Automatic Measurement Algorithms and Methods for the 8000 Series Sampling Oscilloscopes

The Shrinking Life Cycle

Over the last several years, design and test engineers and technicians have seen an exponential growth in the performance requirements for all types of computer and communications devices, modules, and systems. At the same time, the life cycles for these products have continually shrunk – from several years to a year, or even months. As a result, these professionals are being squeezed to design, qualify, and manufacture their products on ever-shorter schedules. To accomplish this feat, they need tools that automate the test and measurement process while allowing them to concentrate their efforts on design and manufacturing process issues.

Enter The Tektronix 8000 Series

The 8000 Series sampling oscilloscope family from Tektronix was designed with these challenges in mind. With excellent measurement repeatability, exceptional vertical resolution, and fast waveform acquisition and display update rates, the TDS8000 digital sampling oscilloscope is a powerful measurement tool for semiconductor testing, TDR characterization of circuit boards, IC packages and cable, and high-speed digital communications. The CSA8000 communications signal analyzer was specifically designed for high-performance communications applications. It is the ideal tool for design evaluation and manufacturing test of datacomm and telecomm components, transceiver sub-assemblies, and transmission systems.

Together, the TDS8000 and CSA8000 offer the widest range of on-board measurement and waveform processing capabilities of any ultra-high bandwidth oscilloscopes available today. Built on a common sampling oscilloscope platform, these instruments share a complete set of measurement capabilities – including automatic measurements on live waveforms and waveform databases, cursor-based measurements, and histograms.

This application note provides background information on the measurement algorithms and methods used in generating automatic measurements. For detailed instructions on how to set up a particular measurement, consult one or more of the following:

- CSA8000 / TDS8000 User Manual
- CSA8000 / TDS8000 Reference
- CSA8000 / TDS8000 Online Help

www.tektronix.com/scopes/
Available Automatic Measurement Types

8000 Series sampling oscilloscopes support a wide variety of automatic measurements. Over 40 measurements are supported in one of four categories: Amplitude, Timing, Area, and Statistical Data-based Measurements. These measurements, along with the ability to control all of the measurement parameters associated with them, allow users to quickly analyze the performance of the device-under-test and assists them in quickly identifying and correcting design and/or manufacturing flaws. (For a detailed description of the measurements supported, see Appendix A.)

Source Waveforms for Automatic Measurements

In order to provide automated measurements on the wide assortment of signals that users need to examine, the 8000 Series sampling oscilloscopes support a variety of measurement algorithms appropriate for these signals.

Given that the 8000 Series oscilloscopes acquire data using sequential equivalent-time sampling, one of two conditions must be satisfied in order to get a stable display of waveform data:

1. The acquired signal must be repetitive and triggered on a signal synchronous to the input signal; or
2. The acquired signals must have a fixed clock rate and be triggered on a signal that is synchronous to that rate.

Signals which meet condition 1, above, are referred to as deterministic signals, while those which meet condition 2 are referred to as random signals.

An example of a deterministic signal is a repetitive data stream triggered on a signal synchronous to that stream (see Figure 1).

Since each waveform record contains data that is synchronous to the trigger, the measurement algorithms for deterministic waveforms are straightforward and applicable to a single acquisition record. For example, one can simply examine the acquired data sequentially and compute changes in amplitude to locate rising and falling edges of the acquired signal. In addition, 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. This synchronicity allows the instrument to make measurements on each waveform record and update those results in real time as additional records are acquired.

The measurement algorithms for random data are much more involved. Figure 2 illustrates a pseudo-random bit sequence (PRBS) with a fixed clock interval of 1.6 nsec. (Waveforms such as this are commonly called eye patterns.) This signal was acquired by triggering the oscilloscope on the data clock of the PRBS generator.

