

Automatic Measurement Algorithms and Methods for High-Performance Communications Applications



The Tektronix CSA/TDS8000 Series of Sampling Oscilloscopes¹ incorporates fast waveform acquisition and display update rates for collecting large amounts of data several times faster than previous generations of instruments.

An extensive library of built-in automatic measurements for high-performance communications applications makes them ideal tools for the design, evaluation and manufacturing test of datacom and telecom components, transceiver subassemblies, and transmission systems.

This application note contains detailed information on CSA/TDS8000 Series algorithms and describes their use to generate and perform automatic measurements, emphasizing the analysis of multivalued data in eye diagrams. The complete library of measurements and their equations is presented in the Appendix.

Getting Started - Considerations for Data Acquisition

Calibration

The first requirement of a successful measurement is calibration. With the CSA/TDS8000 Series, calibration consists of running the *Utility/Compensation* and *Dark Level Compensation* routines, as appropriate.

- **Compensation** (*Utility/Compensation/Compensate/Execute*) should be run after every temperature change and hardware change (including extender cable changes). This routine includes a full *Dark Level Compensation*. In most cases, it is also advisable to save the result for the next power-up (*Utility/Compensation/Save/Execute*).

¹ CSA8000/CSA8000B Communications Signal Analyzer and the TDS8000/TDS8000B Digital Sampling Oscilloscope.

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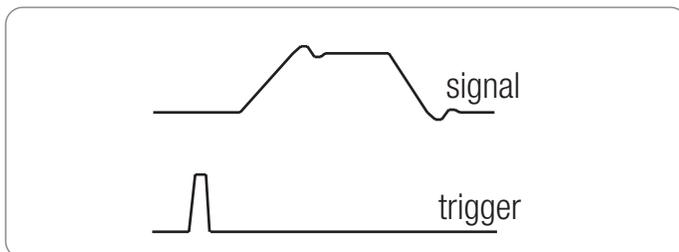
– **Dark Level Compensation** must be run every time the instrument's temperature changes. For sensitive measurements, the *Dark Level Compensation* should be run whenever the settings of the instrument are significantly changed. This is critical for higher values of *Extinction Ratio* (cca over 10). For the most accurate results, the *Dark Level Compensation* should be run with horizontal SCALE (time/div) and vertical SCALE ($\mu\text{W}/\text{div}$) set to the same ranges at which the measurements will be performed. Alternately, the signal level can be monitored when no light is connected, and the *Compensation* run only when the offset level exceeds a desired limit.

Deterministic and Random Signals

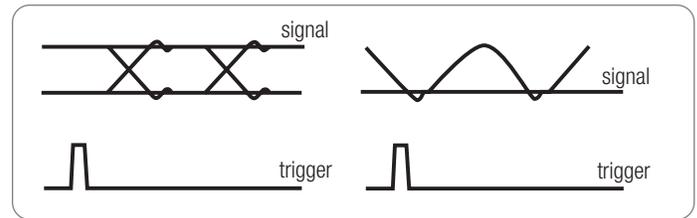
With the CSA/TDS8000 Series, users specify the type of data being measured via the *Signal Type* control in the *Source* tab of the *Measurement* setup dialog. The choices are: **Pulse**² for deterministic signals, **NRZ**³ for NRZ (random) signals, or **RZ**⁴ for RZ (random) signals. The *Signal Type* control is linked to each measurement, so users can independently measure the same or different signals using different algorithms, as appropriate – a great advantage when defining unusual or new measurements.

The CSA/TDS8000 Series acquires data using sequential equivalent time sampling. For a stable display of waveform data, one of two conditions must be satisfied:

1. In the Pulse mode, acquired signals must be deterministic (repetitive) and the instrument should be triggered on a signal synchronous to the input signal (Figure 1).



► **Figure 1.** A deterministic signal.



► **Figure 2.** Random signals – NRZ eye (left), RZ eye (right).

Or,

2. In the NRZ or RZ mode, acquired random signals must have a fixed clock rate and the instrument should be triggered on a signal that is synchronous to that rate (Figure 2).

Measurement algorithms for deterministic waveforms are straightforward and applicable to a single acquisition record. Users simply examine the acquired data sequentially and compute changes in amplitude to locate rising and falling edges of the signal. Since the data is acquired synchronously it is reasonable to use interpolation between adjacent acquired points to estimate the behavior of the signal between those points.

In contrast, sampling of NRZ and RZ signals produces eye diagrams with multiple values per vertical column. Since the consecutive samples are taken from unrelated data bits of unknown value, they cannot be interpolated. Measurement algorithms on such data are more complicated because the data is multi-valued and the algorithms operate on sets of two-dimensional data.

Waveform Databases

As with other oscilloscopes, the CSA/TDS8000 Series *Pulse* mode derives a standard amplitude-time vector (waveform) record of an acquired signal that is used to make standard measurements on deterministic data (e.g., *Peak-to-Peak*, *Rise Time*) and to generate standard displays such as vectors (interpolations between samples) and variable persistence.

² A single-valued waveform.

³ Non Return to Zero; such as OC48.

⁴ Return to Zero; as in some 40 Gb/s systems.

▶ **Table 1. Guidelines for Use of Waveform Databases (*Wfm Databases*)**

Type of Signal(s)	Measurement/Algorithm	Display Type/Length	Use of <i>Wfm Database</i>
Any	Any	Color or Gray Scale	Required
Random	RZ, NRZ statistical tools	Any	Required
Random	Simple Eye diagram, Mask	Normal or Persistence	Optional
Random	Simple Eye diagram, Mask	>400 rows of vertical range	Optional
Pulse with noise, jitter, drift	Statistical operations	Any	Recommended
Pulse	Average or Envelope acquisitions	Any	Optional
Any	Histograms	Any	Recommended

The standard *Waveform* mode is not appropriate for random signals with their multiple values at each horizontal position. To determine levels of random NRZ or RZ signals for an eye diagram analysis, the CSA/TDS8000 Series digitizes (samples) the signal and stores it in a *Waveform (Wfm) Database*. The *Wfm Database* creates an accumulation of many overlaid waveforms, acquired over multiple frames or packets. In addition to standard amplitude and timing information, the database contains a third dimension of count that represents the number of times a specific amplitude-time point has been encountered in the input waveforms.

Most RZ and NRZ eye diagram statistical tools and algorithms require the *Wfm Database*. Because it holds the data indefinitely (infinite persistence), it can also be useful for the analysis of single-valued signals that exhibit modal distributions, noise or jitter, and for envelope or average acquisition modes (see Table 1). Another advantage of the database is that measurements can be performed at any time, even after the acquisition is finished.

The CSA/TDS8000 Series incorporates two *Wfm Databases* that capture data from the output of the optical or electrical sampling modules. They can also be used to store the waveform results of math operations, allowing the CSA/TDS8000 Series to perform complex measurements, such as differential eye diagrams, which adds flexibility and power to the instrument for custom operations.

Another feature of the *Wfm Database* is that it can capture a signal from any vertical window (*Main*, *Mag1* or *Mag2*) allowing users to “zoom in” on areas of interest. While the signal windows can be vertically sized, the underlying database always retains its 400 row by 500-pixel resolution – it is not affected by the height of the display window.

Guidelines for the Use of the Waveform Database

While the *Wfm Database* mode in the CSA/TDS8000 Series offers many advantages over the *Waveform* mode, there are some situations where it should not be used. Here are some guidelines.

Each *Wfm Database* is 500 columns long and 400 rows high. If a waveform longer than 500 samples is to be stored in the database, the data will be binned into the 500 columns. Therefore, deterministic signals may be more effectively handled in *Waveform* mode with a horizontal capacity of 4,000 samples rather than stored in the *Wfm Database* with 500-point horizontal resolution. Similarly, waveforms that need vertical resolution greater than 400 rows should be acquired in the *Waveform* mode to avoid clipping or loss of significant bits.

The *Wfm Database* is required for a number of statistical operations and gradated displays and is strongly recommended for a few others. Table 1 lists some guidelines.

Acquisition Speed in the Database Mode

Advanced hardware resources in the CSA/TDS8000 Series – dedicated DSP per module, PowerPC acquisition processor, and Pentium processor for the UI and math operations – eliminate potential restrictions in data throughput in the *Wfm Database* mode. The high acquisition speed is independent of the number of channels, measurements and databases that are in use. In cases where the instrument is acquiring a very large amount of data (many thousands of waveforms), peak performance can be maintained by simply turning off the measurements and gray scaling until the acquisition is finished.

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Using Automatic Measurements and Algorithms

The CSA/TDS8000 Series Sampling Oscilloscopes provide more than one hundred automatic measurements, reflecting the algorithm differences required by different signals and conditions. These measurements, along with control over all of the parameters associated with them, allow users to quickly analyze the device under test to verify performance or identify and correct design and/or manufacturing flaws. The extensive math capabilities of the CSA/TDS8000 Series allow new measurements to be created from combinations of built-in algorithms, if a standard function is not available for that task.

