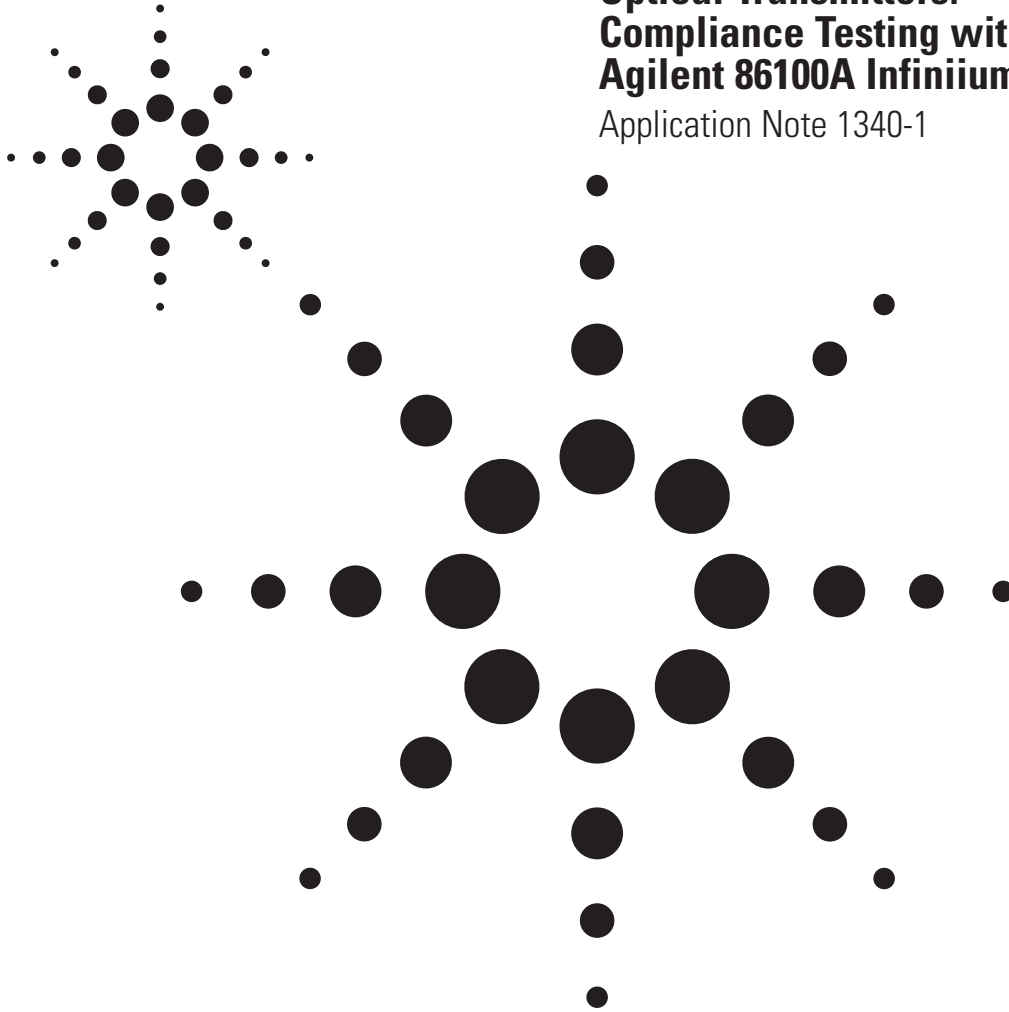


Characterizing High-Speed Optical Transmitters: Compliance Testing with the Agilent 86100A Infiniium DCA

Application Note 1340-1



Agilent Technologies
Innovating the HP Way

Introduction

The need for reliable high-speed digital communications test

The recent explosion in data communications has led to a rapidly increasing demand for high bandwidth communications links. This in turn has spurred the demand for high-speed optical transmitters for fiberoptic communication systems. In order to achieve interoperability between vendors, standards organizations have defined sets of tests which transmitters must pass in order to be considered compliant or capable of performing correctly within an operational communications system. This application note will discuss procedures and best practices for compliance testing at what is commonly called the physical layer. Such testing is often referred to as parametric testing. This application note will focus on parametric testing in the time domain, and will discuss eye diagram measurements and mask testing.¹ These tests are generally performed with a pattern generator and digital communications analyzer.