Because the instrument is triggered on the PRBS clock and not a signal with a fixed sequential relationship to the data stream being acquired, one can no longer simply scan serially through the waveform record to locate rising or falling edges. In addition, since sequentially adjacent points in the waveform record are not necessarily from the same bit in the PRBS signal, one can no longer simply interpolate between adjacent points to approximate the behavior of the signal in times between the acquired points.

Finally, looking at the eye pattern in Figure 2, we see that any particular point acquired in the transition regions can take one of four values (high, low, rising, or falling). Thus the amount of data available to assist in determining rising and
falling edges for automated measurements is one-quarter of that available for deterministic waveforms.

For these and other reasons, an 8000 Series sampling oscilloscope uses a different set of algorithms when making measurements on random waveforms than it uses with deterministic waveforms. Unfortunately, it is very difficult for the instrument to determine whether a particular acquired waveform contains random or deterministic data. Lacking this information, the measurement system assumes the waveform is deterministic unless informed otherwise. (Users can specify the type of data being acquired — deterministic or random — via the Signal Type control in the Source tab of the Measurement setup dialog. Specify Pulse for deterministic data or Eye for random data.)

Waveform Databases as Measurement Sources

An additional factor that affects how measurements are made on a signal is whether the measurements are made on the live signal or on a Waveform Database. 8000 Series Sampling Oscilloscopes provide two waveform databases that can be used to accumulate waveform data.

A waveform database is a three-dimensional accumulation of a source waveform as it is continuously acquired. In addition to the standard amplitude and timing information, a waveform database has a third dimension of count. The count represents the number of times a specific waveform point (time and amplitude) has been acquired.

Having gathered data over many waveform acquisition cycles, the instrument can then use statistical measurement algorithms to return measurement results on a much larger data sample than available in a single acquisition cycle. In addition, since the data in a waveform database is not cleared when acquisition is stopped and restarted, one can choose additional measurements to make after the data has been acquired.

Setting the Use Wfm Database control in the Source tab of the Measurement setup dialog causes the selected measurement to be made on the accumulated data in a waveform database rather than on live data. (See the instrument documentation or on-line help for further information on waveform databases.)

Topline and Baseline Level Determination

The levels that the automatic measurement system derives as High (Topline) and Low (Baseline) for a waveform influence the fidelity of many automated measurements. Depending on the type of waveform being measured, the instrument will use one of three methods for determining these levels.

1. Mode (of Histogram) – For this method of High and Low level derivation, 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). This is done using histograms on the acquired waveform. Since this statistical approach ignores short-term aberrations (overshoot, ringing, and so on), Mode, is the best method for examining pulses. Figure 3 shows graphically the High level for a pulse determined using the Mode of Histogram method. Also shown is a histogram corresponding to that taken to determine this value.

2. Min-Max – This method uses the highest and lowest values of the waveform record as its High and Low values. This setting is best for examining waveforms that have no large, flat portions at a common value, such as sine and triangle waveforms — almost any deterministic waveform except for pulses (see Figure 4).

3. Mean – For this method of High and Low level derivation, the instrument will set the reference levels to the mean of the waveform either above or below the midpoint (depending on whether it is determining the High or Low level). This is done using histograms on the acquired waveform.
This method is particularly useful for eye patterns that exhibit multi-modal distributions in the topline and/or baseline. Such a waveform is shown in Figure 5. Also shown in this figure is a histogram of the baseline and the Low level that would be determined using the Mode method (≈ 6.342 µW). Such a reference level used to compute Q-factor or Extinction Ratio would give results that are overly optimistic, given the bi-modal nature of this signal.

Multi-modal distributions on the topline and baseline of an eye pattern are indicative of pattern-dependent effects such as inter-symbol interference. At low data rates, pattern-dependent effects are typically not an issue, as the bit-times involved are such that the signal can 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 logic-one or -zero value. This results in multi-modal distributions in the topline and baseline of the eye diagram.

In order to account for pattern dependent effects in eye patterns when determining the High and Low values, the 8000 Series sampling oscilloscopes use the Mean method for determining these levels.

