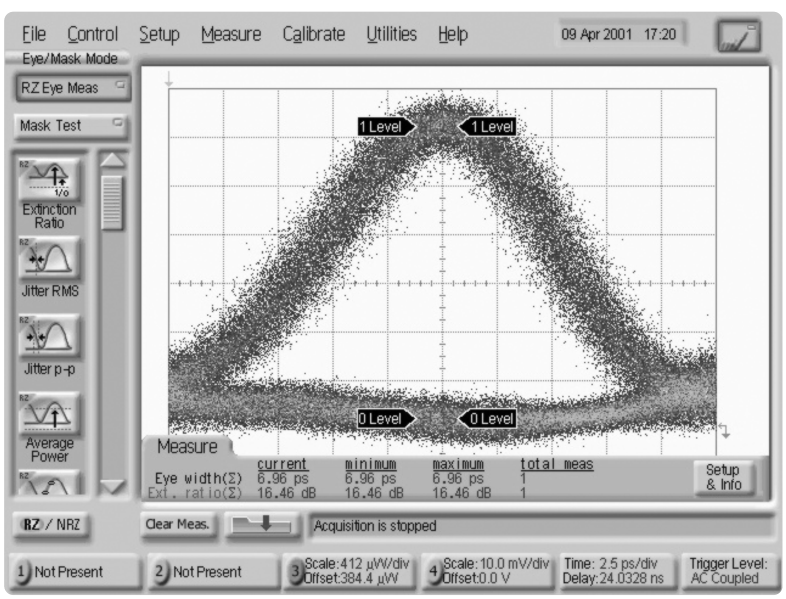
40 Gb/s and Return-to-Zero Measurements Using the Agilent 86100A Infiniium DCA

Product Note 86100-3



Agilent Technologies

Abstract

The digital communications analyzer (DCA) is a standard tool for characterizing high-speed communications waveforms. As research and development expands for transmission rates of 40 Gb/s, the DCA performance will need to improve significantly. The bit period at 40 Gb/s is only 25 ps. Precision measurements will require sub-picosecond jitter measurement capability and timebase resolution. The increased edge-speeds will dictate the widest bandwidth possible in optical detection circuitry. New modulation formats, specifically return-to-zero (RZ) schemes, will require the DCA to also include RZ compatible measurements. This note describes the evolution of the Agilent 86100A Infiniium DCA for 40 Gb/s test and how the above requirements have been implemented in the instrument through improved hardware and firmware. A detailed overview of the new RZ measurement set is included along with step-by-step procedures to perform these measurements.

Introduction

The Agilent 86100A Infiniium DCA was first introduced in early 2000. It is used primarily for the analysis of high-speed communications waveforms. Since its introduction, there have been a variety of improvements in measurement capability and ease-of-use. Most recently, the instrument has been significantly improved specifically for the analysis of 40 Gb/s waveforms. The four areas of improvement are:

- Reduced jitter
- Higher timebase resolution
- Integrated optical receivers with increased bandwidth and reduced distortion
- Addition of an RZ eye diagram measurement set

This document will describe each of these enhancements in detail. The majority of the document will explain RZ measurements as they are extensive and step-by-step procedures are included for each individual measurement.

Reduced Jitter

The specification for the inherent jitter (RMS) of 86100A mainframes shipped prior to December 2000 is:

2.5 ps + 5 x 10^{-5} x (timebase position)

This implies that as signals are viewed with minimal delay settings, the jitter should be much smaller than signals that are viewed with large delay settings. Although the specification indicates that the very best instrument performance is roughly 2.5 ps, achieved performance is actually about 1.5 ps. This jitter performance, although quite good, is likely to be inadequate for viewing 40 Gb/s waveforms. Consider that 1.5 ps of RMS jitter will likely produce almost 9 ps of peak-to-peak jitter. With a bit period of only 25 ps, this would result in significant eye closure for a 40 Gb/s signal. To provide the necessary measurement performance, the 86100A triggering circuitry has been upgraded to significantly reduce the inherent jitter. The following display shows the previous 86100A performance compared to the new performance levels. Both plots indicate typical performance.

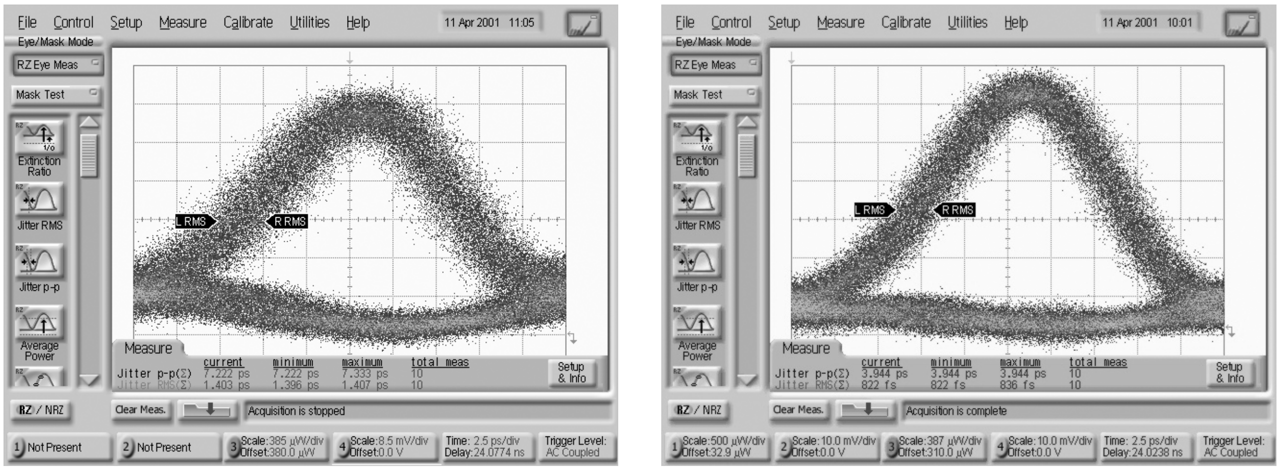


Figure 1. Old performance indicating jitter at 1.4 rms/7.2 pp ps and new performance indicating jitter at 0.82 rms/3.9 pp ps

86100A mainframes with the improved jitter performance began shipping in December of 2000. Thus any instruments ordered today will have the improved jitter performance.

Even with these improvements in the DCA mainframe, jitter due to instrumentation can still be a dominant component of some displayed waveforms. This jitter can be reduced significantly through a novel triggering scheme employed by the Agilent 86107A precision timebase plug-in module. Traditional sampling oscilloscopes attempt to precisely determine the *time* elapsed from a trigger event to a sampled point. The precision timebase module instead determines the relative *phase* of any sampling event within the period of the trigger. This technique yields a dramatic reduction in the timing jitter of the DCA mainframe system to less than 200 fs RMS and 1 ps peak-to-peak. Instrumentation jitter is virtually eliminated so that the jitter of the displayed waveform is due almost completely to the signal under test.