Measurements can be divided into three categories based on the signal types: *Pulse*, *NRZ* and *RZ*. Within each signal category, the measurements are organized into amplitude, timing and area operations. The algorithms for the *Pulse* measurements rely on the deterministic single-valued nature of the signal. Measurements of *RZ* and *NRZ* signals not only quantify multiple values, but also process those values according to where they occur in the UI.

Measurement settings are independent from the rest, so it is possible to simultaneously make separate *RZ*, *NRZ* and *Pulse* measurements with the CSA/TDS8000 Series.

RZ Versus NRZ Eye Diagrams

The *RZ* eye diagram differs from the *NRZ* eye diagram in several important ways:

- In *NRZ*, the left boundary of one bit is also the right boundary of the next, so the timing characteristics (such as jitter) only need to be measured at one point. In *RZ*, the left and right boundaries of each bit are independent, and their characteristics must be measured separately.
- The waveform trajectory of the *RZ* signal is fundamentally different from the *NRZ* signal. The *RZ* 1-1 pattern originates at the *High* level, transitions towards the *Low* without resting on it and ends back at the *High*. The performance of the *High* towards *Low* transitions in this pattern is not directly measured by any of the existing *NRZ* algorithms.
- The *High* level of an *RZ* signal responds differently than the *Low* to step/frequency response distortions, requiring different measurements at each level. In *NRZ* signals, the *High* and *Low* pulses are essentially the same – the whole signal could even be inverted about the crossing level without impacting the measurement algorithms.

- *RZ* signals have no eye crossing points to define a convenient reference for measurements (as there are in *NRZ*). *RZ* vertical references must be defined relative to the bottom and top levels, where the top level is very dependent on the reference filter (the measurement bandwidth).
- The default *RZ* eye aperture is only 5 percent, versus 20 percent in *NRZ*. Fundamental measurements require four times as many samples to retain the same statistical significance.

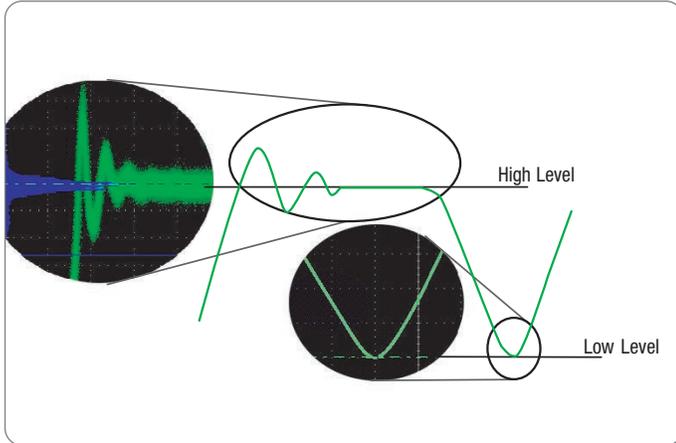
References used by Amplitude (Vertical) Measurements

Low and High Levels

The *Low* and *High* levels are the basic values with which almost all other automatic measurements are built, so the algorithms used to determine them are critical. The *Low* level is the vertical amplitude at the bottom of the signal. For a pulse example, in a perfect rising step waveform, the level in front of the pulse would be the *Low* level and a 10 percent point on the rising edge would be referenced to the *Low* level at zero percent. Similarly the *High* level is the amplitude from which levels are referenced to the top of the signal. In the example of the up-going step, the level after the pulse reaches the top is the *High* level. The *High* level would be the 100 percent reference for a 90 percent point on the rising edge.

The best method for establishing the *Low* and *High* levels depends on the shape of the signal and the effects of aberrations and noise. In order to simplify the measurement task, the CSA/TDS8000 Series automatically selects an appropriate mode for *Low* and *High* level determinations. Depending on the type of waveform being measured, the instrument will use one of three methods for determining these levels.

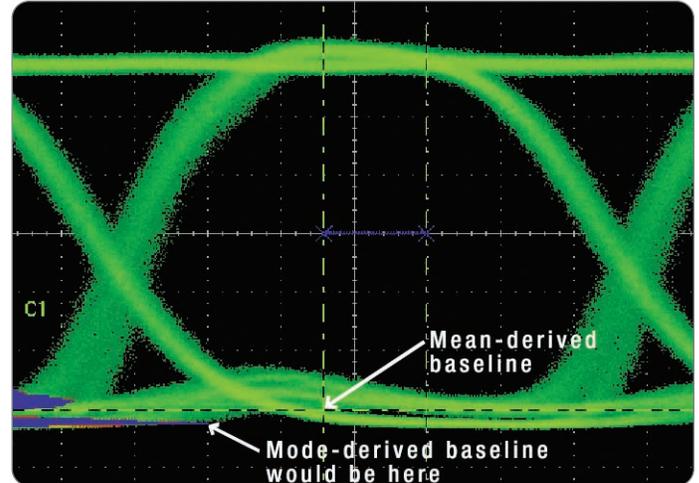
1. **Mode method** – The instrument will select the most common value either above or below the midpoint (depending on whether it is determining the *High* or *Low* level). Histograms of the acquired waveforms are taken to derive the value. Since this statistical approach ignores short-term aberrations (such as overshoot and ringing), *Mode* is the best method for examining pulse waveforms. The upper part of Figure 3 illustrates a *Mode* derivation and shows a histogram of the *High* level.



▶ **Figure 3.** Pulse signal, reference levels.

2. **Min-Max method** – *Min-Max* extracts the highest and lowest values of the waveform record as its *High* and *Low* values. This method is the best for waveforms that have no long flat portions at a common value. Signals of this type include almost any deterministic waveform that is not a pulse, such as sine and triangle shapes. See the bottom of Figure 3.
3. **Mean method** – The instrument uses histograms of the acquired waveform to derive the reference level as the mean of the pertinent part of the waveform. The Mean is particularly useful for eye patterns that exhibit multi-modal distributions in the High level and/or Low level. Figure 4 illustrates this type of signal and shows a histogram of the Low level.

Multi-modal distributions on the *High* level and *Low* level of an eye pattern are indicative of pattern-dependent effects such as inter-symbol interference. Pattern-dependent effects are typically not an issue at low data rates because the bit-times allow the signal to settle to a nominal logic One or Zero value prior to the next data transition. As data rates increase, the amount of settling time between data transitions decreases and the signal may not have sufficient time to settle to its nominal values. In order to robustly handle pattern dependent effects in eye patterns, the CSA/TDS8000 Series Sampling Oscilloscope can use the *Mean* method to determine the *High* and *Low* values.



▶ **Figure 4.** Eye Pattern with bi-modal High level and Low level.

Note that the histogram used to determine the *High* and *Low* values for the *Mean* method has been limited to the central 20 percent of the NRZ eye pattern, and the central 5 percent for the RZ eye patterns (their eye apertures). These definitions are contained in existing NRZ, SONET and SDH standards and/or are expected to be adopted in new RZ; 40 Gb/s recommendations. The CSA/TDS8000 Series allows users to set the width of the eye aperture on a per-measurement basis.

The default setting on the CSA/TDS8000 Series for determining *High* and *Low* level is *Auto*. For random waveforms (such as RZ and NRZ eye patterns), *Auto* selects the *Mean* method. For deterministic waveforms, the instrument will first attempt to use the *Mode* method; but if it determines that the signal has no large flat portion on the *High* level or *Low* level it will automatically switch to the *Min/Max* method. If desired, users can override the automatic process by manually selecting a method in the *High/Low* tab of the *Measurement* setup dialog. As with other measurement parameters, the *High* level/*Low* level determination method is set per measurement.

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References Used by Timing (Horizontal) Measurements

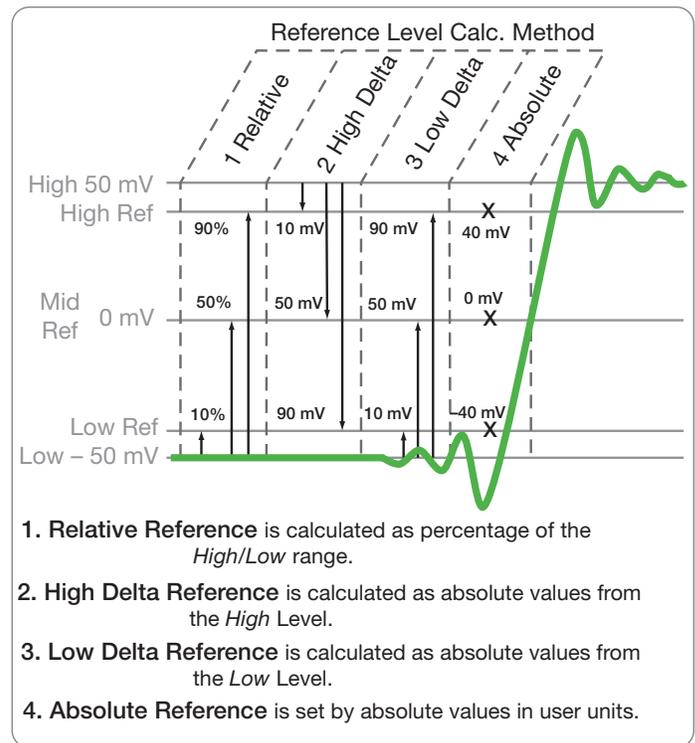
A second set of parameters affects the horizontal time-related measurements. These timing parameters are derived at three amplitude reference levels – *HighRef*, *MidRef*, and *LowRef*. These levels specify the amplitudes at which the “endpoints” of timing measurements are defined.

