement, defined only for optical signals, is the ratio of the optical power with the laser in the on state to that of the laser in the off state. Laser transmitters are never fully shut off because a relatively long period of time is required to turn the laser back on thus limiting the rate at which the laser can operate. The extinction ratio is the ratio of two power levels, one very near zero, and its accuracy is greatly affected by any offset in the input of the measurement system. Optical signals are measured using optical to electrical converters on the front end of the SDA. Any DC offset in the O/E must be removed prior to measuring the extinction ratio. This procedure is known as dark calibration. The output of the O/E is measured with no signal attached (i.e., dark) and this value is subtracted from all subsequent measurements.



Eye Crossing Eye crossing is the point at which the transitions from 0 to 1 and from 1 to 0 reach the same amplitude. This is the point on the eye diagram where the rising and falling edges intersect. The eye crossing is expressed as a percentage of the total eye amplitude. The eye crossing level is measured by finding the minimum histogram width of a slice taken across the eye diagram in the horizontal direction as the vertical displacement of this slice is varied.

Average Power

The average power is a measurement of the mean value of all levels that the data stream contains. It can be viewed as the mean of a histogram of a vertical slice through the waveform, covering an entire bit interval. Unlike the eye amplitude measurement, where we separate the ones and zeroes histograms, the average power is the mean of both histograms. Depending on the data coding that is used, the average power can be affected by the data pattern. A higher density of ones, for example, will result in a higher average power. Most coding schemes are designed to maintain an even ones density resulting in an average power that is 50% of the overall eye amplitude.

Q factor or BER

The Q factor measures the overall signal-to-noise ratio of the data signal. It is computed by taking the eye amplitude and dividing it by the sum of the standard deviations of the zero and one levels. All of these measurements are taken in the center (usually 20%) of the eye.

Jitter measurement

The SDA measures jitter by evaluating the time difference between the data crossing points and those of an ideal reference clock. The reference clock used for jitter measurements in the SDA is the software PLL described above. This approach provides an almost ideal reference because the software clock adds no jitter to the signal beyond the very small contribution from the sampling clock. Software implementation allows very tight control over the clock bandwidth while at the same time allowing a great deal of flexibility.

TIE measurement

Time interval error or TIE is a measurement of the time error between edges of a data (or clock) signal and those from an ideal, jitter-less clock (Figure 4).

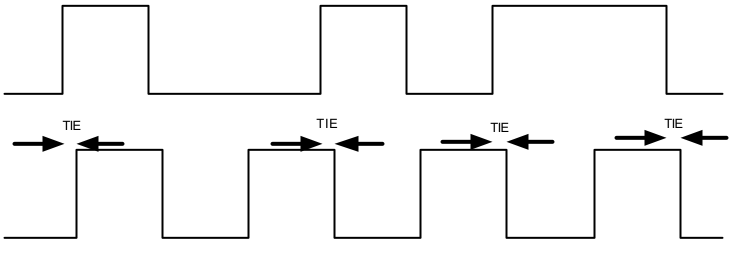


Figure 4. TIE Measurement between Data (above) and Ideal Clock (below)

TIE Histogram

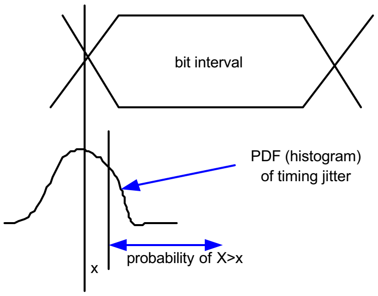
The clock can be a separate reference or, more commonly, a recovered clock from the data stream. A recovered clock allows control of contributions to the overall jitter from components at lower rates. The widely used “Golden PLL” from the Fibre Channel specification has a loop cutoff frequency of the data rate/1667. This PLL has the effect of limiting the contribution of jitter components at low rates to the overall jitter value by enabling the recovered clock to track slow variations in the data rate. Implementation of the PLL in the SDA allows adjustment of the cutoff factor (1667 in the Golden PLL) from 20 to 10,000, giving excellent control of the contributions of jitter at specific rates. Clock recovery and TIE measurement in the SDA are performed on consecutive edges in a single, long acquisition.