The tradeoff in this technique is that it is only viable for clock triggering. Thus the displayed signal is *always* in an eye diagram format, and will essentially display repetitions of a waveform when the timespan is increased outside of one period of the clock trigger. This is a valid methodology for eye-diagram analysis for both RZ and NRZ coded signals. Trigger signals near 10, 20 and 40 GHz are compatible with the 86107 module. This module requires one slot in the 86100A DCA mainframe.

Typical jitter performance is shown in Figure 2. Note that a signal such as a synthesized sinusoid is required to verify this level of jitter performance. (Waveform amplitudes are identical but appear different due to different vertical scale factors)

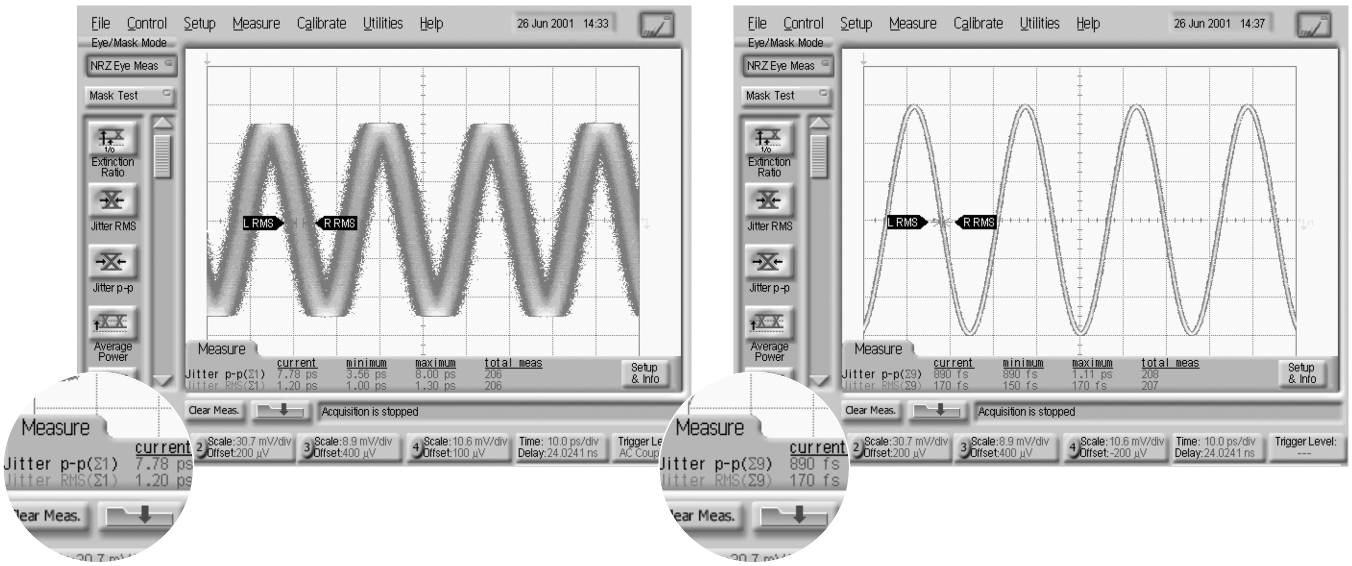


Figure 2. Jitter improvements using the 86107A precision timebase module

Higher Timebase Resolution

At introduction the 86100A mainframe timebase settings could be adjusted from 1 s/division to as low as 10 ps/division. With a 10 ps/division setting, the full span of the instrument is 100 ps. Thus a 40 Gb/s signal, with a 25 ps bit period, would have four bit periods displayed. When displaying eye diagrams, it is typically preferred to display a single bit period, as the other 3 eyes do not provide any additional information about the signal. The ideal timespan for a 40 Gb/s eye diagram should be somewhere between 4 ps/division and 2.5 ps/division. The timebase resolution of the 86100A can now be set from 1 s/division to 2 ps/division. This is shown in the following measurements.

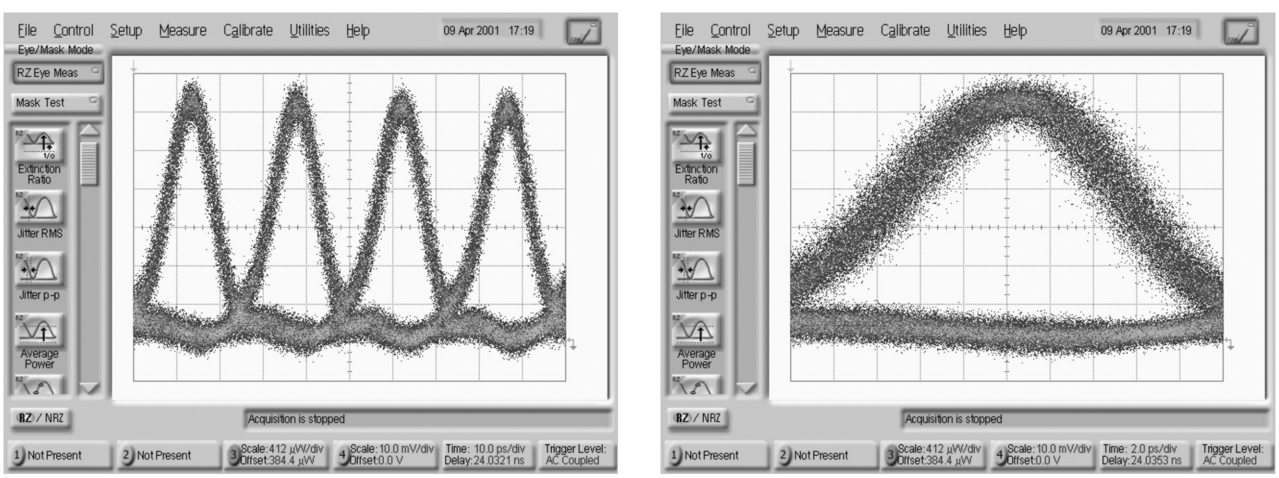


Figure 3. Highest timebase resolution was 10 ps/division and is now 2 ps/division

The new resolution is achieved through firmware enhancements. Thus any 86100A can be easily upgraded to have this capability. Firmware revisions 2.00 or higher have the improved timebase resolution. For upgrade information contact your local Agilent representative.