Figure 6 shows the same eye pattern previously described, but in this case the instrument is using the Mean method to determine the Low Value (≈ 29.67 µW). Also shown is a histogram corresponding to the one used to determine the Low level using this method.

Notice that the histogram used to determine the High and Low values for the Mean method in Figure 6 is limited to the central 20% of the eye pattern. Depending on the signal being examined, it may be appropriate to change the portion of the topline and baseline included in the reference level determination. For the 8000 Series sampling oscilloscopes, this parameter (the eye aperture) can be set on a per measurement basis. (The default value for eye aperture is 20%.)

Example of the Measurement Differences using Mode vs. Mean Reference Level Methods

Previously, we showed that for our example waveform using the Mode method of reference level determination yielded a Low level of 6.342 µW vs. 29.67 µW using the Mean method. In similar fashion, one could determine High values of 560.0 µW vs. 568.2 µW for Mode and Mean methods, respectively. Using the following equation for Extinction Ratio (in dB):

$$ER = 10 \cdot \log(\text{High/\text{Low}})$$

yields Extinction Ratios of 18.16 dB and 12.82 dB for the Mode and Mean methods respectively. From our earlier discussion, you can see that using the Mode method would overstate the extinction ratio by more than 5 dB.

Shown in Figure 7 are the automated Extinction Ratio and Q-Factor measurements for our example signal. These automated measurements use the Mean method of High and Low determination with an eye aperture of 20% (the default).

Automatic Topline and Baseline Level Determination

In order to simplify the user’s measurement task, 8000 Series sampling oscilloscopes will, by default, automatically select a mode for topline and baseline determination.

For random waveforms (i.e., eye patterns), the topline and baseline determination method will be set to Mean. For deterministic waveforms, the instrument will first attempt to use the Mode method; if it determines that the signal has no large flat portion on the topline or baseline, it will automatically select the
Min/Max method of topline and baseline determination. If desired, the user can override the automatic selection of topline and baseline level determination by manually selecting a method in the High/Low tab of the Measurement setup dialog. As with all measurement parameters, the topline/baseline determination method can be set per measurement.

Amplitude Reference Levels for Automatic Timing Measurements

A second set of measurement parameters that affects the fidelity of time-related measurements are the amplitude reference levels used. 8000 Series sampling oscilloscopes allow the user to specify three amplitude reference levels (HighRef, MidRef, and LowRef). These levels specify the amplitudes at which the “endpoints” of timing measurements are set.

For example, rise time measurements are defined as the time it takes for the signal to transit from the LowRef to HighRef values. Depending on the device being evaluated, one user may wish to measure rise times as the time it takes the signal to transit from 10 to 90% of its amplitude. Another user may desire to measure rise times from 20 to 80% of the signal’s amplitude. A third user may require rise time measurement results in terms of the time it takes for the signal to transit between two fixed levels (say 20 mV to 150 mV). The 8000 Series, with its flexible reference level calculation methods, can support any of these measurement requirements.

8000 Series sampling oscilloscopes provide four calculation methods to establish these amplitude reference levels. (Refer to Figure 8 as you read about each method.)

1. Relative Reference levels are calculated as a percentage of the High/Low range. (This is the default reference level calculation method. The default reference levels are 10%, 50%, and 90% for LowRef, MidRef, and HighRef, respectively.)

2. High Delta Reference levels are calculated as absolute values from the High level.

3. Low Delta Reference levels are calculated as absolute values from the Low level.

4. Absolute Reference levels are set as absolute amplitude values.

As with Topline and Baseline Determination Methods, Amplitude Reference Levels can be set on a per measurement basis. (See the Ref Level tab of the Measurement setup dialog.)

Localizing Measurements

Frequently users may wish to specify which portion of a signal is used when making automated measurements. Take, for example, the situation shown in Figure 9. This figure shows a Frame Synchronization signal and a portion of a Data stream associated with it. Also shown is an automatic Delay measurement between the rising edge of Frame Sync and the first positive transition of Data.