For example, rise time is defined as the time it takes for the signal to transition from the *LowRef* to the *HighRef* value. Depending on the device that is evaluated, users could specify rise time as the time it takes the signal to transition from 10 percent to 90 percent of its amplitude. Another can choose to define rise times from 20 to 80 percent of the signal’s amplitude. A third situation may require rise time measurements in terms of the time it takes for the signal to transition between two fixed levels (for example, 20 mV and 150 mV). The CSA/TDS8000 Series, with its flexible reference level calculation methods, supports any or all of these measurement requirements, all at the same time.

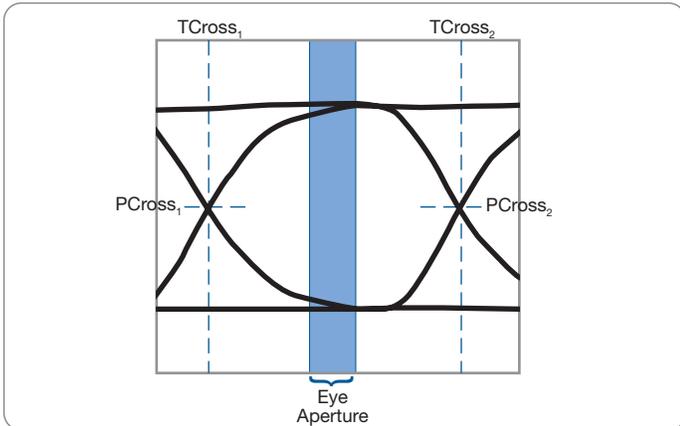
CSA/TDS8000 Series Sampling Oscilloscopes provide four choices of calculation method for establishing the amplitude reference levels at which the timing parameters are measured (see Figure 5):

1. **Relative** reference levels are calculated as a percentage of the *High/Low* range. (This is the default reference level calculation method with values of 10, 50 and 90 percent for *LowRef*, *MidRef*, and *HighRef*, respectively.)
2. **High Delta** reference levels are calculated as amplitude values from the *High* level.
3. **Low Delta** reference levels are calculated as amplitude values from the *Low* level.
4. **Absolute** reference levels are set as absolute amplitude values.

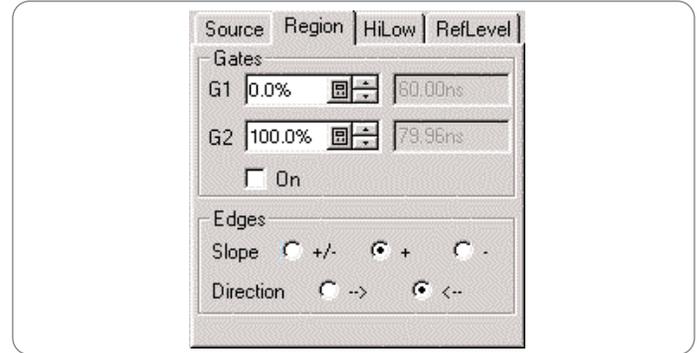
As with *High* level and *Low* level determination methods, *Amplitude* reference levels can be set per measurement. (See the *Ref Level* tab of the *Measurement* setup dialog.)



► **Figure 5.** *HighRef*, *MidRef*, and *LowRef* calculation methods.



▶ **Figure 6.** Eye crossing reference levels for NRZ signal.



▶ **Figure 8.** The Region menu.

Unique Timing Reference for NRZ Signals

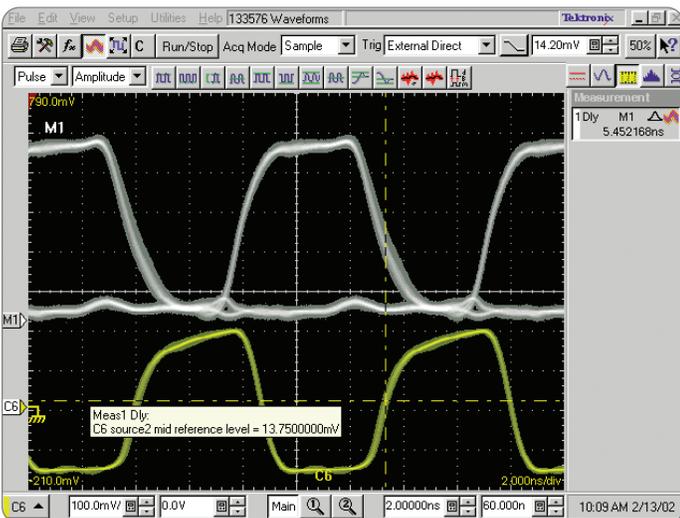
NRZ signals contain a unique reference point – the eye crossing (Figure 6). Since the eye crossing is a stable point in an NRZ waveform, many measurements use it instead of the *Mid Ref* described above.

Localizing the Measurement

Frequently, the characteristics we are seeking require that we specify a portion of the signal to be used by the automated measurements – a process known as “localizing.” This could mean a particular edge, a preset delay before the measurement is taken or a selection of the *High* or the *Low* level in an eye diagram. The CSA/TDS8000 Series offer several ways to localize the measurement, depending on the exact situation.

Region Controls

The waveform in Figure 7 shows an RZ clock signal and a portion of its associated data stream. Also shown is an automatic *Delay* measurement quantifying the time between the first rising edge of data and the last positive transition of the clock. The menu (Figure 8) shows the selections of the parameters in the context-sensitive *Region* menu of the *Measurements* setup.



▶ **Figure 7.** Measuring Delay time from the first positive edge of the data to the last positive edge of the clock.

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Figure 7 also demonstrates some of the customization and annotation features offered in the CSA/TDS8000 Series. The *Source2* waveform is labeled with an annotation cursor that pops up a description of the cursor and its value when the mouse pointer is placed over the cursor line. For this measurement, *Source2* is set to be the positive-going direction when searching from right-to-left. One of the waveforms is an RZ signal and the other is a pulse train, so *Source1* is set to *RZ* and *Source2* to *Pulse* (see Figure 9).

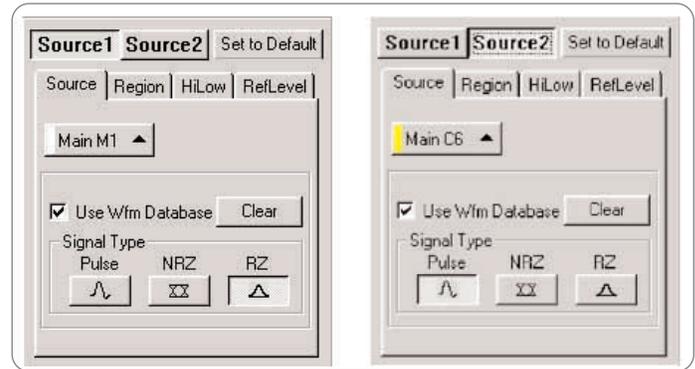
Controls in the *Region* tab of the *Measurement* setup dialog allow you to specify the following measurement localization parameters:

- For *Delay* measurements – the *Direction* (forward or reverse) looks for crossings from the measurement gates
- For RZ eye pattern measurements – the percentage of the eye (the **eye aperture**) to be used in determining *High* and *Low* values as well as *Eye Height*, *Extinction Ratios* and *Q Factor*
- For *Noise* measurements on eye diagrams – whether to measure noise on the *High* level or *Low* level
- For *Jitter* measurements on eye diagrams – whether to measure jitter at the eye crossing (for NRZ signals) or the *MidRef* reference level; and, for RZ eye diagrams, which slope to measure

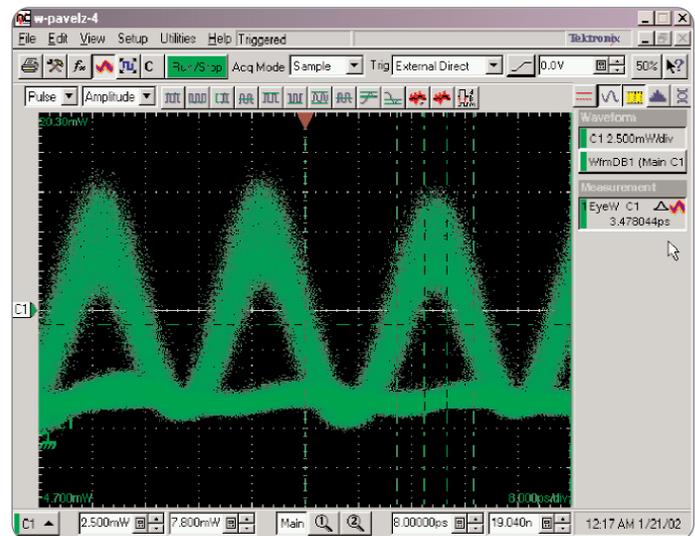
Gating

Cursor Gating is a tool that allows users to specify a portion of a waveform to be used for automated measurements. This feature is common on modern oscilloscopes, but the CSA/TDS8000 Series goes a step further by allowing different gating for each waveform and each source (when there is more than one source, such as in *Delay* measurements).