Wide Bandwidth Optical Receivers

Several plug-in modules with integrated optical receivers can be used with the 86100A mainframe. The 86109A plug-in provides 30 GHz of optical bandwidth. A 40 Gb/s signal is likely to have rise and falltimes on the order of 10 ps. RZ signal formats will require even faster edge speeds. A bandwidth of 30 GHz will not be sufficient to accurately measure these signals. However, designing a wide-bandwidth receiver with high-fidelity pulse response can be extremely difficult. If the frequency response is not carefully controlled, the displayed waveform can exhibit overshoot, undershoot, and ringing. Figure 4 shows the optical impulse responses for the 86109A, 86109B, and 86116A plug-in modules with 30, 40 and 55 GHz bandwidths respectively. The impulse responses (FWHM pulse-width) are 17, 12 and 8 picoseconds respectively. Note that even with the significant improvements in channel bandwidths, the waveform distortion has actually improved from the original 30 GHz bandwidth product.

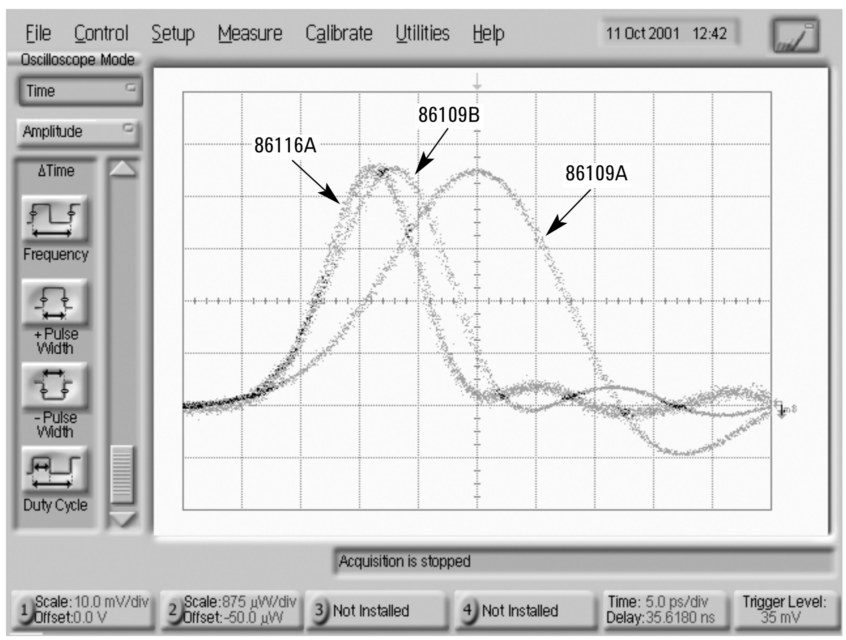


Figure 4. Impulse response comparisons for 86109A and the new 86109B

Return-to-Zero (RZ) measurements

The Agilent 86100A Infiniium DCA wide-bandwidth oscilloscope is used to view and characterize both optical and electrical waveforms used in digital communications. One of the most common uses of this instrument is to view eye diagrams generated by high-speed transmitters. The instrument has several built in measurements designed specifically for evaluating and analyzing eye-diagrams. Traditionally, optical communication schemes have used an NRZ (non-return-to-zero) format for rates as fast as 10 Gb/s. The Agilent 86100A includes an extensive measurement set optimized for NRZ eye diagrams.

An RZ signaling scheme can provide an attractive method to overcome some of the performance barriers encountered when using optical fiber. Many designers will take advantage of an RZ modulation format as 40 Gb/s systems are developed. Some ultra-long distance transmission systems operating at rates below 40 Gb/s are also based on an RZ format.

Considering the 25 ps bit period of a 40 Gb/s signal, even minor signal dispersion can become a significant distortion element leading to eye closure and degraded bit error rates. RZ transmission can be used to offset some of the dispersive effects of optical fiber. For example, soliton pulses are a class of RZ signals that take advantage of the nonlinear effects of fiber to minimize chromatic dispersion.

When an oscilloscope performs an automatic measurement of a waveform, it will analyze the signal and “search” for specific characteristics. For example, when performing an extinction ratio measurement for an NRZ eye diagram, the waveform is scanned to locate the crossing points. Once the crossing points are found, the central region of the eye can be located and scanned to determine the logic ‘1’ and ‘0’ levels. Since crossing levels do not exist in an RZ waveform, the extinction ratio algorithm designed for an NRZ eye cannot be applied to an RZ signal. However, the 86100A now has an RZ mode with an extensive set of waveform measurements specifically for use with RZ signals. The remainder of this product note will define the new measurements and their procedures. (RZ measurement capability is available with 86100A firmware release A.02.10 and higher. Firmware upgrades are free. Contact your local Agilent representative).

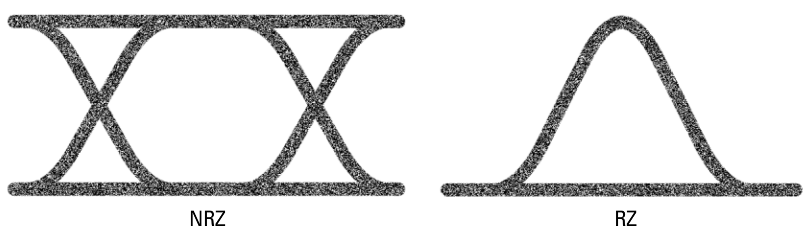


Figure 5. NRZ and RZ eye diagrams

RZ measurements available in the 86100A

The 86100A measurement set for RZ signals includes the following:

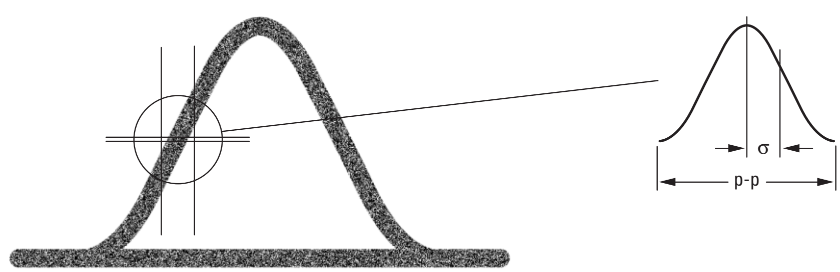
- RMS jitter
- Peak-to-peak jitter
- Extinction ratio
- Average power (optical channels only)
- Risetime
- Falltime
- One level
- Zero level
- Eye amplitude
- Eye height
- Eye opening factor
- Signal-to-noise ratio
- Pulse width
- Eye width
- Duty cycle
- Bit rate
- Contrast ratio

The measurements available for RZ waveforms are similar to the NRZ set. Pulse width, eye opening factor, duty cycle and contrast ratio have been added while an RZ version of crossing percentage is not available. In addition, there are some subtle differences in the RZ measurement definitions.

All measurements, with the exception of average power, are made on an infinite persistence database. That is, samples from many waveforms are overlapped and analyzed. Thus test results are made on the composite and not a single waveform.