Suppose now that you wanted to measure the delay from the rising edge of Frame Sync to the first negative transition of Data. The 8000 Series sampling oscilloscopes allow you to specify the slopes of all edges used in delay measurements. (See the Region tab of the Measurements setup dialog.) Figure 10 shows the automatic measurement resulting from specifying a negative slope for Source 2 of the delay measurement.

![Figure 7. Automated measurements on multi-modal eye pattern.](image)

![Figure 8. HighRef, MidRef, and LowRef calculation methods.](image)
A second set of controls that allows you to specify what portion of a waveform is used for automated measurements are the Measurement Gates. These controls are used to choose the starting and ending times over which the measurement system does its measurement. In the example above, we saw that the Delay measurement by default measures delay time from the first specified transition (+ or −) of the first source waveform to the first specified transition of the second source waveform. By setting the Measurement Gates for the second source waveform to 50-100% of the displayed waveform, we can cause the automated Delay measurement to measure the time from the rising edge of Frame Sync to the second positive transition of the Data signal. This is shown in Figure 11.

Additional 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) to look for crossings from the measurement gates.
- For Eye Pattern measurements – what percentage of the eye (the Eye Aperture) to use in determining High and Low (topline and baseline) values as well as Eye Height, Extinction Ratios, and Q-Factor.
- For Noise measurements on eye diagrams – whether to measure noise on the topline or baseline
- For Jitter measurements on eye diagrams – whether to measure jitter at the eye crossing or the MidRef reference level.

Summary

By combining detailed control over all measurement parameters with a sophisticated set of measurement algorithms and intelligent defaults, 8000 Series sampling oscilloscopes allow users to concentrate their efforts on design and/or manufacturing process issues, decreasing design and manufacturing debug times.
Appendix A: Automatic Measurement Definitions

All measurements are based on the power level, the voltage level, or the time locations of edges within each acquisition. Tables A-1 through A-4 define the measurements the TDS8000 Series supports within four categories: Amplitude, Timing, Area, and Eye Pattern/Optical.

Refer to Figure A-1 (at the end of this appendix) for assistance in interpreting the definitions of measurements in categories Amplitude, Timing, and Area. Refer to Figure A-2 for assistance in interpreting the definitions of measurements in the category Eye Pattern/Optical.

Table A-1: Supported Amplitude Measurements

<table>
<thead>
<tr>
<th>Name</th>
<th>Category and Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC RMS</strong></td>
<td>Amplitude measurement. The AC RMS valued measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td></td>
<td>[ AC_{\text{RMS}} = \sqrt{\frac{\sum y^2}{dx}} - \bar{y}^2 ]</td>
</tr>
<tr>
<td></td>
<td>where: ( dx = ) sample interval ( \bar{y} = ) mean</td>
</tr>
<tr>
<td><strong>Amplitude</strong></td>
<td>Amplitude measurement. The high value less the low value measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td></td>
<td>( \text{Amplitude} = \text{High} - \text{Low} )</td>
</tr>
<tr>
<td><strong>Cycle Mean</strong></td>
<td>Amplitude measurement. The arithmetic mean over the first cycle in the waveform or the first cycle in the gated region.</td>
</tr>
<tr>
<td><strong>Cycle RMS</strong></td>
<td>Amplitude measurement. The true Root Mean Square amplitude over the first cycle in the waveform or the first cycle in the gated region.</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>Amplitude measurement. The ratio of amplitude measurements for two waveforms. Measured over the entire waveforms or gated regions.</td>
</tr>
<tr>
<td></td>
<td>( \text{Gain} = \frac{\text{Amplitude}<em>{\text{Source2}}}{\text{Amplitude}</em>{\text{Source1}}} )</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>Amplitude measurement. The value used as 100% whenever High Ref, Mid Ref, and Low Ref values are needed (as in fall time and rise time measurements). Calculated using the min/max, histogram mean, or mode method. See Topline and Baseline Level Determination section. Measured over the entire waveform or gated region.</td>
</tr>
</tbody>
</table>