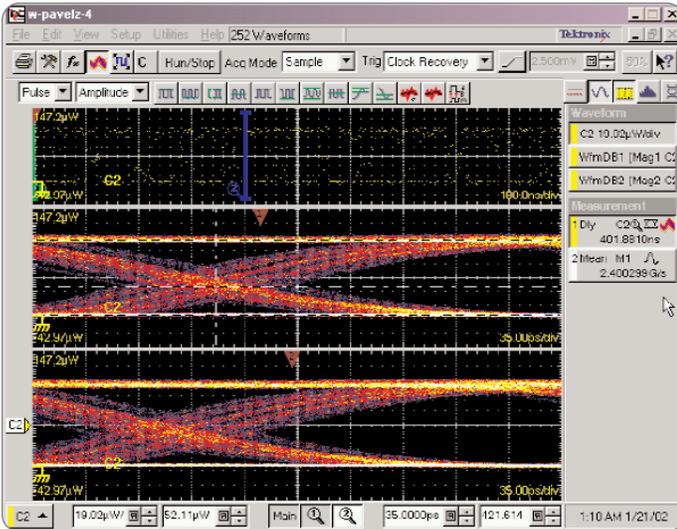
Figure 10 shows an example of measuring the eye width of just one of the eyes displayed on an RZ eye pattern. The CSA/TDS8000 Series Sampling Oscilloscope uses *Gating* to set cursors at 50 percent (middle of the screen) and 100 percent (right edge of the screen) to extract the area of the third pulse of the RZ train. The levels and timing intervals found within the area are displayed as annotations.



► **Figure 9.** Two sources, two signal types for *Delay* measurement.



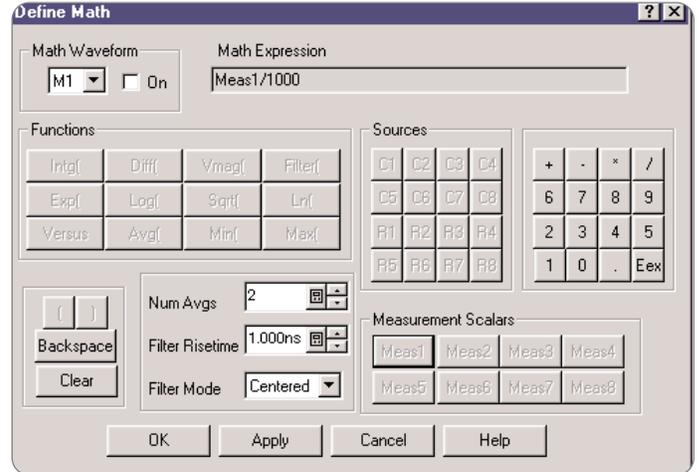
► **Figure 10.** Measuring *Eye width* in an RZ pulse train.



► **Figure 11.** Measuring Delay time of 1000 eye crossings on an OC48 signal.

Magnifier Windows

Magnifier windows allow higher resolution when measuring features of signals that are far apart. In Figure 11, the main timebase spans several thousands of unit intervals of an OC48 communication signal, so selecting just one cycle with cursor gating would not be feasible. Instead, window *Mag1* is opened and zooms in on one of the first eye crossings. An eye crossing 1000 eyes later is captured in window *Mag2*. The delay over 1000 crossings (*Measurement 1*) was divided by 1000 in order to more accurately express the time between two adjacent eye crossings. The result is shown in the *Measurement 1* readout as 401.8810 ns.



► **Figure 12.** Custom Delay measurement.

Figure 12 is a screenshot of the appropriate math expression. The resulting waveform (a flat line at the resulting amplitude) was measured using *Measurement 2* to display the calculated result (Figure 11). The result of this measurement has also been processed by the built-in math system and converted to frequency; yielding the bit rate of 2.488299 Gb/s in *Measurement 2*.

The zoom in the CSA/TDS8000 Series is an acquisition zoom – each window is acquired separately, with its own optimized sample interval. The accuracy of this measurement is ensured by the stability of the *Long Timebase*, which is 100 ppm. If higher accuracy is needed, the instrument can be locked to an even more stable external frequency reference.

Custom Measurements

As demonstrated in the previous section, the measurement system of a CSA/TDS8000 Series supports custom mathematical operations and ways to export data. New or custom measurements can typically be calculated from the measurements supplied by the built-in measurement system.

Optical Modulation Amplitude (*OMA*) is a good example of an emerging new measurement. IEEE 802.3ae is in the process of adopting *OMA* as one of the more important parameters of the optical transmission for 10 Gigabit Ethernet. *OMA* describes the absolute difference between the optical power at the logic One level and the optical power at the logic Zero level, as measured on a specific pattern (e.g., 00001111) in a 20 percent aperture. The utility of this measurement is similar to that of *Extinction Ratio* and *Average Optical Power* folded in one.

If *OMA* is not available as a standard function in an instrument's measurement library, custom math operations can be used to calculate the parameter. The calculations are based on the test method that is selected.

In IEEE 802.3ae, the standard method of measuring *OMA* is to generate and capture a slow square wave test signal. The test uses pulse measurements (not an eye diagram) to calculate the *Mean* of the high area and the *Mean* of the low area. The high and low areas are defined with gating to be 20 percent apertures. Then, the math system calculates

$$OMA_{dB} = 10 \log((mean_{High} - mean_{Low})/1 \text{ mW})$$

If the math system produces this result as a waveform, the single value parameter can be obtained by simply measuring the *Mean* of that waveform.

The standard also presents an "alternative method" for measuring *OMA* on a real data stream (rather than on the defined square wave pattern). However, this method requires an unusual measurement setup and a low noise level that may not be available in a live environment.

There is another method for estimating *OMA* on live data that will serve very well for information purposes (compliance-verification would still require the standard method). The estimated "*OMA* Calculated" (*OMAC*) method uses the familiar *Amplitude* measurement from the eye diagram.

Here is an example of the equation for *OMAC* with the result conveniently expressed in dBm:

$$OMAC_{dB} = 10 \log\left(\frac{Amplitude}{1 \text{ mW}} \cdot Cf\right) \dots (dBm ; mW)$$

Depending on the shape of the live waveform in the eye aperture, *OMAC* will probably require a correction to compare with the standard square-wave method. Under controlled conditions, the correction factor, *Cf*, is derived by measuring *OMA* in the standard way, with the transmitter in the square-wave mode, then switching the transmitter to live data for the *OMAC* measurement. The difference in the measurements is the correction factor that can be used to relate the *OMAC* result to the square-wave *OMA* measurement. Typically, one correction factor will suffice for each type of laser transmitter.

While *OMAC* is a simple calculation, it is a good example of the flexibility that custom math functions provide in an oscilloscope or signal analyzer. The ability to define new measurements is especially important when developing products for standards such as RZ signaling.

Need Help with Custom Measurements?

A troubleshooting procedure for the design and use of measurements in the CSA8000 is offered in the CSA8000 FAQ file, at <http://www.tektronix.com/Measurement/Support/scopes/faq/tdscsa8000>.

Summary

The measurements of high speed signals range from simple to very complex. The Tektronix CSA/TDS8000 Series of Sampling Oscilloscopes meet the measurement challenges with instruments that are capable of performing simple tasks with ease and still offer access to the detailed algorithms and methods for full customization. Extensive libraries of built-in automatic measurements for high-performance communications applications make them ideal tools for the design, evaluation and manufacturing test of winning products for the demanding markets of today and tomorrow.

For additional information, consult the following (available at www.tektronix.com):

1. *CSA8000B & TDS8000B User Manual*; offers detailed instructions on how to set up a particular measurement.
2. *CSA8000B/TDS8000B Online Help* (available on the instrument itself); offers detailed instructions on how to set up a particular measurement.
3. Users of the CSA8000 (non-B) and TDS8000 (non-B) can use the above documents for software feature comments, as long as their firmware has been updated to V1.3.x or higher; however, hardware performance numbers are slightly different .
4. Application notes and Technical Briefs, in particular the RZ measurements brief.

Appendix: Automatic Measurement Definitions

This reference lists a definition for each automatic measurement type organized in three groups according to the type of signal being measured: Pulse, RZ, and NRZ measurements. Within each group, measurements are listed in three categories – Amplitude (Vertical), Timing (Horizontal) and Area.