The TIE values measured from the data signal are collected into a histogram of TIE value vs. the number of occurrences of that value. This histogram is computed over the complete set of measurements in a given acquisition, and is updated on each subsequent acquisition so that the histogram is the cumulative result of all acquisitions from the last reset. The main object of measuring the histogram of TIE is to determine the likelihood of a jitter value exceeding a given maximum. Systems typically specify bit error rates in the 10^{-12} range. When performing jitter measurements, one is interested in determining the probability that a data transition occurs at the same time that the data is being sampled by the detector. This results in the conditional probability of a data edge occurring at a given time within a bit period, given that the data is sampled at that time. This relationship is shown graphically in the bathtub curve which will be discussed shortly.

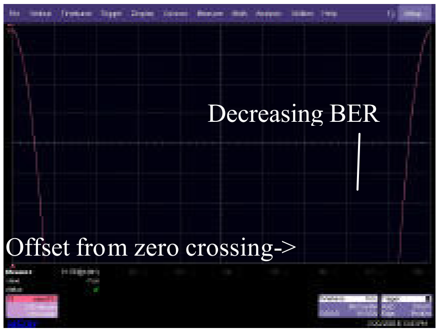
Top: TIE Histogram,
Bottom: Log of TIE Histogram (red) and Extrapolated Tails (blue)

In order to measure events with probabilities on the order of 10^{-12}, a sufficient number of edges must be sampled to determine the likelihood of such an event. It is not practical with any sort of instrument to directly measure the jitter histogram to this level, so the histogram is extrapolated from a smaller set of measurements. The jitter histogram is a complex combination of sources that are bounded (deterministic) and random. Bounded components have a specific range of values that is limited and does not grow with sample size. That is, these bounded components do not grow as they are observed over longer and longer time spans. Random jitter components, on the other hand, are Gaussian in nature and grow without bound as the observation time increases. The goal of extrapolating the jitter histogram is to observe the signal long enough so that the deterministic components are completely characterized and the extremes of the histogram are Gaussian. Once the histogram is measured, the logarithm of the distribution is taken. The Gaussian tails of this curve will have a quadratic shape ($\log(\exp(x^2)) = x^2$). A least squares fit of a quadratic curve is then made to each tail of the log-scaled histogram. The resulting composite curve is the equivalent histogram for a very long observation (up to 10^{16} bits). This histogram represents the complete probability distribution function (PDF) of TIE.

The object of this measurement is to determine the probability of a data transition occurring at a particular time, given that the data is sampled at that time. The PDF of TIE is centered at a zero crossing of the data, and its mean is at the ideal zero crossing. The probability of a data crossing occurring at any time is 1 so the integral of the PDF from negative to positive infinity is 1. Suppose we wish to find the probability of an edge occurring at x ps, or more, to the right of the crossing point. This value can be found by integrating the PDF from infinity to x. This is the probability that an edge will occur at our sampling point if we sample at x. This probability is, of course, also the probability of a bit error occurring if the data is sampled at point x. The concepts of probability of a certain jitter value occurring and bit error rate are directly related. By integrating the PDF of TIE for all values of offset, the CDF (total jitter curve) is created. The total jitter curve is also centered at the zero crossing of the data. The probability of a given jitter value to the right of the crossing is given by the values on the right-hand side of the curve, while probabilities on the left are given by the left-hand side of the curve.



The Bathtub Curve



The data stream consists of a large number of consecutive bits, and the jitter distribution applies to any transition in the data stream. One can look at the left-hand side of the total jitter curve as the probability of an edge occurring before the given transition or, equivalently, as the probability that an edge will occur before the *next* transition. By arranging the total jitter curve in this way, we arrive at the bathtub curve. The bathtub curve offers an excellent way to view the relationship between bit error rate and jitter. The sides of the bathtub give the bit error rate for any given sampling point within a bit interval. The horizontal distance between the curves at a given vertical displacement or bit error rate gives the eye opening at that BER. As long as the sides of the curve do not touch, there is a sampling point at which the desired bit error rate can be achieved.