Jitter: RMS and Peak-to-peak

Jitter is a measure of the instability of a signal from its ideal time position. In an RZ signal, jitter is manifested as a broadening in both the rising and falling edges of the eye. To characterize the jitter, histograms are constructed on the first edge from the left of the screen, either rising or falling. The histogram boundary defining the data set is wide enough in time to include the full spread on the edge, but narrow enough in amplitude to minimize the influence of the edge slope on the histogram width.

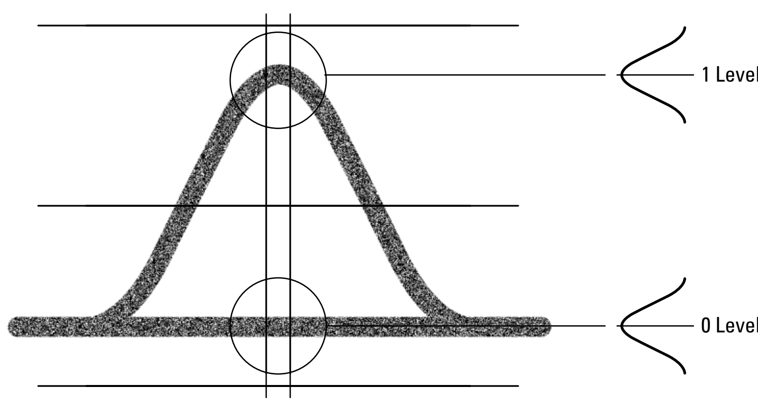


The RMS jitter is determined by calculating the standard deviation of the histogram. The peak-to-peak jitter is determined by finding the difference between the extreme data points of the histogram. Note that with an NRZ signal, the jitter definitions are similar, but the data is acquired at the crossing point. Since the RZ signal has no crossing point, the 50% height of the edge is analyzed. (Users can define this parameter).

Extinction Ratio

For NRZ eyes, the industry has standardized on the following definition: Extinction ratio is simply the ratio of the power levels of the eye diagram's '1's to the '0's. Power levels are determined by performing a histogram analysis of the upper and lower regions in the central 20% of the eye. The measurements are made with a low-pass filtered reference receiver which performs an integrating function. The integrating receiver combined with the data extracted from the center of the eye should effectively yield the aggregate power of the 1's and 0's.

For the RZ eye, the above approach is not used. The receiver is not low-pass filtered, hence there is no integrating function. Instead it is typical to use the widest bandwidth receiver possible. Although the default value for the NRZ eye window is 20%, it is user definable and good practice to define this value smaller for RZ signals to avoid having the rising and falling edges contribute to the histogram results. The default eye window for RZ measurements is the central 5% of the logic '1' pulse. Thus what is effectively being measured is the aggregate power in the central region of the eye '1' level and the aggregate power in the '0' level over the same time period. Note that the aggregate power of the center of the '1' level is not the same as the peak value of the '1' level power. The peak value of the '1' level power would be the maximum amplitude of the signal. The aggregate power in the peak involves constructing a histogram that includes all the data in the upper half of the waveform that falls within the narrow window. The diagram below illustrates the histogram construction.

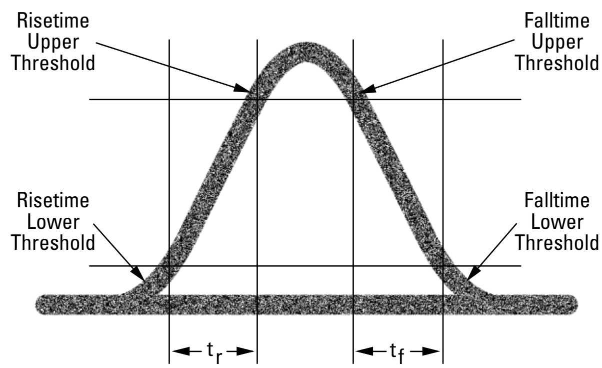


Extinction ratio (linear) = (1 level- dark level)/(0 level - dark level)
Extinction ratio (%) = ((0 level - dark level) /(1 level- dark level)) x 100
Extinction ratio (dB) = 10 $\log_{10}$ ((1 level- dark level)/(0 level - dark level))

Dark level represents any residual signals in the analyzer that exist when no signal is present and are automatically removed when a proper extinction ratio calibration is performed.

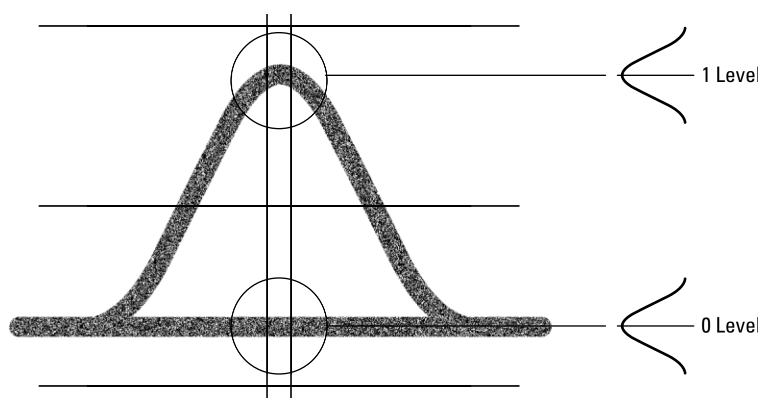
Risetime and Falltime

The transition speed from a ‘0’ to a ‘1’ is given by a risetime measurement. The transition speed from a ‘1’ to a ‘0’ is given by a falltime measurement. The measurement results are calculated for the aggregate infinite persistence displayed waveform. The measurement is constructed by locating the appropriate signal edge and finding the time points for the defined thresholds. These thresholds can be set to the 10% and 90%, 20% and 80% or user defined amplitudes relative to the ‘1’ level. The default thresholds are 20% and 80%. For signals with significant noise, overshoot or ringing the 20 and 80% thresholds are recommended.



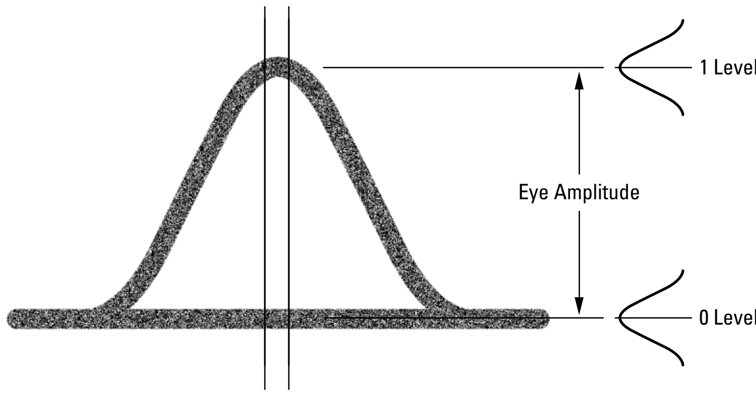
One (‘1’) and Zero (‘0’) level

The measurement procedure for the ‘1’ and ‘0’ levels was described previously in the explanation of RZ extinction ratio.