Definitions

- **Measurement region** – area of the waveform measured, in the largest sense. This can be the whole window, or limited explicitly by measurement *Gates*. Some measurements further define smaller (sub-) regions – e.g., an eye aperture, or the sliver in which the *RMS Noise* is measured.
- **Samples within region** – This reference identifies multi-valued data by defining a set, or a population of samples within a region of the eye diagram in **boldface**. For example, in the histogram shown for the set, the vertical position of an individual sample is named *VertPos(s)*, and the total population of vertical positions is denoted by *VertPos(s)*. For this discussion, every hit in the database counts as a sample.
- **VertPos(s)** ≡ (set of N) values of measurements of vertical positions of the N samples $s_{1...N}$ from set *s* in a region.
- **HorPos(s)** ≡ (set of N) values of measurements of horizontal positions of the N samples $s_{1...N}$ from set *s* in a region.
- **Histogram (histogr)** of a set of values is a vector of bins containing the number of occurrence of the values. e.g., *histogr(HorPos(s))* is a vector which when plotted shows the horizontal histogram of the samples *s*.
- **Database vs. non-database measurements:** The descriptions given are focused on Waveform Database (*Wfm Database*) measurements. The measurements are valid for vector (Pulse) operations, but the sample sets will usually contain only one, possibly interpolated sample in non-database measurements.
- **Mean (mean)** for a set *s* of N samples $s_{1...N}$ in a region

$$\text{mean}(\mathbf{s}) \equiv \mu = \frac{1}{N} \sum_{i=1}^N s_i$$

- **Standard deviation (stdev)** for a set *s* of N samples $s_{1...N}$ in a region

$$\text{stdev}(\mathbf{s}) \equiv \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (s_i - \text{mean}(\mathbf{s}))^2}$$

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Pulse Measurements

Pulse Measurements - Amplitude

Name	Definition
 AC RMS	$AC\ RMS = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n) - mean(VertPos(s)))^2}{N}}$ Where s is the set of N samples $s_{1...N}$ within the measured region.
 Amplitude	Amplitude = High – Low. See High and Low.
 Average Optical Power (dBm), AOP_{dBm}	$AOP_{dBm} = 10\ Log\left(\frac{AOP_w}{1mW}\right)$ See Average Optical Power (Watts) for the definition of AOP_w .
 Average Optical Power (Watts), AOP_w	The true average component of an optical signal, measured in dedicated hardware rather than from the calculation of digitized waveform data. Therefore, it has no settable parameters. $AOP = \frac{O/E's\ bias\ current}{O/E's\ factory-calibrated\ conversion\ gain} (W); \left(\frac{A}{W}\right)$ Measured once per second. Measured before any signal filters applied. Optical channels only.
 Cycle Mean	The mean over the first cycle of the measured waveform. See Mean.
 Cycle RMS	The RMS (amplitude) of the waveform within the first period of the measured region. See RMS.
 Gain	The ratio of amplitudes between Source1 and Source2. Sources are fully independent. See Amplitude.
 High	The top reference level, or Topline. The HiLow (Tracking Method) menu selects the method applied to the data sampled in the upper half of the waveform to determine the High value.
 Low	The bottom reference level, or baseline. The HiLow (Tracking Method) menu selects the method applied to the data sampled in the lower half of the waveform to determine the Low value.
 Max	Maximum amplitude, $Max = \max(VertPos(s))$ Where s is the set of samples within the measured region. By definition, Max has no settable references.
 Mean	The arithmetic mean of the waveform over the measured region: $Mean = mean(VertPos(s)) = \frac{1}{N} \sum_{i=1}^N VertPos(s_i)$ over all samples $s_{1...N}$ within the measured region.
 Mid	$Mid = \frac{Max + Min}{2}$ See Max, Min
 Min	Minimum amplitude, $Min = \min(VertPos(s))$ Where s is the set of samples within the measured region. By definition, Min has no settable references.
 +Overshoot	$PositiveOvershoot = \left(\frac{Max - High}{High - Low}\right) 100\%$ All values measured within the same measured region. See Max, High, Low.
 -Overshoot	$NegativeOvershoot = \left(\frac{Low - Min}{High - Low}\right) 100\%$ All values measured within the same measured region. See Min, High, Low.

Name	Definition
 <i>Peak-to-Peak Noise</i>	$Pk-Pk\ Noise = \max(VertPos(s)) - \min(VertPos(s))$ Where s is the set of samples within a fixed-width vertical slice located at the center of the measured region. Users need to ensure that the slice lies on a flat part of the waveform (as any slope over the slice will be included in the result). This measurement requires the use of a waveform database.
 <i>Peak-to-Peak (Pk-Pk)</i>	$Pk-Pk = Max - Min$. See <i>Max</i> , <i>Min</i> .
 <i>RMS</i>	$RMS = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n))^2}{N}}$ over all N samples $s_{1..N}$ within the measured region; i.e., one standard deviation of the amplitude.
 <i>RMS Noise</i>	$RMS\ Noise = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n) - \text{mean}(VertPos(s)))^2}{N - 1}}$ Where s is the set of N samples $s_{1..N}$ within a fixed-width vertical slice located at the center of the measured region. Users need to ensure that the slice lies on a flat part of the waveform (because any slope within the slice will be included in the result). This measurement requires the use of a waveform database.
 <i>Signal-to-Noise Ratio</i>	The ratio of the signal amplitude (see <i>Amplitude</i>) to noise (see <i>RMS Noise</i>). This measurement requires the use of a waveform database.

Pulse Measurements - Timing

Name	Definition
 <i>Burst Width</i>	The time between the first and last <i>Mid</i> reference level crossings (both either positive or negative) within the measured region. See <i>Cross+</i> , <i>Cross-</i> .
 <i>Cross+</i>	The time of the positive crossing: $Cross+ = \text{mean}(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the first positive crossing.
 <i>Cross-</i>	The time of the negative crossing: $Cross- = \text{mean}(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the first negative crossing.
 <i>Delay</i>	$Delay = \text{mean}(HorPos(s_1)) - \text{mean}(HorPos(s_2))$ Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice at the first crossing, of <i>Source1</i> and <i>Source2</i> respectively. (Because the sources can be set independently to <i>Pulse</i> , <i>RZ</i> or <i>NRZ</i> signals, see the <i>Delay</i> measurements for formulas in those categories, if needed.)
 <i>+Duty Cycle</i>	$PositiveDutyCycle = \left(\frac{PositiveWidth}{Period}\right) 100\%$ Measured using the first cycle in the measured region. Neither slope nor direction is available. See <i>+Width</i> , <i>Period</i> .
 <i>-Duty Cycle</i>	$NegativeDutyCycle = \left(\frac{NegativeWidth}{Period}\right) 100\%$ Measured using the first cycle in the measured region. Neither slope nor direction is available. See <i>-Width</i> , <i>Period</i> .
 <i>Fall Time</i>	$Fall\ Time = \text{mean}(HorPos(s_2)) - \text{mean}(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>High</i> reference level and the following <i>Low</i> reference level, respectively.

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Name	Definition
 <i>Frequency</i>	$Frequency = \frac{1}{Period}$ See <i>Period</i> .
 <i>Period</i>	$Period = mean(HorPos(s_3)) - mean(HorPos(s_1))$ Where s_1 and s_3 are the sets of samples in a horizontal slices at the first two consecutive crossings on the same slope at the <i>Mid</i> reference level. Neither slope nor direction is settable.
 <i>Phase</i>	$Phase = \left(\frac{mean(HorPos(S_{12})) - mean(HorPos(S_1))}{mean(HorPos(S_3)) - mean(HorPos(S_1))} \right) 360^\circ$ Where s_1 and s_3 are the sets of samples in horizontal slices at the first two consecutive crossings on the same slope at the <i>Mid</i> reference level, and s_{12} is the set of samples at the <i>Mid</i> reference level on first crossing, second source. Note that the denominator is the <i>Period</i> . Neither slope nor direction is settable.
 <i>Peak-to-Peak (Pk-Pk) Jitter</i>	$Pk-Pk\ Jitter = max(HorPos(s)) - min(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the crossing. The slope and the direction of search for the crossing are settable. This measurement requires the use of a waveform database.
 <i>Rise Time</i>	$Rise\ Time = mean(HorPos(s_1)) - mean(HorPos(s_2))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>Low</i> reference level and the following <i>High</i> reference level, respectively.
 <i>RMS Jitter</i>	$RMS\ Jitter = stdev(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the first positive crossing This measurement requires the use of a waveform database.
 <i>+Width</i>	$+Width = mean(HorPos(s_2)) - mean(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at <i>Mid</i> reference level at the first positive and following negative crossings, respectively. Neither slope nor direction is settable.
 <i>-Width</i>	$-Width = mean(HorPos(s_2)) - mean(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at <i>Mid</i> reference level at the first negative and following positive crossings, respectively. Neither slope nor direction is settable.