Agilent Technologies is a leading supplier of specialized wide bandwidth sampling oscilloscopes that are also referred to as communication analyzers.² The HP 83480A and the new Agilent Technologies 86100A are used throughout the telecommunications and data communications industries to ensure that high-speed components and communications systems are functioning according to industry standards.

Measurements, standards organizations and relevant documents

This product note will focus on the testing of optical transmitters used by three communications technologies: SONET/SDH, Gigabit Ethernet, and Fibre Channel. This paper will discuss the following measurements: extinction ratio, jitter, average power, rise time, and mask testing. The Agilent 86100A has a number of other built-in measurements for eye characterization including: crossing percentage, fall time, one level, zero level, eye height, eye width, signal-to-noise, and duty cycle distortion. These measurements are sometimes recommended but not required by the standards organizations and are therefore beyond the scope of this application note.

SONET/SDH

SONET or Synchronous Optical Network is the North American standard governing high-speed optical telecommunications. SDH or Synchronous Digital Hierarchy is the international equivalent of SONET. SONET was developed in the early 1980s and was originally based on mapping the ANSI T-1 rates onto optical carriers.³ Bellcore, now known as Telcordia, was instrumental in working with ANSI in the development of the SONET standards. The Bellcore OC-48 (2.488 Gb/s) standards document is "GR-253-CORE: Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria" and the Bellcore OC-192 (9.953 Gb/s) standards document is "GR-1377-CORE: SONET OC-192 Transport System Generic Criteria". The Telecommunications Industry Association (TIA) in association with the Electronic Industries Association (EIA) has also published recommendations for implementing the SONET standards in the document "OFSTP-4A: Optical Eye Pattern Measurement Procedure".

SDH standards were created and are maintained by the International Telecommunications Union — Telecommunication Standardization Sector (ITU-T) in Geneva, Switzerland. The STM-4 and STM-16 (622 Mb/s and 2.5 Gb/s) standards are referenced by standards G.957 and G.958. The International Electrotechnical Commission has also published test procedures for implementing the SDH standards in IEC 61280-2-2 Test Procedures for Digital Systems — Optical Eye Pattern, Waveform, and Extinction Ratio.

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- 1 There are additional parametric tests associated with frequency/wavelength domain measurements which are performed with optical spectrum analyzers or multi-wavelength meters, tunable laser sources and optical power meters.
 - 2 Digital communications analyzers are wide bandwidth oscilloscopes with enhanced measurement capabilities that are used with reference optical receivers to make measurements such as extinction ratio and to perform mask tests. In this paper both terms will be used interchangeably, with the understanding that when the term oscilloscope is used it is an oscilloscope with the enhanced measurement capabilities of a digital communications analyzer.
 - 3 ANSI stands for the American National Standards Institute.

Gigabit Ethernet

Gigabit Ethernet is an evolution of the Ethernet data communications standard. It is a shared communications medium that is used for high-speed applications and network backbones. It uses 8B/10B encoding and runs at a bit rate of 1.25 Gb/s which results in a data transfer rate of 1 gigabaud. The 8B/10B encoding prevents the use of certain bit patterns which are prone to errors by using an additional 2 bits (10 bits total) to represent each 8 bit word. The Gigabit Ethernet standards are contained in the ANSI/IEEE document IEEE Std 802.3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications. The standards referring to ethernet systems running at the 1.25 Gb/s rate are categorized as 1000BASE-X.

Fibre Channel

Fibre Channel is used primarily in storage area networks and for high-speed point-to-point computer communications. The Fibre Channel standards are specified in the American National Standard for Information Technology document ANSI X3.297-1997: Fibre Channel — Physical and signaling Interface-2 (FC-PH-2). Currently most Fibre Channel systems are running at a bit rate of 1.0625 Gb/s. However, at the time of this writing, some companies are working on parts for the next approved data rate of 2.125 Gb/s, and the standard also specifies a future data rate of 4.25 Gb/s.