The total jitter is simply the width of the total jitter curve. Note that the total jitter curve becomes wider as bit error rate becomes lower (Figure 5):

Total Jitter, Rj, and Dj

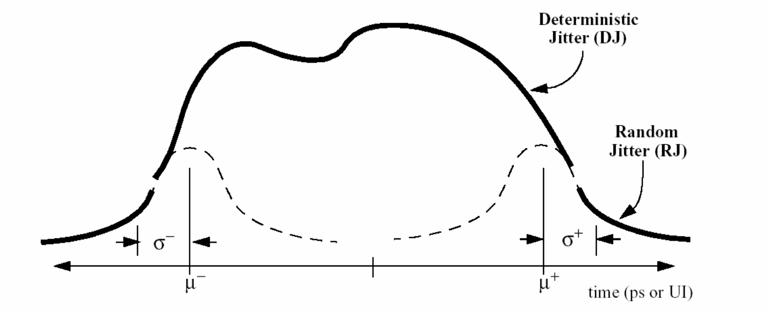


Figure 5. Random and deterministic jitter

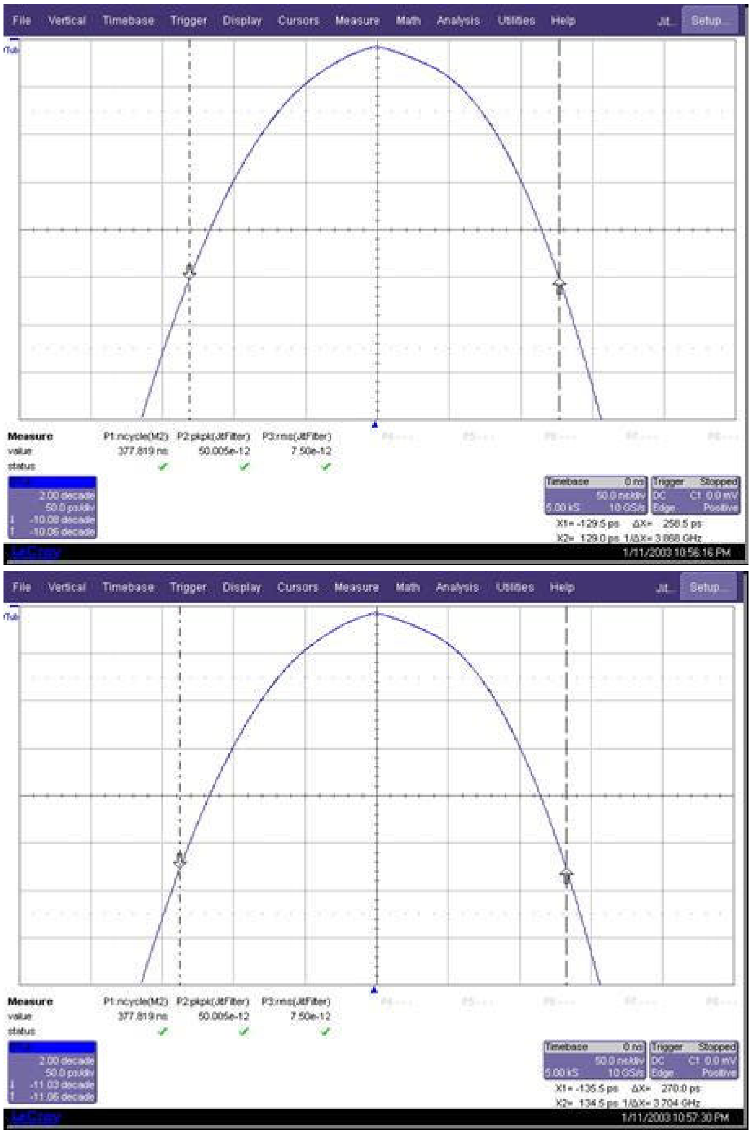
For this reason, the bit error rate must be specified when referring to total jitter. The total jitter is a function of the measured and extrapolated histogram of TIE, and is well understood and can be accurately measured using a number of techniques. The separation of random and deterministic jitter is less well defined, however. There are several techniques employed for separating random and deterministic jitter from total jitter. The SDA uses the effective Dj model defined in the Fibre Channel specification (Figure 5) and is also used in the BERt scan method. Deterministic jitter, as defined in this standard and adopted by other standards that require Dj measurements, is based on the model:

$$T_j = \alpha R_j + D_j$$

The Dj parameter is the separation between the two Gaussian distributions that are used to fit the tails of the histogram. The above equation gives a method for relating total jitter to its random and deterministic components. The total jitter curve gives the total jitter as a function of bit error rate. The width of this curve at any given vertical displacement or bit error rate is the total jitter for that BER. The random jitter is Gaussian in nature, so its distribution is completely defined by the mean and standard deviation. The mean values of the two Gaussians are separated by the value of Dj as defined in the above equation and in Figure 5. The standard deviation is the value Rj, which is assumed to be the same for both tails. The value a is the number of standard deviations from the mean of a Gaussian distribution corresponding to the selected bit error rate or, equivalently, where the probability is less than the BER. The values of α are well known, so finding Rj and Dj is a matter of solving the total jitter equation for these two values. We need a minimum of two Tj values to do this , but we have many available in the total jitter curve. Figure 6 shows an example using two measurements of Tj. We have