Pulse Measurements - Area

Name	Definition
 <i>Area</i>	$Area = \frac{\Delta t}{N} \sum_{n=1}^N VertPos(s_n)$ Over all N samples $s_{1...N}$ within the measured region of duration Δt . Neither slope nor direction is settable.
 <i>Cycle Area</i>	$Cycle\ Area = \frac{\Delta t}{N} \sum_{n=1}^N VertPos(s_n)$ Over all N samples $s_{1...N}$ within the region of duration Δt between crossings one and three. Neither slope nor direction is settable.

RZ Measurements

Notes:

- Perform Dark Level calibration before any optical amplitude measurements are done
- RZ measurements are done on one of the following:
 - The *Databases* (default), or
 - A temporary 1-hit-deep data base, if the *Database* selection is not enabled. This case is not recommended because many measurements will not get enough data to yield a result
 - Direct hardware (all measurements based on AOP)
- For most mid-level timing measurements, the *Mid* reference level is adjustable and defaults to 50 percent of the RZ maximum pulse amplitude

RZ Measurements - Amplitude

Name	Definition
 RZ AC RMS	$RZ\ AC\ RMS = \sqrt{\frac{\sum_{n=1}^N (\text{VertPos}(s_n) - \text{mean}(\text{VertPos}(s)))^2}{N}}$ <p>Where <i>s</i> is the set of N samples $s_{1...N}$ within the measured region.</p>
 RZ Amplitude	<p><i>Amplitude</i> = High – Low, within the eye aperture. See <i>High</i> and <i>Low</i>.</p>
 RZ Average Optical Power (dBm)	$RZ\ AOP_{dBm} = 10\text{Log}\left(\frac{AOP_w}{1\ mW}\right)$ <p>See <i>Average Optical Power (Watts)</i> for the definition of AOP_w.</p>
 RZ Average Optical Power (Watts)	<p>The true average component of an optical signal, measured in dedicated hardware rather than from the calculation of digitized waveform data; therefore, it has no settable parameters.</p> $RZ\ AOP = \frac{O/E's\ bias\ current}{O/E's\ factory-calibrated\ conversion\ gain} \quad (W); \quad \left(\frac{A}{W}\right)$ <p>Measured once per second. Measured before any signal filters applied. Optical channels only.</p>
 RZ Extinction Ratio	$RZ\ ER = \frac{RZ\ High}{RZ\ Low}$ <p>See <i>RZ High</i>, <i>RZ Low</i>.</p>
 RZ Extinction Ratio (%)	$RZ\ ER_{\%} = \left(\frac{RZ\ Low}{RZ\ High}\right) 100\%$ <p>See <i>RZ High</i>, <i>RZ Low</i>.</p>
 RZ Extinction Ratio (dB)	$RZ\ ER_{dB} = 10\log\left(\frac{RZ\ High}{RZ\ Low}\right)$ <p>See <i>RZ High</i>, <i>RZ Low</i>.</p>
 RZ Eye Height	$RZ\ Eye\ Height = (RZ\ High - 3stdev(\text{VertPos}(s_{RZHigh}))) - (RZ\ Low + 3stdev(\text{VertPos}(s_{RZLow})))$ <p>Where s_{RZHigh}, s_{RZLow} are the sets of samples within the eye aperture which are located vertically on the <i>RZ High</i> and <i>RZ Low</i> levels. See <i>RZ High</i>, <i>RZ Low</i>.</p>

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Name	Definition
 RZ Eye Opening Factor	$RZ \text{ Eye Opening Factor} = \frac{(RZ \text{ High} - stdev(VertPos(s_{RZHigh}))) - (RZ \text{ Low} + stdev(VertPos(s_{RZLow})))}{RZ \text{ High} - RZ \text{ Low}}$ <p>Where s_{RZHigh}, s_{RZLow} are the sets of samples within the eye aperture which are located vertically on the <i>RZ High</i> and <i>RZ Low</i> levels. See <i>RZ High</i>, <i>RZ Low</i>.</p>
 RZ Gain	$RZ \text{ Gain} = \frac{RZ \text{ Amplitude}_{Source2}}{RZ \text{ Amplitude}_{Source1}}$ <p>Where <i>RZ Amplitude Source2</i>, <i>Source1</i> are the RZ amplitudes of the two respective waveforms. See <i>RZ Amplitude</i>.</p>
 RZ High	The logical 1 level of the RZ signal (within the eye aperture). $mean(VertPos(s_{RZHigh}))$
 RZ Low	The logical 0 level of the RZ signal (within the eye aperture). $mean(VertPos(s_{RZLow}))$
 RZ Max	<p>Maximum amplitude: $RZ \text{ Max} = max(VertPos(s))$ Where s is the set of samples within the measured region. <i>Max</i> has no settable references.</p>
 RZ Mean	$RZ \text{ Mean} = mean(VertPos(s)) = \frac{1}{N} \sum_{i=1}^N VertPos(s_i)$ <p>Over all samples $s_{1..N}$ within the measured region.</p>
 RZ Mid	<p>Middle amplitude: $RZ \text{ Mid} = \frac{RZ \text{ Max} + RZ \text{ Min}}{2}$ See RZ_{Max} and RZ_{Min}.</p>
 RZ Min	<p>Minimum amplitude, $RZ \text{ Min} = min(VertPos(s))$ Where s is the set of samples in the measured region. <i>Min</i> has no settable references.</p>
 RZ Peak-to-Peak (Pk-Pk)	<p>The difference between the Max and Min vertical values of the waveform that is sampled within the measured region. $RZ \text{ Pk-Pk} = RZ \text{ Max} - RZ \text{ Min}$. See <i>RZ Max</i>, <i>RZ Min</i>.</p>
 RZ Peak-to-Peak Noise	$RZ \text{ Pk-Pk Noise} = max(VertPos(s)) - min(VertPos(s))$ <p>Where s is the set of samples within a fixed width vertical slice located at the center of the eye aperture at either the <i>High</i> or the <i>Low</i> level (settable: <i>Noise at High</i>, <i>Noise at Low</i>).</p>
 RZ Q Factor	$RZ \text{ Q Factor} = \frac{RZHigh - RZLow}{stdev(VertPos(s_{RZHigh})) + stdev(VertPos(s_{RZLow}))}$ <p>Where s_{RZHigh}, s_{RZLow} are sets of samples each within the eye aperture and located vertically around the <i>High</i> and <i>Low</i> eye levels in fixed-width slices horizontally located at the center of the eye. Also see <i>RZ High</i>, <i>RZ Low</i>.</p>
 RZ RMS	$RZ \text{ RMS} = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n))^2}{N}}$ <p>RMS amplitude over all N samples $s_{1..N}$ within the measured region; i.e., one standard deviation of the amplitude.</p>
 RZ RMS Noise	$RZ \text{ RMS}_{Noise} = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n) - mean(VertPos(s)))^2}{N - 1}}$ <p>Where s is the set of N samples $s_{1..N}$ within a fixed width vertical slice located at the center of the eye aperture at either the <i>High</i> or <i>Low</i> level (settable: <i>Noise at High</i>, <i>Noise at Low</i>).</p>

Name	Definition
 <i>RZ Signal-to-Noise Ratio</i>	The ratio of the signal amplitude to noise. See <i>RZ Amplitude</i> , <i>RZ RMS Noise</i> .
 <i>RZ Suppression Ratio (RZ Contrast Ratio)</i>	The ratio of the average power level of the logic <i>High</i> to the average power level in the “Corrected” Suppressed area (the distribution of suppressed area minus the distribution of <i>Low</i> area.): $RZ\ SR = \frac{RZ\ High}{mean(histogram(VertPos(s_{RZLow})) - histogram(VertPos(s_3)))}$ See <i>RZ Low</i> , <i>RZ High</i> and note that, as defined in the preface, $RZ\ High = mean(VertPos(s_{RZHigh})) \equiv mean(histogram(VertPos(s_{RZHigh})))$. The region s_3 is the Suppressed region – offset one-half bit interval horizontally from the eye aperture and of horizontal width equal to the eye aperture (no independent control) This measurement is also known as <i>RZ Contrast Ratio</i> .
<i>RZ Suppression Ratio (%)</i>	$RZ\ Suppression\ Ratio_{\%} = \frac{1}{RZ\ Suppression\ Ratio}$, i.e. $RZ\ SR_{\%} \equiv \frac{1}{RZ\ SR}$ See <i>RZ Suppression Ratio</i> .
<i>RZ Suppression Ratio (dB)</i>	$RZ\ Suppression\ Ratio_{dB} = 10 \cdot \log_{10}(RZ\ Suppression\ Ratio)$, i.e., $RZ\ SR_{dB} = 10 \cdot \log_{10}(RZ\ SR)$. See <i>RZ Suppression Ratio</i> .