Amplitude Measurements

Amplitude measurements can be made on any waveform or waveform database. They return measurement values in units of amplitude (volts, amps, watts, ohms, rho, etc.). Measurement statistics (mean, min, max, and standard deviation) can be displayed for amplitude measurements based on live waveforms. When measuring waveform databases, measurement statistics are not generated, since these measurements are already statistical in nature. Refer to Figure A-1 for assistance in interpreting the definitions of measurements in this category.
<table>
<thead>
<tr>
<th>Name</th>
<th>Category and Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid</td>
<td><strong>Amplitude measurement.</strong> The midpoint level between the 0% and 100% amplitude levels. Measured over the entire waveform or gated region. &lt;br&gt;[ \text{Mid} = \frac{\text{High} + \text{Low}}{2} ]</td>
</tr>
<tr>
<td>Low</td>
<td><strong>Amplitude measurement.</strong> The value used as 0% whenever High Ref, Mid Ref, and Low Ref values are needed (as in fall time and rise time measurements). Calculated using the min/max, histogram mean, or mode method. See Topline and Baseline Level Determination section. Measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td>Maximum</td>
<td><strong>Amplitude measurement.</strong> The maximum amplitude. Typically the most positive peak voltage. Measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>Amplitude measurement.</strong> The arithmetic mean over the entire waveform or gated region.</td>
</tr>
<tr>
<td>Minimum</td>
<td><strong>Amplitude measurement.</strong> The minimum amplitude. Typically the most negative peak voltage. Measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td>Negative Overshoot</td>
<td><strong>Amplitude measurement.</strong> Measured over the entire waveform or gated region. &lt;br&gt;[ \text{NegativeOvershoot} = \frac{\text{Low} - \text{Min}}{\text{Amplitude}} \times 100% ]</td>
</tr>
<tr>
<td>Peak-to-Peak</td>
<td><strong>Amplitude measurement.</strong> The absolute difference between the maximum and minimum amplitude in the entire waveform or gated region.</td>
</tr>
<tr>
<td>Positive Overshoot</td>
<td><strong>Amplitude measurement.</strong> Measured over the entire waveform or gated region. &lt;br&gt;[ \text{PositiveOvershoot} = \frac{\text{Max} - \text{High}}{\text{Amplitude}} \times 100% ]</td>
</tr>
<tr>
<td>RMS</td>
<td><strong>Amplitude measurement.</strong> The true Root Mean Square amplitude over the entire waveform or gated region.</td>
</tr>
</tbody>
</table>
Area Measurements

Area measurements can be made on any waveform or waveform database. They return measurement values in units of amplitude times time (volt-sec, watt-sec, etc.). Measurement statistics (mean, min, max, and standard deviation) can be displayed for Area measurements based on live waveforms. When measuring waveform databases, measurement statistics are not generated, since these measurements are already statistical in nature. Refer to Figure A-1 for assistance in interpreting the definitions of measurements in this category.

<table>
<thead>
<tr>
<th>Name</th>
<th>Category and Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Area measurement. The area over the entire waveform or gated region in vertical units times horizontal units, such as volt-seconds and watt-seconds. Area measured above ground is positive; area below ground is negative. Algorithm follows: If Start = End then return the (interpolated) value at Start Otherwise, $\text{Area} = \int_{\text{Start}}^{\text{End}} \text{Waveform}(t) dt$</td>
</tr>
<tr>
<td>Cycle Area</td>
<td>Area measurement. The area over the first cycle in the waveform, or the first cycle in the gated region, vertical units times horizontal units, such as volt-seconds and watt-seconds. Area measured above ground is positive; area below ground is negative.</td>
</tr>
</tbody>
</table>
Eye Pattern and Optical Measurements
Statistical Data Based measurements can be made on either of two waveform databases. They return measurement values in a variety of units depending on the measurement. Refer to Figure A-2 (at the end of this appendix) for assistance in interpreting the definitions of measurements in this category.