$$258.5 = 12.7R_j + DE_j$$
$$270 = 13.4R_j + D_j$$

which gives Rj = 16.43 ps and Dj = 49.86 ps. This computation is performed by the SDA for many values of Tj from bit error rates of 10^{-10} down to 10^{-16}. The average of all the computed Rj and Dj values is the final result displayed on the instrument.



Measure	P1:ncycle(M2)	P2:pkpk(JitFilter)	P3:rms(JitFilter)
value	377.819 ns	50.005e-12	7.50e-12
status	✓	✓	✓

2.00 decade
50.0 ps/div
↓ -10.08 decade
↑ -10.05 decade

Timebase 0 ns
50.0 ns/div
5.00 kS 10 GS/s

Trigger Stopped
DC C1 0.0 mV
Edge Positive

X1= -129.5 ps ΔX= 258.5 ps
X2= 129.0 ps 1/ΔX= 3.868 GHz

1/11/2003 10:56:16 PM

Measure	P1:ncycle(M2)	P2:pkpk(JitFilter)	P3:rms(JitFilter)
value	377.819 ns	50.005e-12	7.50e-12
status	✓	✓	✓

2.00 decade
50.0 ps/div
↓ -11.03 decade
↑ -11.06 decade

Timebase 0 ns
50.0 ns/div
5.00 kS 10 GS/s

Trigger Stopped
DC C1 0.0 mV
Edge Positive

X1= -135.5 ps ΔX= 270.0 ps
X2= 134.5 ps 1/ΔX= 3.704 GHz

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Figure 6.

Components of Dj

Deterministic jitter is caused by a number of systematic effects. Jitter can be periodic so that it appears as a sine save or some other repeating shape. It can also come from data pattern dependent sources. The former is often referred to as periodic jitter (Pj), while the latter is called Data Dependent Jitter (DDj) or Intersymbol Interference (ISI). A third source of deterministic jitter is known as Duty Cycle Distortion (DCD), a measure of the pulse width difference between a logical 1 and 0. There is also a fourth source known as bounded, uncorrelated jitter, which is from other sources not related to the data rate or pattern.

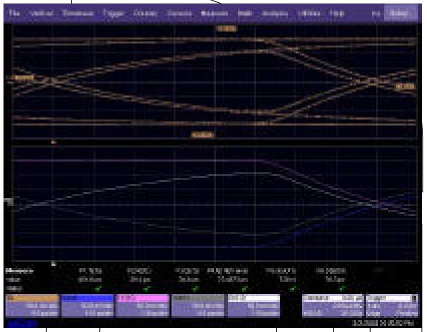
Periodic Jitter

Periodic jitter is the repetitive variation of the data rate (or bit interval) over time. Its sources are often related to instabilities in reference clocks or power supply harmonics. In some cases, the data rate is varied at a specific rate and amplitude in order to spread the clock energy. This is known as spread spectrum clocking. While the SDA reports Dj by analyzing the overall jitter distribution, periodic jitter is measured by looking at the jitter in the frequency domain through the use of an FFT. The Fourier transform is taken of the trend of the time interval error measurements, and the spectrum is evaluated to determine the presence of periodic jitter.

Since the time interval error is measured for each bit transition, the maximum frequency that can be seen in its spectrum is 1/2 the data rate (this is the equivalent of the Nyquist rate). There may be spectral lines at the repetition rate of the data pattern if the data contains a repeating pattern. Spectral components at these points are ignored by the Pj algorithm in the SDA. You must enter the pattern length on the SDA jitter dialog to ensure that the software will recognize the data pattern in the jitter. An adaptive threshold is applied to the spectrum, and the level of all spectral components above this line (except for those at the pattern repetition rate) are added together to compute the total periodic jitter.