Eye Amplitude

Eye amplitude is simply the difference between the '1' level and the '0' level and represents the power in the eye diagram that is actually carrying information. This measurement is similar to eye height, but does not account for any noise that may be present on the signal.



Eye Height

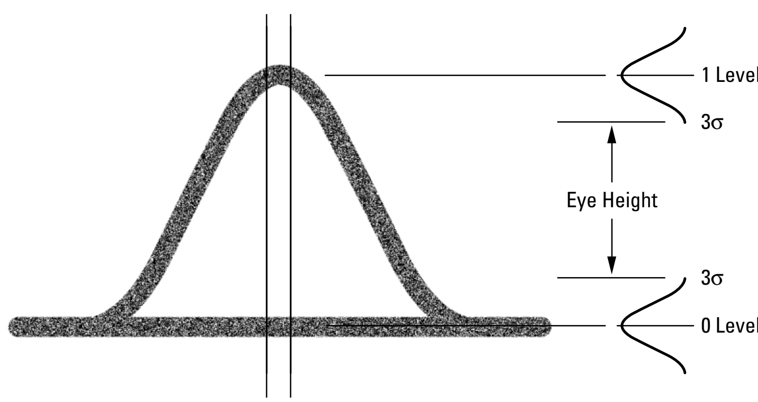
This measurement is used to quantify the vertical opening of the eye diagram. The mean '1' level is determined. Then the 3 standard deviation noise or "spread" of the signal at the '1' level is determined. The process is repeated for the '0' level. The eye height is then calculated as:

$(1 \text{ level} - 3\sigma_1) - (0 \text{ level} + 3\sigma_0)$

or when expressed in decibels

$10 \log_{10} ((1 \text{ level} - 3\sigma_1) - (0 \text{ level} + 3\sigma_0))$

The region of the signal being measured and methods used to compute these values are consistent with the extinction ratio and '1' and '0' level measurements.



Eye Opening Factor

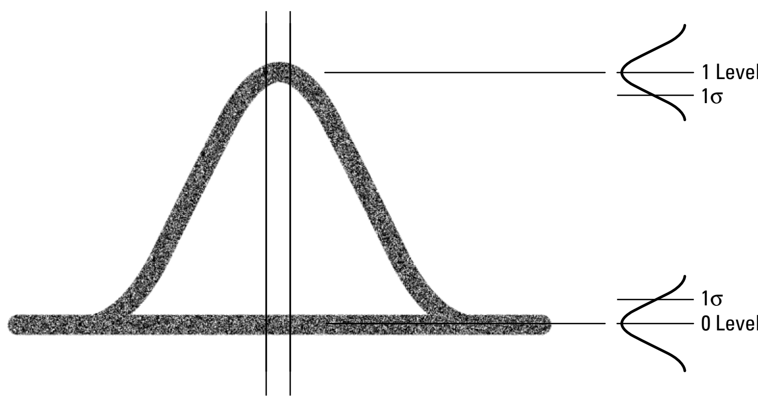
The eye opening factor is very similar to eye height. It is a measure of the actual eye opening relative to the ideal noise-free eye. Similar parameters and measurement techniques are used with eye height and eye opening. However, eye opening uses one standard deviation for the noise contribution while eye height uses three standard deviations. The result is computed as:

1 standard deviation Eye height/eye amplitude

or in another form:

$((1\text{ level} - \sigma_1) - (0\text{ level} + \sigma_0))/(1\text{ level} - 0\text{ level})$

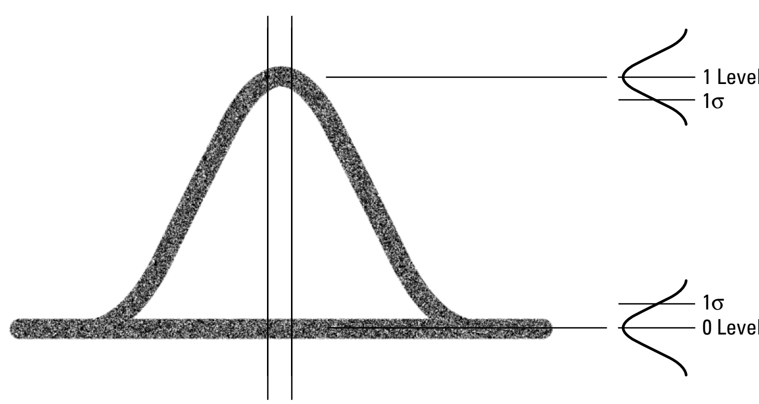
If the eye were noise free, the eye opening factor becomes one, indicating the eye is completely open. As noise increases the factor eventually goes to zero.



Signal-to-noise ratio

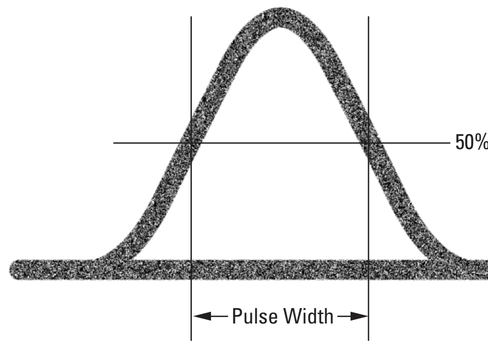
This parameter is also similar to eye height and eye opening. In signal-to-noise the “signal” is the information power of the signal indicated by the difference between the ‘1’ and ‘0’ level. The “noise” is the combined standard deviations of the ‘1’ level spread and the ‘0’ level spread. The measurement is constructed as:

$(1\text{ level} - 0\text{ level})/(\sigma_1 + \sigma_0)$



Pulse Width

This measurement yields the time between the 50% amplitude of the rising edge and the 50% amplitude of the falling edge. The threshold value is defaulted at 50% but can be adjusted by the user.