RZ Measurements - Timing

Name	Definition
 <i>RZ Bit Rate</i>	$RZ\ Bit\ Rate = \frac{1}{RZ\ Bit\ Time}$ see <i>RZ Bit Time</i> .
 <i>RZ Bit Time</i>	The time interval between two consecutive rising or falling edges: $RZ\ Bit\ Time = mean(HorPos(s_3)) - mean(HorPos(s_1))$ Where s_1 and s_3 are the sets of samples in horizontal slices at the first two consecutive edges with the same slope at the <i>Mid</i> reference level. Neither slope nor direction is settable.
 <i>RZ Cross+</i>	The time of the positive edge: $RZ\ Cross+ = mean(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the first positive edge. By definition, polarity is not settable.
 <i>RZ Cross-</i>	The time of a negative edge: $RZ\ Cross- = mean(HorPos(s))$ Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the first negative edge. By definition, polarity is not settable.
 <i>RZ Delay</i>	$RZ\ Delay = mean(HorPos(s_1)) - mean(HorPos(s_2))$ Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice at the first edge, of <i>Source1</i> and <i>Source2</i> respectively. (Sources can be set independently to Pulse, RZ or NRZ – see <i>Delay</i> measurement formulas for those forms, if needed.).
 <i>RZ + Duty Cycle</i>	The ratio of the <i>RZ + Width</i> to the <i>RZ Bit Time</i> .
 <i>RZ Eye Width</i>	The 3-sigma guarded delta between the rising and falling edge: $RZ\ EyeWidth = (mean(HorPos(s_2)) - 3stdev(HorPos(s_2))) - (mean(HorPos(s_1)) + 3stdev(HorPos(s_1)))$ Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice at the first positive and following negative edge, respectively. Neither slope nor direction is settable.

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Name	Definition
 RZ Fall Time	$RZ \text{ Fall Time} = \text{mean}(\text{HorPos}(s_2)) - \text{mean}(\text{HorPos}(s_1))$ <p>Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>High</i> reference level and the following <i>Low</i> reference level, respectively. Near noise-free Suppression Region crossing at the reference level required.</p>
 RZ Phase	$\text{Phase} = \left(\frac{\text{mean}(\text{HorPos}(S_{12})) - \text{mean}(\text{HorPos}(S_1))}{\text{mean}(\text{HorPos}(S_3)) - \text{mean}(\text{HorPos}(S_1))} \right) 360^\circ$ <p>Where s_1 and s_3 are the sets of samples in horizontal slices at the first two consecutive edges with the same slope at the <i>Mid</i> reference level, and s_{12} is the set of samples at the <i>Mid</i> reference level on first edge, second source. Note that the denominator is the <i>Period</i>. Only <i>Reference Level Calc Method</i> is settable.</p>
 RZ Peak-to-Peak (Pk-Pk) Jitter	$RZ \text{ Pk-Pk Jitter} = \max(\text{HorPos}(s)) - \min(\text{HorPos}(s))$ <p>Where s is the set of samples in a horizontal, <i>Mid</i> reference slice on one slope. The slope, the direction of search, and the <i>Reference Level Calc Method</i> are settable. Note that in RZ, the jitter is often different on rising vs. falling edge.</p>
 RZ Pulse Symmetry	$RZ \text{ Pulse Symmetry} = \left(\frac{\text{HorPos}_{\text{VertMax}}(S_{1-2}) - \text{mean}(\text{HorPos}(S_1))}{\text{mean}(\text{HorPos}(S_2)) - \text{mean}(\text{HorPos}(S_1))} \right) 100\%$ <p>Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice at the first positive and negative edge, respectively, and s_{1-2} is the set of all samples between $\text{mean}(\text{HorPos}(s_1))$ and $\text{mean}(\text{HorPos}(s_2))$. $\text{HorPos}_{\text{VertMax}}$ is the horizontal position of the vertical maximum. Only <i>Reference Level Calc Method</i> is settable.</p>
 RZ Rise Time	$RZ \text{ Rise Time} = \text{mean}(\text{HorPos}(s_2)) - \text{mean}(\text{HorPos}(s_1))$ <p>Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>Low</i> reference level and the following <i>High</i> reference level, respectively. Near noise-free Suppression Region crossing at the reference level is required.</p>
 RZ RMS Jitter	$RZ \text{ RMS Jitter} = \text{stdev}(\text{HorPos}(s))$ <p>Where s is the set of samples in a horizontal, <i>Mid</i> reference slice at the edge. The slope, the direction of search, and the <i>Reference Level Calc Method</i> are settable. Note that in RZ, the jitter is often different on rising edge vs. on falling edge.</p>
 RZ + Width	<p>RZ Pulse width, also known as FWHM (Full Width Half Maximum), FDHM (Full duration Half Maximum), and even FWHH (full width half/height), Half-Maximum Pulse Width: $RZ + \text{Width} = \text{mean}(\text{HorPos}(s_2)) - \text{mean}(\text{HorPos}(s_1))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at <i>Mid</i> reference level at the first positive and following negative edge, respectively. Neither slope nor direction is settable.</p>

RZ Measurements - Area

Name	Definition
 RZ Area	$RZ \text{ Area} = \frac{\Delta t}{N} \sum_{n=1}^N \text{VertPos}(s_n)$ <p>over all N samples $s_{1..N}$ within the measured region of duration Δt.</p>
 RZ Cycle Area	$RZ \text{ Cycle Area} = \frac{\Delta t}{N} \sum_{n=1}^N \text{VertPos}(s_n)$ <p>over all N samples $s_{1..N}$ within the region of duration Δt between two consecutive edges of the same slope at the <i>Mid</i> reference level. Neither slope nor direction is settable.</p>

NRZ Measurements

NRZ Measurements - Amplitude

Name	Definition
 NRZ AC RMS	$NRZ\ AC\ RMS = \sqrt{\frac{\sum_{n=1}^N (VertPos(s_n) - mean(VertPos(s)))^2}{N}}$ <p>Where s is the set of N samples $s_{1...N}$ within the measured region.</p>
 NRZ Amplitude	<p>Amplitude = High – Low within the eye aperture. See High and Low.</p>
 NRZ Average Optical Power (dBm), AOP	$NRZ\ AOP_{dBm} = 10\text{Log}\left(\frac{AOP_w}{1\ mW}\right)$ <p>See Average Optical Power (Watts) for the definition of AOP_w.</p>
 NRZ Average Optical Power (Watts), AOP [W]	<p>The true average component of an optical signal, measured in dedicated hardware rather than from the calculation of digitized waveform data; therefore, it has no settable parameters.</p> $NRZ\ AOP = \frac{O/E's\ bias\ current}{O/E's\ factory-calibrated\ conversion\ gain} (W); \frac{(A)}{(W)}$ <p>Measured once per second. Measured before any signal filters applied. Optical channels only.</p>
 NRZ Crossing %	<p>The eye crossing point as a percentage of eye height:</p> $NRZ\ Crossing\ \% = \left(\frac{mean(VertPos(s)) - NRZ\ Low}{NRZ\ High - NRZ\ Low}\right) 100\%$ <p>Where s is the set of samples in a vertical slice at the eye crossing. See NRZ High, NRZ Low.</p>
 NRZ Crossing Level	<p>The mean signal level at the eye crossing.</p> $NRZ\ Crossing\ Level = mean(VertPos(s))$ <p>Where s is the set of samples in a vertical slice at the eye crossing.</p>
 NRZ Extinction Ratio	$NRZ\ ER = \frac{NRZ\ High}{NRZ\ Low}$ <p>See NRZ High, NRZ Low.</p>
 NRZ Extinction Ratio (%)	$NRZ\ ER_{\%} = \left(\frac{NRZ\ Low}{NRZ\ High}\right) 100\%$ <p>See NRZ High, NRZ Low.</p>
 NRZ Extinction Ratio (dB)	$NRZ\ ER_{dB} = 10\text{Log}\left(\frac{NRZ\ High}{NRZ\ Low}\right)$ <p>See NRZ High, NRZ Low.</p>
 NRZ Eye Height	$NRZ\ Eye\ Height = (NRZ\ High - 3stdev(VertPos(s_{NRZHigh}))) - (NRZ\ Low + 3stdev(VertPos(s_{NRZLow})))$ <p>Where $s_{NRZHigh}$, s_{NRZLow} are sets of samples within the eye aperture which are located vertically on the logical high and on the logical low levels. See NRZ High, NRZ Low.</p>
 NRZ Gain	$NRZ\ Gain = \frac{NRZ\ Amplitude_{Source2}}{NRZ\ Amplitude_{Source1}}$ <p>Where NRZ Amplitude Source2, Source1 are the NRZ amplitudes of the two respective waveforms. See NRZ Amplitude.</p>
 NRZ High	<p>The logical One level of the NRZ signal (within the eye aperture); $mean(VertPos(s_{NRZHigh}))$.</p>
 NRZ Low	<p>The logical Zero level of the NRZ signal (within the eye aperture); $mean(VertPos(s_{NRZLow}))$.</p>