Data Dependent Jitter (or ISI)

This type of jitter is the result of differences in the propagation time through the transmission medium among different data patterns. A simple example is a transmission medium that acts as a low-pass filter. To simplify this example, let us assume that the 3 dB cutoff frequency is at the bit rate. A data pattern consisting of repeating 1 and 0 values (1010101….) will have a strong component at the bit rate and, passing through the filter, it will be attenuated and possibly phase shifted as well. Another pattern with fewer transitions (11001100…) will have more energy at a lower frequency, and will have very little attenuation and no phase shift. The lower signal level out of the channel for the first pattern will tend to shift the crossing point, since the position of the slope of the transitions is shifted. Any phase shift will also add to this.



DDj caused by low-pass filter. Note the slow rise time induced by the low-pass filter

The second pattern, of course, is unaffected by the filter and so it propagates through the system without distortion. The time difference between the two crossing points is data dependent jitter.

The SDA measures DDj directly on the acquired waveform and does not use the statistics computed for the Tj measurement. The measurement uses a long acquisition of bits and searches the waveform for patterns of a selected length. This length is variable from 3 to 7 bits. Once a pattern length is selected, the waveform is searched for all combinations of bits in a pattern of that length. For example, if a 5 bit pattern is selected, the waveform is searched for all 32 different bit patterns that the 5 bits can have. The recovered clock gives a timing reference for the bits in the waveform so that we know exactly where to sample the waveform to determine its bit value. The waveform is scanned 5 bits at a time in this example, and the 5-bit window is stepped in one-bit increments for each comparison. The waveforms for bit patterns of the same value are averaged together.

At the completion of the measurement in our 5-bit example, there are 32 averaged 5-bit-long waveforms. The averaging removes all random noise and jitter, as well as periodic components of jitter. These waveforms are overlaid by lining up the first bit and viewing the transition to the last bit. An eye diagram is presented on the display, which is centered around the 4th bit. The DDj parameter displays the width of the zero crossing at the right of this eye pattern.

Duty Cycle Distortion

Duty cycle distortion is a measure of the difference between the pulse width of a 1 level and that of a 0 level. This measurement, like all of the other measurements of Dj components, is measured directly on the captured waveform in the SDA. Duty cycle distortion is measured as the width at the 50% amplitude of the positive-to-negative transitions and the negative-to-positive transitions.

This measurement is unique in that it is always taken at the 50% level while all of the other measurements including time interval error are measured at a user-selected level, which can be set at the true crossing point. For signals with crossing points significantly different from 50%, one can observe high DCD while at the same time measuring little or no deterministic jitter (Dj). This occurs when the crossing point for jitter measurements is set to the data crossing point. This is valid since measuring duty cycle distortion at the crossing point will always give a value of zero. Therefore, it is meaningless to measure DCD at the crossing point.

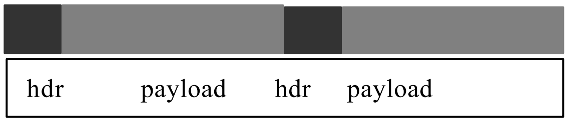
Bit Error Rate

The SDA measures bit error rate directly on the captured bit stream by using the recovered clock to sample the waveform and a user-selectable threshold. The data are assumed to be NRZ, so a high level is interpreted as a ‘1’ and a low level is interpreted as a ‘0.’ The bit stream that is decoded in this process is compared bit-by-bit with a userdefined known pattern. Since the instrument does not have any information as to which bit in the pattern it has received, a searching algorithm is used to shift the known pattern along the received data until a match is found.

A match is determined when more than half of the bits are correct for a given shift of the known pattern. No match can be found if the bit error rate is over 50% or if the wrong pattern is selected. In this case, the bit error rate will indicate 0.5, meaning that exactly 1/2 of the bits are in error, which, of course, is the worst case.

Bit Error Map

A further level of debugging is available through the bit error map. This display is a view of the bit errors in the data stream relative to any framing that may be present in the signal. There are several options for framing that may be set. The general form of the data signal is shown below.



The header portion is a fixed pattern that can be set to any pattern. The header must be one or more bytes if it is present. The software searches for the header if present and treats the bits between headers as a frame. Each frame is displayed as a line of pixels in an x-y map, and each successive frame is displayed below the previous one in a raster fashion. Bit errors are computed only on the payload sections of the hdr payload hdr payload data stream. Framing can also be defined by a specific number of bits without a header.