Eye Width

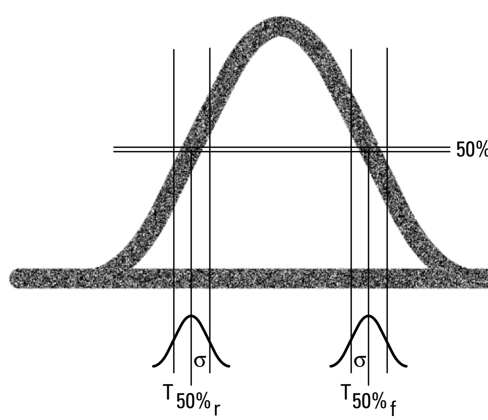
Eye width is similar to the eye height measurement except that it is used to quantify the horizontal opening of the eye. Due to jitter and noise, there will be some width to the rising and falling edges of the many ‘1’ pulse samples that make up the RZ eye diagram. In an NRZ eye, width is measured between the crossing points of the eye. For the RZ signal, the 50% height is determined as the half way point between the ‘1’ and ‘0’ levels. The rising edge is scanned to determine the time where the aggregate waveform reaches this 50% level. At this point a histogram is constructed to determine the horizontal spread of the signal. Three standard deviations are used. The process is repeated for the falling edge. The eye width is determined as:

$(T_{50\%\ \text{falling edge}} - T_{50\%\ \text{rising edge}}) - (\sigma_r + \sigma_f)$

or when expressed as a percentage:

$[((T_{50\%\ \text{falling edge}} - T_{50\%\ \text{rising edge}}) - (\sigma_r + \sigma_f))/\text{bit period}] \times 100$

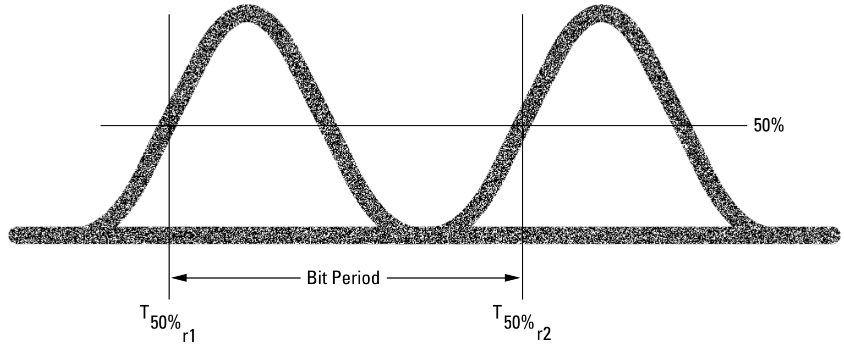
The user has the option of choosing a threshold other than 50%



Bit Rate

Bit rate is the inverse of the bit period. The oscilloscope does not have any direct frequency measurement capability, but it can measure the time between two rising edges. The bit rate is computed as follows:

$(T_{50\%\ \text{rising edge 2}} - T_{50\%\ \text{rising edge 1}})^{-1}$

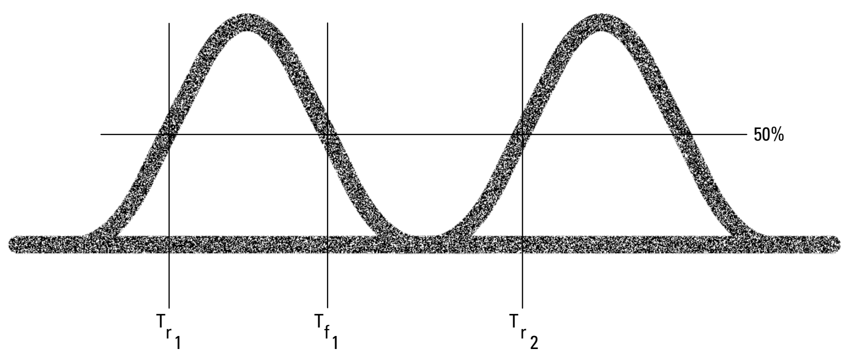


Duty Cycle

Duty cycle is a measure of the duration of the '1' pulse relative to the full bit period. It is defined as

$(T_{50\%\ \text{falling edge}} - T_{50\%\ \text{rising edge}})/(T_{50\%\ \text{rising edge 2}} - T_{50\%\ \text{rising edge 1}})$

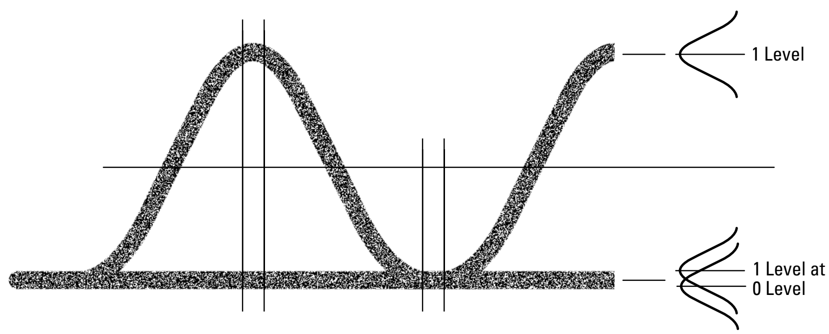
The user does have some ability to control the threshold of where the pulse duration is measured. The default level is 50%.



Contrast Ratio

Contrast ratio is used to determine how well the logic ‘1’’s return to the zero amplitude. It is different than extinction ratio in that the ‘1’ level at the central region of the eye is compared to the ‘1’ level *between* pulses. Note that the signal between bits is a combination of the ‘1’ and the ‘0’. To remove the effect of the ‘0’, the ‘0’ level is measured in the central region of the eye. The ‘0’ level between pulses is assumed to be similar in both the central region of the eye and between pulses. The ‘0’ level is then mathematically removed from the complete signal measured between pulses, the residual being the ‘1’ level. The window over which the measurement is constructed is user definable for the central region of the eye and is defaulted to the central 5%. The window for the measurement between pulses is identical in width to that used to measure the ‘1’ level, but is placed a half bit period later in time.

Contrast ratio= ‘1’ level from central window/’1’ level from offset window



Procedures for Performing the Measurements

The RZ measurements are designed only for eye diagrams that have the characteristics of an RZ eye. They generally will not work on an NRZ eye. To view an RZ signal on the 86100A, the oscilloscope must be triggered with a clock signal. This clock rate can be the same as the data rate, or at a submultiple of the data rate. For example, to measure a 10 Gb/s signal, the clock signal can be at 10 GHz or at a subrate such as 5 GHz, 2.5 GHz or 1 GHz. The trigger signal must be highly coherent with the signal being measured. (A data signal can also be used as a trigger signal, but is not recommended due to the resulting misrepresentation of jitter and half of the test pattern never being sampled). If a trigger signal that is synchronized to a data pattern is used, a pulse train will be displayed. Since this will not be an eye diagram, the RZ measurements will generally fail. In this case the general purpose “oscilloscope mode” measurements should be used.

The 86100A must be configured to measure a signal with an RZ format. This is achieved by selecting the Measure/Eye Mask/RZ from the pulldown menu at the top of the display. The left vertical toolbar will switch to a set of RZ eye measurements. Mask measurements do not change for RZ test and are currently identical to the NRZ set.