With so many sources to reference, it is difficult to precisely define "standards compliant". This paper is an attempt to document a set of tests that can be implemented to determine whether an optical transmitter is compliant. However, since standards are constantly evolving, and since the standards documents themselves are subject to interpretation, it is strongly recommended that the reader spend time researching the original documents to ensure that their testing procedures are adequate.

Parametric testing overview

Digital Communications Analyzers and Bit Error Ratio Testers

It is important to understand the relationship between testing with a digital communications analyzer and testing with a bit error ratio tester (BERT). Transmitters are qualified by using a digital communications analyzer to perform mask tests and measure eye parameters such as extinction ratio, rise time, and jitter. Bit error ratio testing is used to qualify a receiver or a complete communications system.

In simple terms, bit error ratio (BER) is the ratio of the number of erroneous bits received to the total number of bits received. A bit error ratio tester uses a pattern generator to generate a specific sequence of bits which are input to the transmit side of a communications system. The transmitter sends this signal across a link to the receiver, and then the BERT compares the pattern coming out of the receiver to the original bit sequence created by the pattern generator and calculates the bit error ratio. For communications system testing, the pattern generator sends the signal to the transmitter under test which is linked to the receiver under test and the BER is determined for that entire system. For receiver testing, a reference transmitter with a specific power and extinction ratio is used for the transmit side of the test and the BER is measured for the receiver.

Full BER tests can be quite time consuming.⁴ Many companies reduce the time per test by inserting a laboratory quality variable optical attenuator in the link. The optical power of the link is incrementally reduced and a BER versus optical power curve is generated. This curve is extrapolated to estimate what the results of a full power BER test would be. The lower power testing generates more errors and a statistically significant number of errors is attained in a much shorter timeframe. Models are created to correlate the lower powered BER test with a full BER test, and the lower powered BER test is used to predict what the full BER test results would be.

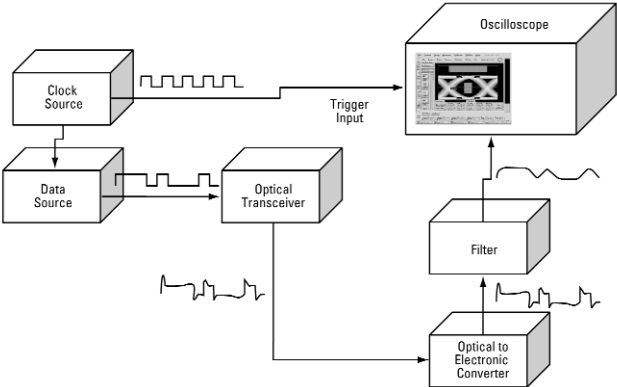
4 For example, if you wanted to get a sample of 1000 errors to prove a bit error ratio of 10^{-12} on an OC-48 line running at 2.488 Gb/s, it would take $1000 \text{ errors} \times 10^{12} \text{ bits/error} \div (2.488 \times 10^9 \text{ bits/sec}) \div 3600 \text{ secs/hr}$ or 111.6 hours to complete this test. Likewise, to test to a bit error ratio of 10^{-10} would take 1.12 hours.

The combination of the bit error ratio and eye/mask tests allow developers and manufacturers to build communications components and systems which will be functional when deployed as operational systems. If the transmitter passes a specific set of parametric tests (extinction ratio, average power, jitter, mask, etc.), and the receiver has the required sensitivity (BER versus power), then a properly designed and implemented system using these components should be able to achieve a minimum BER for a specified transmission link.