Table A-3: Supported Eye Pattern/Optical Measurements

<table>
<thead>
<tr>
<th>Name</th>
<th>Category and Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Optical Power</td>
<td>Eye pattern/optical measurement. This measurement is not actually taken on an acquired waveform; rather, it is taken by the hardware in the optical sampling module. Average Optical Power only measures optical channels, taken at a rate of one reading per second.</td>
</tr>
<tr>
<td>Crossing Percent</td>
<td>Eye pattern/optical measurement. The eye crossing point as a percentage of eye height.</td>
</tr>
<tr>
<td>Duty Cycle Distortion</td>
<td>Eye pattern/optical measurement. Ratio of the Peak-to-peak time variation of the eye crossing measured at MidRef to the eye period.</td>
</tr>
<tr>
<td>Extinction Ratio</td>
<td>Eye pattern/optical measurement. Ratio of eye top to base.</td>
</tr>
<tr>
<td>Extinction Ratio %</td>
<td>Eye pattern/optical measurement. Ratio of eye base to top in %.</td>
</tr>
<tr>
<td>Extinction Ratio dB</td>
<td>Eye pattern/optical measurement. Ratio of eye top to base in dB.</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Eye pattern/optical measurement. The eye height in watts or volts.</td>
</tr>
</tbody>
</table>

Note: Optical sampling modules may subtract the dark current voltage from the PTop mean and PBasemean values. Check the documentation for your sampling module.

$$\text{Crossing} \% = \frac{\text{PCross}1_{\text{mean}} - \text{PBasemean}}{\text{PTopmean} - \text{PBasemean}} \times 100\%$$

$$\text{DCD(\%)} = \frac{\text{TDCOD}_{\text{pp}}}{\text{TCross2}_{\text{mean}} - \text{TCross1}_{\text{mean}}} \times 100\%$$

$$\text{Ext Ratio} = \frac{\text{PTop}_{\text{mean}}}{\text{PBasemean}}$$

$$\text{Ext Ratio } \% = \frac{\text{PBasemean}}{\text{PTopmean}} \times 100\%$$

$$\text{Ext Ratio dB} = 10 \times \log \left( \frac{\text{PTop}_{\text{mean}}}{\text{PBasemean}} \right)$$

$$\text{Eye Height} = (\text{PTop}_{\text{mean}} - 3 \times \text{PTop\_sigma}) - (\text{PBasemean} + 3 \times \text{PBasemean})$$
<table>
<thead>
<tr>
<th>Name</th>
<th>Category and Definition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Width</td>
<td>Eye pattern/optical measurement. The eye width in seconds.</td>
<td>$\text{Eye Width} = (TCross_2_{\text{mean}} - 3 \times TCross_2_{\text{sigma}}) - (TCross_1_{\text{mean}} + 3 \times TCross_1_{\text{sigma}})$</td>
</tr>
<tr>
<td>Jitter Pk-Pk</td>
<td>Eye pattern/optical measurement. The peak-to-peak value for the edge jitter in the current horizontal units.</td>
<td>$\text{Jitter PP} = TCross_1_{\text{pp}}$</td>
</tr>
<tr>
<td>Jitter RMS</td>
<td>Eye pattern/optical measurement. The RMS value of the edge jitter in the current horizontal units.</td>
<td>$\text{Jitter RMS} = TCross_1_{\text{sigma}}$</td>
</tr>
<tr>
<td>Noise Pk-Pk</td>
<td>Eye pattern/optical measurement. The peak-to-peak value of the noise of the topline or baseline of the signal as specified by the user.</td>
<td>$\text{Noise PP} = PTop_{\text{pp}}$ or $PBase_{\text{pp}}$</td>
</tr>
<tr>
<td>Noise RMS</td>
<td>Eye pattern/optical measurement. The RMS value of the noise of the topline or baseline of the signal as specified by the user.</td>
<td>$\text{Noise RMS} = PTop_{\text{sigma}}$ or $PBase_{\text{sigma}}$</td>
</tr>
<tr>
<td>Quality Factor</td>
<td>Eye pattern/optical measurement. Ratio of eye amplitude to RMS noise.</td>
<td>$\text{Quality Factor} = \frac{PTop_{\text{mean}} - PBase_{\text{mean}}}{PTop_{\text{sigma}} + PBase_{\text{sigma}}}$</td>
</tr>
<tr>
<td>S/N Ratio</td>
<td>Eye pattern/optical measurement. Ratio of eye amplitude to noise on topline or baseline as specified by the user.</td>
<td>$\text{S/N Ratio} = \frac{PTop_{\text{mean}} - PBase_{\text{mean}}}{PTop_{\text{sigma}}}$ or $\frac{PTop_{\text{mean}} - PBase_{\text{mean}}}{PBase_{\text{sigma}}}$</td>
</tr>
</tbody>
</table>
Timing Measurements