An example of this is a pseudorandom bit sequence (PRBS) of a specific length, 127 bits for example. In this case, setting the frame size to 127 will display one repetition of this sequence per line of the error map. Bit errors are displayed as a lighter color whereas non-errored bits are shown in a dark blue color. By displaying bit errors on a frame by frame basis, pattern dependent errors can be clearly seen as lightly colored vertical lines in the error map. Refer to Figure 7 and Figure 8.

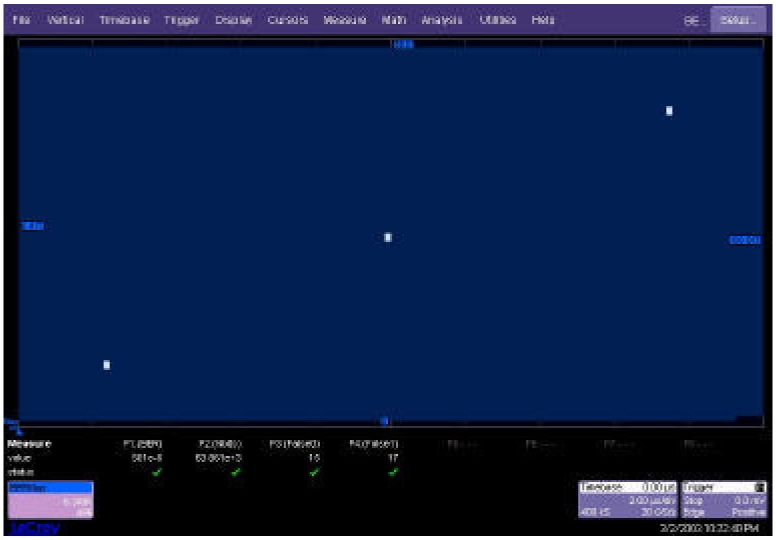


Figure 7. Bit Error Map for 127-bit Pattern Containing Random Errors (White Squares)

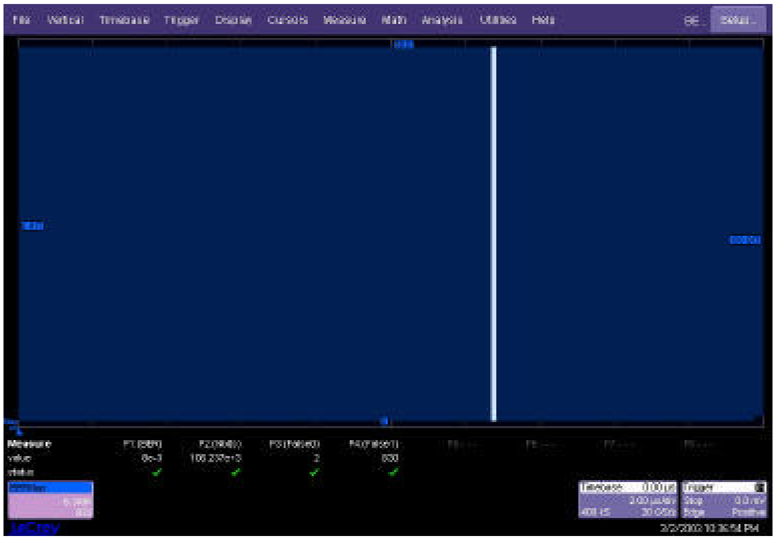


Figure 8. Bit Error Map for 127 Bit Pattern Containing Pattern Dependent Errors

Operator’s Reference

Main SDA Dialog

Enter the main SDA setup dialog by selecting **Serial Data** from the Analysis menu or by pressing the SERIAL DATA button on the SDA front panel. You can also access this dialog by touching any descriptor label associated with an SDA measurement.

Data Source: C1
☑ Recover clock from data
Clock Source: C1
Signal Type: XAUI
Signal Frequency: 3.125000000 GHz
Signal Mode: driver far
Cutoff Divisor: 1667
PLL Frequency: 1.874625 MHz
☑ PLL On

SCOPE

This button enters the scope mode; that is, it disables all SDA measurements. Any waveforms that were shut off when the SDA mode was entered will be redisplayed upon pressing the scope button.

MASK TEST

Displays the eye pattern of the signal under test along with any selected mask. The dialog changes to the Mask Test dialog. Any selected mask measurements will also be displayed as parameters below the waveform grid.

JITTER

Enters the jitter test mode and displays the Jitter dialog. Selected jitter measurements may also appear below the grid.

BER

Displays the bit error test screen and dialog.