Oscilloscope Test Block Diagram

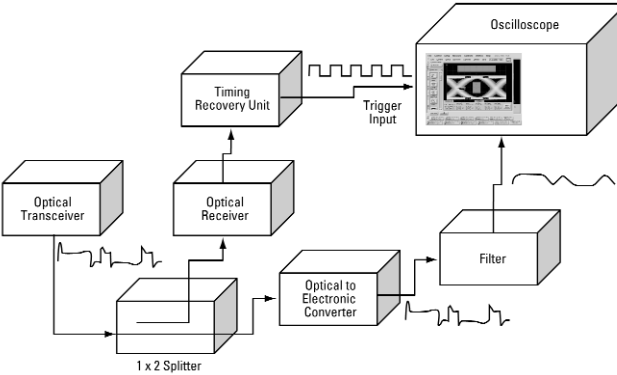
Figure one shows a basic block diagram for testing optical transmitters such as light emitting diodes (LEDs), CD lasers, Fabry-Perot lasers and vertical cavity surface emitting lasers (VCSELs). The oscilloscope is the basic instrument used to view and measure the waveforms generated by the optical transmitter. An external clock source is used to time the data and also to trigger the sampling oscilloscope. Oftentimes the clock source and the data source are integrated into a single chassis such as the Agilent 86130A or the Agilent 71612B. The optical to electrical converter (O/E) along with specially designed filters allow the output from the optical transmitter to be viewed and measured by the oscilloscope. The Agilent 86100A integrates the O/E with switchable Bessel-Thomson filters to create SDH/SONET reference receiver plug-in modules.

Figure 1:
Test setup with external clock source available.



Additional equipment will be necessary when testing higher-level communication systems if an external clock source is not available. In this situation, it is important to use a clock recovery system and not use the data signal to trigger on. Using the data signal as a trigger will result in an incomplete sampling of the signal and, due to timing inconsistencies, give inaccurate jitter measurements. The clock recovery system consists of an optical splitter, a second optical to electrical converter, and a clock recovery circuit. The Agilent 83492A (multimode) and 83493A (single-mode) clock recovery modules each provide an integrated splitter, optical receiver and timing recovery unit.

Figure 2:
Test setup with clock recovery system when an external clock source is not available.



Reference receivers and the Bessel-Thompson filtered response

All three standards (SDH/SONET, Gigabit Ethernet, and Fibre Channel) require that eye mask tests be performed with an optical receiver that has a 4th-order Bessel-Thompson filtered response.⁵ The Bessel-Thomson low pass response must have a smooth rolloff and provide a 3dB attenuation at the reference frequency which is defined to be 75% of the data rate under consideration. It is important to note that it is the combination of the filter and the O/E converter that must meet this response, not just the filter. The Bessel-Thomson filter and the O/E must be matched to attain this frequency response, which is why using a communications analyzer with a fully integrated architecture is preferable. The Agilent 86100A even goes one step further by having the entire measurement system including the filter, the O/E converter, and the scope's circuitry meet the Bessel-Thomson response requirements. The Agilent 86100A has built-in Bessel-Thomson filters that can be switched in and out with high bandwidth microwave switches. Since the entire plug-in module is tested to reference receiver specifications and the filters are permanently part of the receiver, there is much higher confidence that the system remains a reference receiver.⁶

There are two reasons for using a specified filtered response. The first is to gain consistency among different measurement systems — having a standard response for your measurement system allows measurements that were taken on different measurement systems to be compared. The second reason is to limit out of band frequencies, which would not be detected by an operational receiver. Limiting the reference receiver's bandwidth with the filter shows the waveform as it would appear to a lower bandwidth operational receiver. This allows measurements to be taken which are more relevant to the operational use of the transmitter.

Unfiltered measurements

In addition to filtered measurements, such as mask testing, some standards recommend taking unfiltered measurements. The unfiltered measurements allow you to use the full bandwidth of the measurement system to view the behavior of the transmitter under test. High frequency ringing and overshoot can be viewed and measured. Rise and fall time measurements are more accurate since you have greater measurement bandwidth available to measure the signal source with.⁷

5 See ITU G.957 or IEEE Std. 802.3 for the mathematical definition of the Bessel-Thomson transfer function.

6 With high-speed signals, slight impedance mismatches from cables and connectors can render a reference receiver non-compliant. Likewise, differences in Bessel-Thomson filters mean that some combinations of receivers and filters will pass the required response and yet a certain Bessel-Thomson filter with a certain receiver may not pass reference receiver requirements due to their interaction and the resultant overall reference receiver system frequency response.

7 The reduced bandwidth of the filtered measurements suppresses the high frequency signal content inherent in the faster edge speeds. The unfiltered measurements give additional insight into what the laser is actually doing by providing more accurate rise time measurements and showing overshoot and ringing.