Timing measurements can be made on any waveform or waveform database. They return measurement values in units of time (seconds or bits). Measurement statistics (mean, min, max, and standard deviation) can be displayed for Timing measurements based on live waveforms. When measuring waveform databases, measurement statistics are not generated, since these measurements are already statistical in nature. Refer to Figure A-1 for assistance in interpreting the definitions of measurements in this category.

Table A-4: Supported Timing Measurements

<table>
<thead>
<tr>
<th>Name</th>
<th>Category &amp; Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burst Width</td>
<td>Timing measurement. The duration of a burst. It is the time from the 1st Mid Ref crossing in the burst to the last. Measured over the entire waveform or gated region.</td>
</tr>
<tr>
<td>Delay</td>
<td>Timing measurement. The time between the Mid Ref crossings of two different traces or the gated region of the traces.</td>
</tr>
<tr>
<td>Fall Time</td>
<td>Timing measurement. The time taken for the falling edge of the first pulse in the waveform or gated region to fall from a High Ref value (default = 90%) to a Low Ref value (default =10%) of its final value.</td>
</tr>
<tr>
<td>Frequency</td>
<td>Timing measurement. The frequency taken for the first cycle in the waveform or in the gated region. The reciprocal of the period. Measured in Hertz (Hz) where 1 Hz = 1 cycle per second.</td>
</tr>
<tr>
<td>Negative Crossing</td>
<td>Timing measurement. The distance between the trigger and the first negative crossing of the Mid Ref (default 50%) amplitude point for a pulse. Measured over the first pulse in the waveform or in the gated region.</td>
</tr>
</tbody>
</table>
| Negative Duty Cycle | Timing measurement. The ratio of the negative pulse width to the signal period expressed as a percentage. Measured over the first cycle in the waveform or in the gated region.  
  \[ \text{Negative Duty Cycle} = \frac{\text{Negative Width}}{\text{Period}} \times 100\% \] |
| Negative Width | Timing measurement. Measured over the first negative pulse in the waveform or in the gated region. Distance (time) between Mid Ref (default 50%) amplitude points of a negative pulse. |
| Period       | Timing measurement. Time it takes for the first complete signal cycle to complete in the waveform or in the gated region. The reciprocal of frequency. Measured in seconds. |
| Phase        | Timing measurement. The amount one waveform leads or lags another in time. Expressed in degrees, where 360° comprise one waveform cycle. |
| Positive Crossing | Timing measurement. The distance between the trigger and the first positive crossing of the Mid Ref (default 50%) amplitude point for a pulse. Measured over the first pulse in the waveform or in the gated region. |
## Positive Duty Cycle

**Category and Definition**: Timing measurement. Measured using the first cycle in the waveform or in the gated region. The ratio of the positive pulse width to the signal period expressed as a percentage.

\[
PositiveDutyCycle = \frac{PositiveWidth}{Period} \times 100\%
\]

## Positive Width

**Category and Definition**: Timing measurement. Measured over the first positive pulse in the waveform or in the gated region. The distance (time) between Mid Ref (default 50%) amplitude points of a positive pulse.