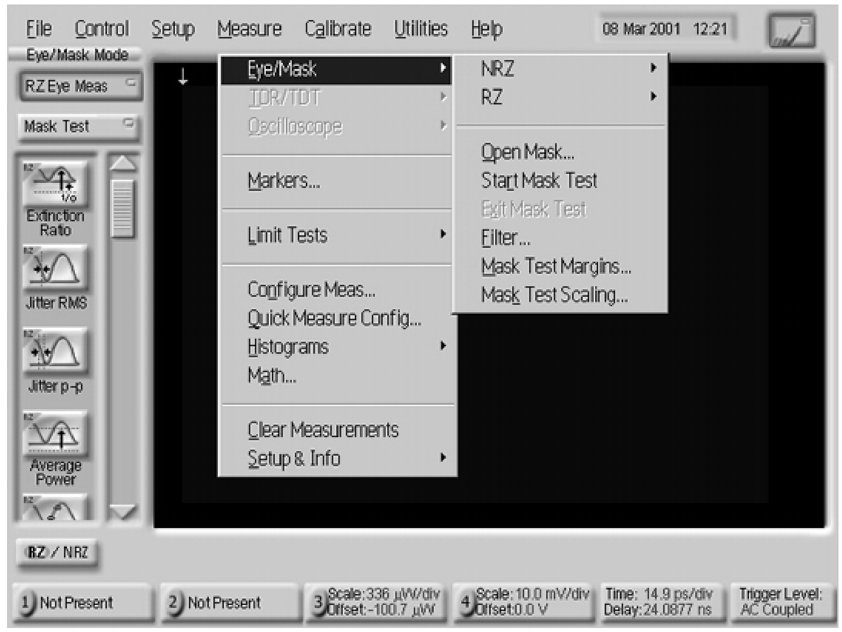


Figure 6. Instrument display for RZ measurements

The RZ measurements require the signal be correctly positioned on the display. The basic requirements are:

1. The full height of the waveform is visible with no clipping at the top or bottom of the signal.
2. At least 1.5 periods of the signal are displayed such that a full pulse followed by the complete rising edge of a subsequent pulse, or a complete falling edge followed by a complete pulse is seen.

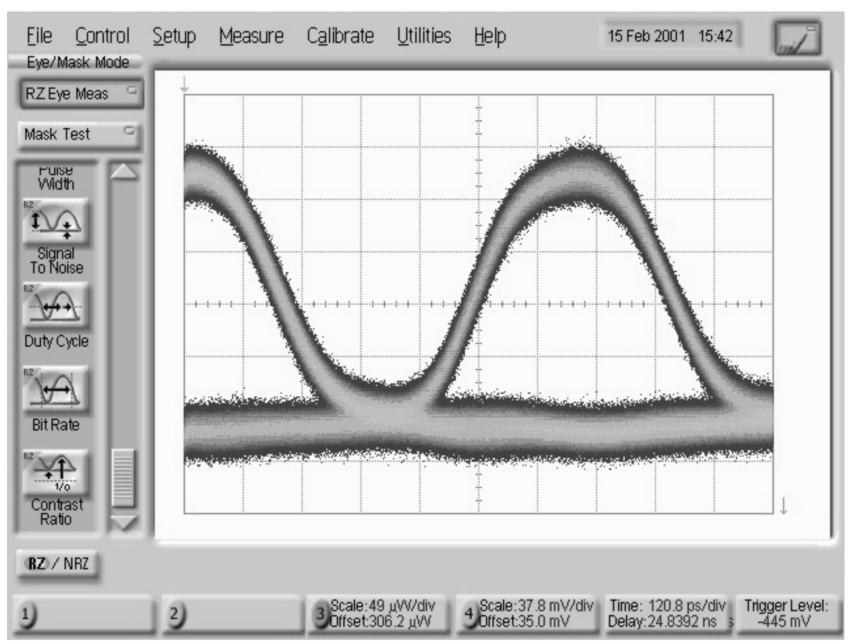


Figure 7. Horizontal scale requirements for automatic RZ measurements

The easiest way to achieve this is by executing an autoscale. Note that when the RZ mode is selected, the autoscale routine is optimized for RZ eye diagrams.

The instrument should also be configured in terms of measurement thresholds and definitions. For example, if risetimes are to be measured from the 20% to 80% levels, this should be set. For narrow RZ pulses, the eye window boundaries default to the 47.5% and 52.5% points (central 5%). These can be changed by selecting Measure from the pulldown menu, and selecting Configure Measure.

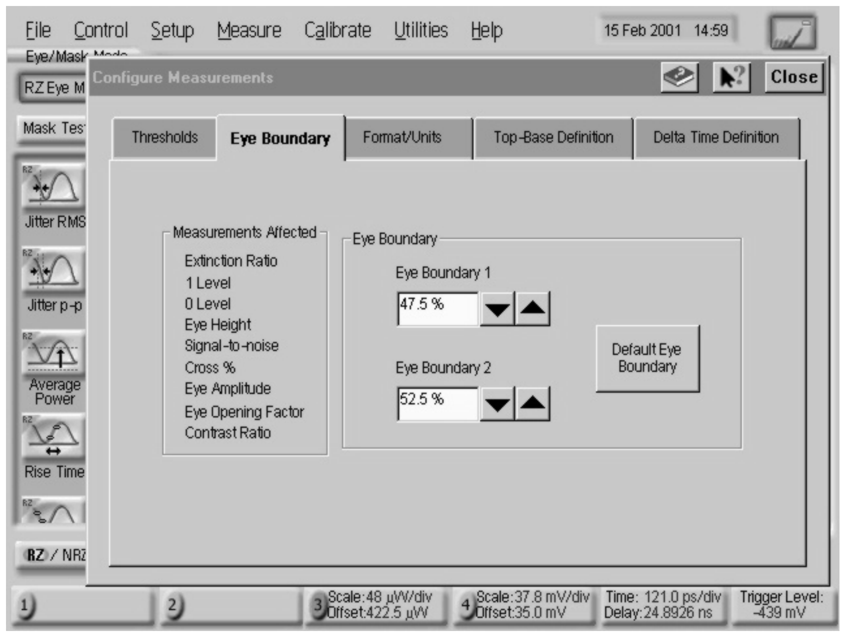


Figure 8. Configuring the instrument

With the instrument configured and the signal correctly placed on the display, measurements can now be performed.

Measurements are activated through the RZ measurement toolbar or the pulldown menu. Simply touch the icon for the desired measurement. The pulldown menu is activated by pressing "Measure" from the pulldown menu at the top of the instrument screen. Then select Eye/Mask, RZ, and the appropriate class of measurements needed. For example, to measure the logic '1' amplitude, after selecting RZ, press Amplitude and Logic '1' Amplitude.