Trigger source In order to accurately see high frequency signal components such as ringing and overshoot, it is desirable to have bandwidth from 3 to 5 times the bit rate of the signal being tested. However, with the current acceleration of the deployment of faster data rates, finding the ideal combination of DC coupled bandwidth, flat frequency response, and sensitivity can be difficult. Oftentimes the engineer must compromise and use the best bandwidth available, which may be less than the ideal 3 to 5 times multiplier.

Measurements made with a digital communications analyzer are highly dependent on the signal that the DCA is using as a timing reference or trigger. The best source to use for a trigger is a reference clock source directly from the original electrical PRBS⁸ or data generator that is driving the transmitter under test. If this is not available, a recovered clock with a minimal amount of jitter is the second best choice. Using the data signal also as a trigger source is not recommended for a number of reasons. First of all, the DCA needs either a rising edge or a falling edge to trigger on. This means that if you are triggering on data and have a series of '0's' or '1's' you won't be taking any samples during this period. A data trigger can miss up to 75% of the bits being transmitted.⁹ Since you won't be taking samples during these periods when there isn't a transition, you will miss that part of the signal and not know how well your transmitter does during these bit sequences.

The second reason not to use a data signal as a trigger is that the data signal may have jitter associated with it and therefore it won't be a stable timing reference. The jitter on the data will affect the timing of scope triggering which can cause erroneous jitter measurements. Using the data signal also as a trigger means that you are comparing the signal to itself instead of comparing it to a stable timing reference. A data trigger can make the displayed waveform look more or less jittery than it really is.

**Measurement System
Frequency Response**

It is critical that the entire measurement system exhibits a flat frequency response with a smooth rolloff. A low or a high frequency emphasis within the reference receiver will distort how the signal is displayed and can lead to waveform aberrations which are not actually being caused by the device under test. It is also important that the measurement system have a flat frequency response all the way back to DC. Extinction ratio measurements require that the DC component of the signal under test be accurately measured.

⁸ PRBS stands for Pseudo Random Bit Sequence

⁹ There are four possible combinations of two bits: 00, 01, 10, and 11. You can set the scope to trigger on either a 0 to 1 or a 1 to 0 transition, but not both. Thus, triggering on a rising (0 to 1) or falling (1 to 0) edge means that you will be generating triggers approximately 25% of the time (1 out of 4 possible two bit combinations).

Calibration In order to ensure accurate measurements, it is important to calibrate the 86100A at the recommended intervals. In particular, extinction ratio measurements require calibrations at regular intervals to ensure accurate and repeatable results. Table 1 summarizes the recommended calibration cycles for the Agilent 86100A.

Table 1: Recommended calibrations

Calibration	What is calibrated	Measurements Affected	Recommended Interval
Service Horizontal (Time base) Calibration	Time base of the mainframe	All time base measurements such as rise time, fall time, eye width, jitter, etc.	Annually at the Agilent Service Center or if operating temp has changed and remains 5° C or more from calibration temp. See specifications in online help.
Optical Channel Service Calibration	The photodetector responsivity	All optical channel amplitude based measurements at factory calibrated standard wavelengths.	Annual factory re-calibration of standard wavelengths.
Optical Channel User Calibration	The photodetector responsivity	All optical channel measurements at user defined wavelengths.	Annual re-calibration of user defined (non-factory) wavelengths. See online help.
User Vertical (Amplitude) Calibration	Vertical offset and vertical scale accuracy for both electrical and optical channels.	Any optical or electrical amplitude measurement (Vp to p, eye height, extinction ratio, etc.).	Perform after any power cycle or once every 10 hours during continuous use or if operating temp changes >5° C or a module has been removed and then reinserted into the mainframe. Note: For the highest possible accuracy, a recalibration is recommended if the operating temperature changes by ±1° C.
User Extinction Ratio Calibration	Measures the channel signal without any light present and this value is used in the extinction ratio algorithm.	Extinction ratio	ER calibration is recommended when: 1) the vertical scale or vertical offset is changed, 2) the module is installed or removed, 3) the operating temperature has changed ±5° C from the last vertical cal temp, 4) the scope has been operating continuously for 10 hours, or 5) the power is cycled. Note: For the absolute best accuracy, a recalibration is recommended if the operating temperature changes by ±1° C.
External Scale (feature not available at initial release)	Compensates for gain or loss associated with external devices (calibrates vertical scale to external device)	Any amplitude measurement taken through an external device	Whenever using external devices such as a clock recovery system.