## Rise Time

**Category and Definition**: Timing measurement. Time taken for the leading edge of the first pulse in the waveform or gated region to rise from a Low Ref value (default = 10%) to a High Ref value (default = 90%) of its final value.
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Levels Used in Taking Amplitude, Timing, and Area Measurements

Refer to Figure A-1 and the descriptions that follow to aid in the interpretation of the definitions of measurements in categories Amplitude, Timing, and Area.

**High**
The value used as the 100% level in amplitude measurements, such as Peak and +Overshoot. High is also used to help derive the HighRef, MidRef, MidRef2, and LowRef values.

**Low**
The value used as the 0% level in amplitude measurements, such as Peak and –Overshoot. Low is also used to help derive the HighRef, MidRef, MidRef2, and LowRef values.

**HighRef**
The waveform high reference level, used in such measurements as fall time and rise time. Typically set to 90%.

**MidRef**
The waveform middle reference level used in such measurements as Period and Duty Cycle. Typically set to 50%.

**LowRef**
The waveform low reference level. Used in fall time and rise time calculations. Typically set to 10%.

**Mid2Ref**
The middle reference level for a second waveform (or the second middle reference of the same waveform). Used in two-waveform time measurements, such as Delay and Phase measurements.

Levels Used in Taking Eye Measurements

All eye-diagram measurements are based on the power level, the voltage level, or the time locations of edges within each acquisition.

Figure A-2 shows an eye-diagram and the areas from which values are taken that are used to calculate measurements.

**P Values**

The P values include the mean and standard deviation of the vertical location of PTop and PBase. These areas are used with a specified sample size to statistically measure the following values:

- **PTopmean** The mean value of PTop.
- **PTopsigma** The standard deviation of PTop.
- **PTopp** The vertical peak-to-peak deviation of PTop.
- **PBasemean** The mean value of PBase.
- **PBasessigma** The standard deviation of PBase.
- **PBasopp** The vertical peak-to-peak deviation of PBase.

![Figure A-1. Levels used to determine measurements.](image-url)

![Figure A-2. Eye-diagram and optical values.](image-url)
All of these values are limited to the region specified by the eye aperture. The eye aperture defaults to the center 20% of the interval from TCross₁ to TCross₂ but is user settable from 0% to 100% of that interval. (In the Measurement Setup dialog box, first select an eye measurement; then select the Region tab.)

**T1 Values**

The T1 values are vertical and horizontal values associated with the leftmost crossing point. These areas are used to establish the following values:

- **TCross₁mean**: The horizontal mean of the left crossing point at TCross₁.
- **TCross₁sigma**: The horizontal standard deviation of the left crossing point at TCross₁.
- **TCross₁pp**: The horizontal peak-to-peak deviation of the left crossing point at TCross₁.
- **PCross₁mean**: The vertical mean of the left crossing point at PCross₁.

**T2 Values**

The T2 values are vertical and horizontal values associated with the rightmost crossing point. These areas are used to establish the following values:

- **TCross₂mean**: The horizontal mean of the right crossing point at TCross₂.
- **TCross₂sigma**: The horizontal standard deviation of the right crossing point at TCross₂.
- **TCross₂pp**: The horizontal peak-to-peak deviation of the right crossing point at TCross₂.

**DCD Values**

The DCD values are horizontal values associated with the leftmost crossing point at MidRef level (default = 50%) of the eye height. These areas are used to establish the DCDpp, the horizontal peak-to-peak deviation of the left crossing point at MidRef level of the eye.
Automatic Measurement Algorithms for the 8000 Series Sampling Oscilloscopes

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