CLOCK

Enables you to designate an input to be an actual clock, as opposed to a serial data stream. This mode of operation produces a bathtub curve, TIE histogram, and key clock parameter measurements Tj, Rj, and Dj.

SUMMARY

Displays the summary screen, which includes eye pattern, jitter bathtub, jitter histogram, and amplitude histogram along with Tj, Rj, Dj and rise/fall time.

Data Source

This control lets you define the signal to be tested. The signal can be any channel or math trace. For example, when testing differential signals , it is often desired to measure the true differential crossing point. This can be done by forming a math trace that is one channel minus another.

Clock Source

This channel is processed by the software clock recovery algorithm in the SDA to provide the reference clock for all measurements. This can be the same as the data channel or a separate signal.

Signal Frequency

The signal frequency (bit rate) is the symbol transmission rate of the signal under test. This value is set by the selected signal type, or you can manually set it to any value when **Custom** is selected as the standard. The value in this control represents the start frequency for the software clock recovery. If it is significantly different from the actual data rate, the recovered clock may not converge.

Find Frequency

Find frequency measures the average bit rate across the entire acquired waveform. This control can be used to adjust the initial estimate of the PLL frequency for signals that are not operating exactly at the specified bit rate. It is also a useful way to use standard masks with non-standard bit rates.

PLL Cutoff Divisor

This sets the PLL loop bandwidth as a ratio of the bit rate. The default value is 1667, which is the standard value for the so-called "Golden PLL," as defined in the Fibre Channel standard. This value is variable from 20 to 10,000 to allow other loop bandwidths to be used.

PLL Frequency

This control displays the cutoff frequency of the PLL. It is locked to the PLL cutoff divisor, and changes along with that value. You can select either the frequency or the divisor.

PLL On

The **PLL On** checkbox allows measurements to be made without the PLL being engaged. When this box is left unchecked, the average data rate is used for all timing measurements.

Mask Test

The Mask Test dialog controls eye pattern tests with the SDA. From this dialog, you can select measurements and parameters for performing eye pattern tests.

Eye Mode

Eye mode sets the method used for creating the eye pattern. The two choices are **Traditional** and **Sequential.** Traditional mode uses an external clock to position the waveform samples on the display in the same way that an oscilloscope uses external triggering to build an eye pattern. Sequential mode uses the software clock recovery to divide the waveform into bit sized samples to create the eye pattern. This is described in more detail in the preceding Theory section. The clock for either mode is the channel selected in the **Clock Source** control in the SDA main dialog.

Eye Persistence

Persistence can be viewed in color-graded or gray scale mode. The color-graded scale shows less frequent occurrences in blue and more frequent ones in white. The monochrome setting shows the frequency of occurrence in the degrees of intensity.

User Signal

This can be any channel or math function in the instrument. The selected channel is captured synchronously with the signal under test, selected in the **Data Source** control in the main dialog. This signal is displayed in the mask violation locator screen, using the same time scale as the waveform displaying the mask violations. The correlated view allows diagnosis of mask failures caused by interfering signals.

Mask Margins

These controls allow you to increase the size of the “illegal” areas of the mask by the specified percentage, in either the X or Y dimension. Mask margins allow testing of signals to tighter standards, and the separate x and y controls enable independent specification of jitter and noise margins.

Vertical Auto Fit

Checking this box causes the instrument to scale the eye pattern to fit the mask in the vertical dimension by centering the mean 1 and 0 values between the respective mask polygons. Auto fit is available for all signal types; however, it is unchecked by default for those masks that are defined as absolute. Absolute masks are defined in terms of voltage on the vertical axis and the absolute value of the waveform amplitude. Checking this box, when using absolute masks, will result in measurements that are invalid for the given standard. There are cases when the mask may seem to disappear in the case of waveforms that are grossly offset from the specified value. This is normal operation, since absolute masks are positioned by their voltage values.

Clock Setup

The software clock recovery system in the SDA operates by detecting threshold crossings. The threshold type control allows you to set this threshold as either absolute (in volts) or relative (as a percentage of the p-p signal). The slope control determines the slope of the first zero crossing that is used for clock recovery. If **Positive** is selected, clock recovery begins with the first rising edge in the data, while **Negative** slope will start with the first falling edge. The **Percent Level** control is used to set either the absolute or percentage level of the threshold.

Testing

Checking this box enables mask testing. Testing is performed on each bit in the waveform. Violations are indicated by red circles in the eye pattern display.