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Name	Definition
 <i>NRZ Max</i>	Maximum amplitude: $NRZ Max = \max(\text{VertPos}(s))$ Where s is the set of samples within the measured region. By definition, <i>Max</i> has no settable references.
 <i>NRZ Mean</i>	$NRZ Mean = \text{mean}(\text{VertPos}(s)) \equiv \frac{1}{N} \sum_{i=1}^N \text{VertPos}(s_i)$ over all samples $s_{1..N}$ within the measured region.
 <i>NRZ Mid</i>	Middle amplitude: $NRZ Mid = \frac{NRZ Max + NRZ Min}{2}$ See <i>NRZ Max</i> and <i>NRZ Min</i> .
 <i>NRZ Min</i>	Minimum amplitude, $NRZ Min = \min(\text{VertPos}(s))$ Where s is the set of samples within the measured region. By definition, <i>Min</i> has no settable references.
 <i>NRZ + Overshoot</i>	$NRZ Positive Overshoot = \left(\frac{NRZ Max - NRZ High}{NRZ High - NRZ Low} \right) 100\%$ All values are taken within the same measured region. See <i>NRZ Max</i> , <i>NRZ High</i> , <i>NRZ Low</i> .
 <i>NRZ - Overshoot</i>	$NRZ Negative Overshoot = \left(\frac{NRZ Low - NRZ Min}{NRZ High - NRZ Low} \right) 100\%$ All values are taken within the same measured region. See <i>NRZ Max</i> , <i>NRZ High</i> , <i>NRZ Low</i> .
 <i>NRZ Peak-to-Peak (Pk-Pk)</i>	The difference between the <i>Max</i> and <i>Min</i> vertical values of the waveform that is sampled within the measured region. $NRZ Pk-Pk = NRZ Max - NRZ Min$ See <i>NRZ Max</i> , <i>NRZ Min</i> .
 <i>NRZ Peak-to-Peak (Pk-Pk) Noise</i>	$NRZ Pk-Pk Noise = \max(\text{VertPos}(s)) - \min(\text{VertPos}(s))$ Where s is the set of samples within a fixed width vertical slice located at the center of the eye aperture at either the <i>High</i> or the <i>Low</i> level (settable to: <i>Noise at High</i> , <i>Noise at Low</i>).
 <i>NRZ Q Factor</i>	$NRZ Q Factor = \frac{NRZ High - NRZ Low}{stdev(\text{VertPos}(s_{RZHigh})) + stdev(\text{VertPos}(s_{RZLow}))}$ Where s_{RZHigh} , s_{RZLow} are sets of samples each within the eye aperture that are located vertically around the high and the low eye levels. See <i>NRZ High</i> , <i>NRZ Low</i> .
 <i>NRZ RMS</i>	$NRZ RMS = \sqrt{\frac{\sum_{n=1}^N (\text{VertPos}(s_n))^2}{N}}$ over all N samples $s_{1..N}$ within the measured region; i.e., one standard deviation of the amplitude, i.e., RMS amplitude.
 <i>NRZ RMS Noise</i>	$NRZ RMS Noise = \sqrt{\frac{\sum_{n=1}^N (\text{VertPos}(s_n) - \text{mean}(\text{VertPos}(s)))^2}{N - 1}}$ Where s is the set of N samples $s_{1..N}$ within a fixed width vertical slice located at the center of the eye aperture at either the <i>High</i> or <i>Low</i> level (settable to: <i>Noise at High</i> , <i>Noise at Low</i>).
 <i>NRZ Signal-to-Noise Ratio</i>	The ratio of the signal amplitude to noise. See <i>NRZ Amplitude</i> , <i>NRZ RMS Noise</i> .

NRZ Measurements - Timing

Name	Definition
 NRZ Bit Rate	$NRZ\ Bit\ Rate = \frac{1}{NRZ\ Bit\ Time}$ See NRZ Bit Time.
 NRZ Bit Time	The time interval between two consecutive eye-crossing (<i>Eye Cross</i>) points: $NRZ\ Bit\ Time = mean(HorPos(s_2)) - mean(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in horizontal slices at the first two consecutive crossings (not <i>Mid Ref Level</i>). No settable parameters. Nominally equal to one UI.
 NRZ Crossing Time	The horizontal position of the eye crossing: $NRZ\ Crossing\ Time = mean(HorPos(s_1))$ Where s_1 is the sets of samples in horizontal slice at the first crossing (not <i>Level</i>). No settable parameters.
 NRZ Delay	The time interval between two consecutive eye-crossing points: $NRZ\ Bit\ Time = mean(HorPos(s_2)) - mean(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in horizontal slices for NRZ at the crossing (not <i>Mid Ref Level</i>); direction is settable. (Sources can be set independently to Pulse, RZ or NRZ, see <i>Delay Measurement</i> info for those forms, if needed.).
 NRZ Duty Cycle Distortion	The time between the rising and falling edge, relative to UI: $NRZ\ DCD = \frac{(mean(HorPos(s_2)) - mean(HorPos(s_1)))}{NRZ\ Bit\ Time}$ Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice of the preceding and –following edges, respectively, at the time of the left-most eye crossing (<i>Eye Cross</i>). A special algorithm is used if the sets overlap.
 NRZ Eye Width	The 3-sigma guarded delta between the rising and falling edge crossings. $NRZ\ Eye\ Width = (mean(HorPos(s_2)) - 3stddev(HorPos(s_1))) - (mean(HorPos(s_1)) + 3stddev(HorPos(s_1)))$ Where s_1 and s_2 are the sets of samples in a horizontal, <i>Mid</i> reference slice at the first and second crossings (<i>Eye Cross</i>), respectively. Crossing points are used, rather than levels,.
 NRZ Fall Time	$NRZ\ Fall\ Time = mean(HorPos(s_2)) - mean(HorPos(s_1))$ Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>High</i> reference level and the following <i>Low</i> reference level, respectively. Will use (<i>Crossing-to-Low</i> and <i>Crossing-to-High</i>) when necessary. Near noise-free crossing for the references is required.
 NRZ Frequency	$NRZ\ Frequency = \frac{1}{NRZ\ Period} = \frac{1}{2 \cdot NRZ\ Bit\ Time}$ See NRZ Period.
 NRZ Period	$NRZ\ Period = 2(NRZ\ Bit\ Time)$ NRZ Period is twice the time interval between two consecutive eye-crossing (<i>Eye Cross</i>) points. It is the period of a digital signal of a 0-1-0-1 stream. See NRZ Bit Time.

Automatic Measurement Algorithms for Communications Applications

► Application Note

Name	Definition
 NRZ Phase	<p>Phase (UI $\equiv 180^\circ$)</p> $Phase = \left(\frac{mean(HorPos(S_{12})) - mean(HorPos(S_1))}{mean(HorPos(S_3)) - mean(HorPos(S_1))} \right) 360^\circ$ <p>Where s_1 and s_3 are the sets of samples at the eye crossing level of first and third consecutive crossings on the same slope at the <i>Mid</i> reference level, and s_{12} is the set of samples at the eye-crossing level on first crossing, second source. Note that the denominator is the <i>NRZ Period</i>. If less than one <i>NRZ Period</i> is available, the algorithm will attempt to measure <i>NRZ Bit Time</i> and calculate the <i>NRZ Period</i> from it.</p>
 NRZ Pk-Pk Jitter	$NRZ Pk-Pk Jitter = max(HorPos(s)) - min(HorPos(s))$ <p>Where s is the set of samples in a horizontal slice. The level of the slice is selected to either <i>Eye Cross</i> or <i>Mid Ref</i> (which is then settable).</p>
 NRZ Rise Time	$NRZ Rise Time = mean(HorPos(s_2)) - mean(HorPos(s_1))$ <p>Where s_1 and s_2 are the sets of samples in a horizontal slice at the first <i>Low</i> reference level and the following <i>High</i> reference level, respectively. Will use (<i>Crossing-to-High</i> and <i>Crossing-to-Low</i>) when necessary. Near noise-free mid-eye crossing for the references is required.</p>
 NRZ RMS Jitter	$NRZ RMS Jitter = stdev(HorPos(s))$ <p>Where s is the set of samples in a horizontal slice. The level of the slice is selected to either <i>Eye Cross</i> or <i>Mid Ref</i> (which is then settable).</p>

NRZ Measurements - Area

Name	Definition
 NRZ Area	$NRZ Area = \frac{\Delta t}{N} \sum_{n=1}^N VertPos(s_n)$ <p>over all N samples $s_{1..N}$ within the measured region of duration Δt. Neither slope nor direction is settable.</p>
 NRZ Cycle Area	$NRZ Cycle Area = \frac{\Delta t}{N} \sum_{n=1}^N VertPos(s_n)$ <p>over all N samples $s_{1..N}$ within the region of duration Δt between crossings one and three. Neither slope nor direction is settable.</p>

▶ **Notes:**

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► Application Note



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