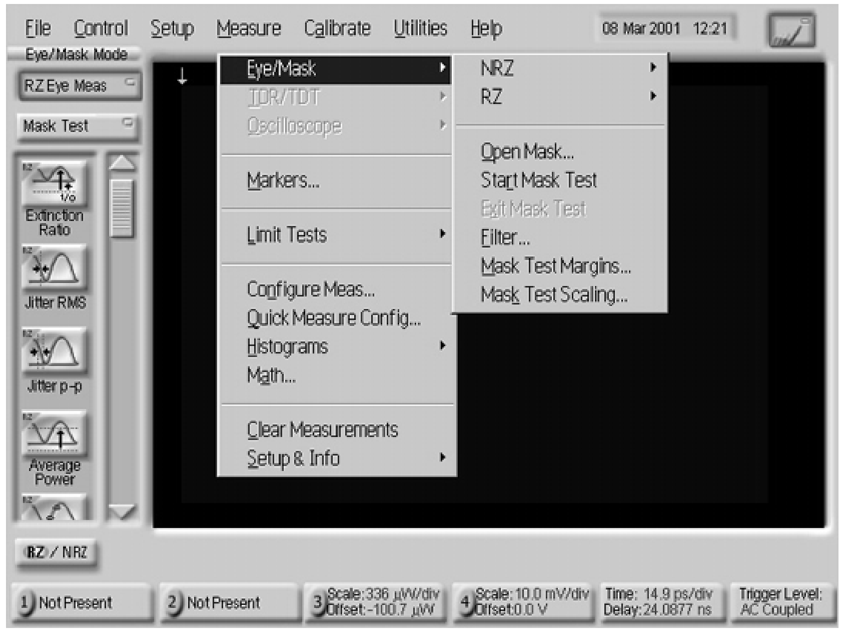


Figure 9. Using the pulldown menu procedure for RZ measurements

Up to four measurements can be active and simultaneously displayed. If a fifth measurement is selected, the first measurement will be dropped from the display.

When a measurement is activated, it can be annotated to provide feedback on how the instrument is performing the analysis. The following example shows how annotation is used to document the construction of a contrast ratio measurement.

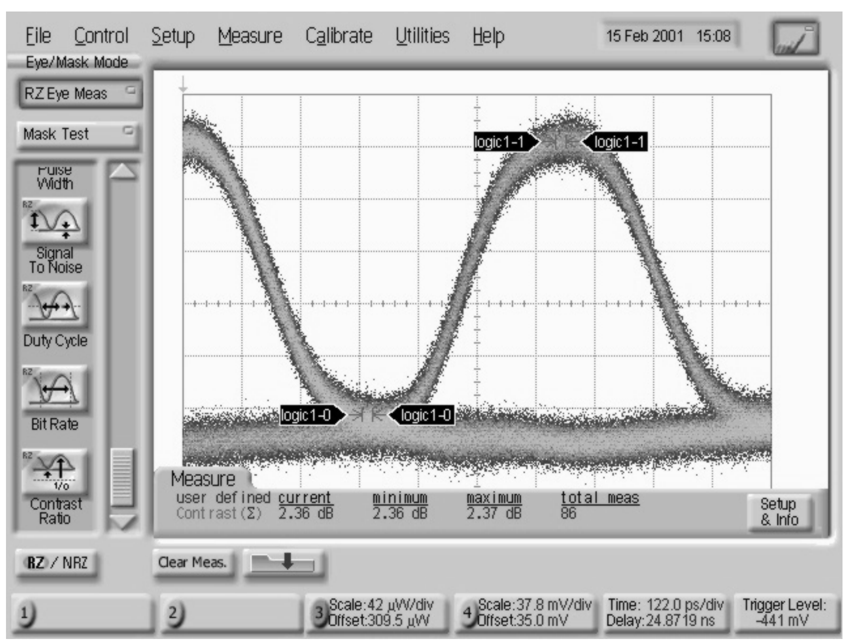


Figure 10. Using annotation to gain insight into measurement construction

To activate annotation press the “Setup & Info” key on the measurement tab below the graticule (after activating any measurement). The same steps can be used to disable annotation.

All RZ measurements are performed on an infinite persistence display. Thus the waveform is a composition of samples from many bits in a datastream. This type of measurement is indicated on the measure results tab with a “(Σ)” such as “Contrast Ratio (Σ)” as seen in Figure 10. Measurements tend to be more accurate as the sample size increases through the acquisition of several waveforms. However, valid measurements are usually available after just a few seconds of acquisition time. Usually 15 to 30 waveforms are quite adequate for a stable and repeatable measurement. To assure a minimum sample size for measurements, the instrument will not report a result until at least one pixel on the display has been hit at least 15 times. Once a database of significant size is obtained, new measurements can be activated without having to acquire new data. In other words, multiple measurements can and should be made on a single database. If horizontal or vertical scaling parameters are altered, a database is rendered invalid and is cleared and acquisition is restarted.

Acknowledgement

The author would like to acknowledge Chris MacGregor of Nortel/QTERA for help in developing the suite of RZ measurements

Agilent Technologies'
Test and Measurement Support, Services, and Assistance

Agilent Technologies aims to maximize the value you receive, while minimizing your risk and problems. We strive to ensure that you get the test and measurement capabilities you paid for and obtain the support you need. Our extensive support resources and services can help you choose the right Agilent products for your applications and apply them successfully. Every instrument and system we sell has a global warranty. Support is available for at least five years beyond the production life of the product. Two concepts underlie Agilent's overall support policy: "Our Promise" and "Your Advantage."

Our Promise

Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

Your Advantage

Your Advantage means that Agilent offers a wide range of additional expert test and measurement services, which you can purchase according to your unique technical and business needs. Solve problems efficiently and gain a competitive edge by contracting with us for calibration, extra-cost upgrades, out-of-warranty repairs, and on-site education and training, as well as design, system integration, project management, and other professional engineering services. Experienced Agilent engineers and technicians worldwide can help you maximize your productivity, optimize the return on investment of your Agilent instruments and systems, and obtain dependable measurement accuracy for the life of those products.

By internet, phone, or fax, get assistance with all your test & measurement needs.

Online assistance:
www.agilent.com/comms/lightwave

Phone or Fax
United States:
(tel) 1 800 452 4844

Canada:
(tel) 1 877 894 4414
(fax) (905) 282 6495

Europe:
(tel) (31 20) 547 2323
(fax) (31 20) 547 2390

Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Latin America:
(tel) (305) 269 7500
(fax) (305) 269 7599

Australia:
(tel) 1 800 629 485
(fax) (61 3) 9210 5947

New Zealand:
(tel) 0 800 738 378
(fax) 64 4 495 8950

Asia Pacific:
(tel) (852) 3197 7777
(fax) (852) 2506 9284

Product specifications and descriptions in this document subject to change without notice.

Printed in USA November 15, 2001
5988-2039EN

Agilent Technologies