Recommended Tests and Measurement Procedures

Mask testing

A mask test defines the allowable shape of the transmitter waveform. The mask test is highly efficient since it quantifies both time and amplitude parameters in one measurement. High-speed data and telecommunications standards have specific masks designed for each data rate. The Agilent 86100A comes equipped with a number of defined masks, and a feature, which will automatically align the mask to the waveform.

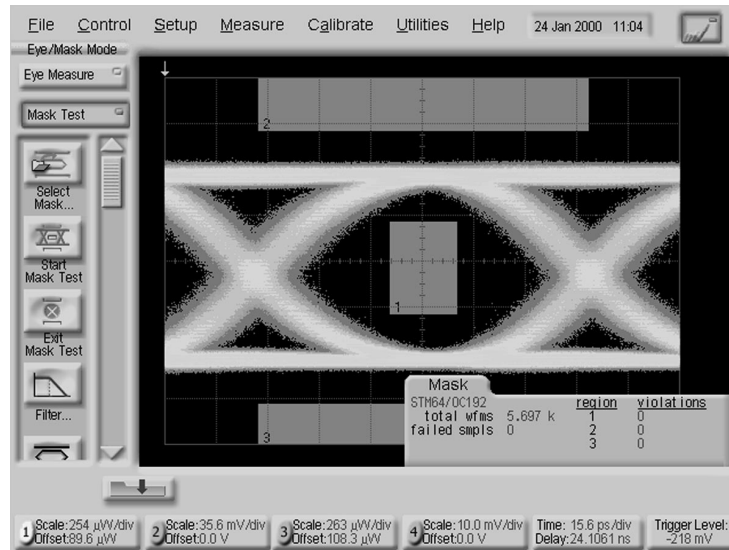


Figure 3:
Mask test shown on Agilent 86100A.

Mask margins

The Agilent 86100A allows the user to place adjustable margins around the mask to provide a measurement buffer in addition to the compliance mask test. These margins are quite useful as a manufacturing process control measure to track performance variations and correct any degradation before actual mask failures occur. The margin is defined as a percentage and the 86100A will separately tabulate the number of standard mask violations as well as the number of hits within the mask margins. Figure 4 shows a mask test with a 35% mask margin activated.

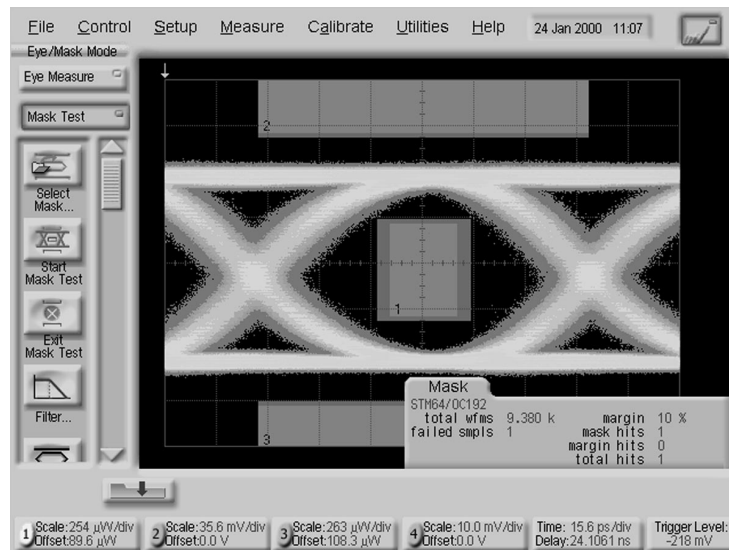


Figure 4:
The Agilent 86100A allows the user to define mask margin percentage. Note that actual failed samples are tabulated separately from those samples which passed the mask test but fell within the mask margin area.

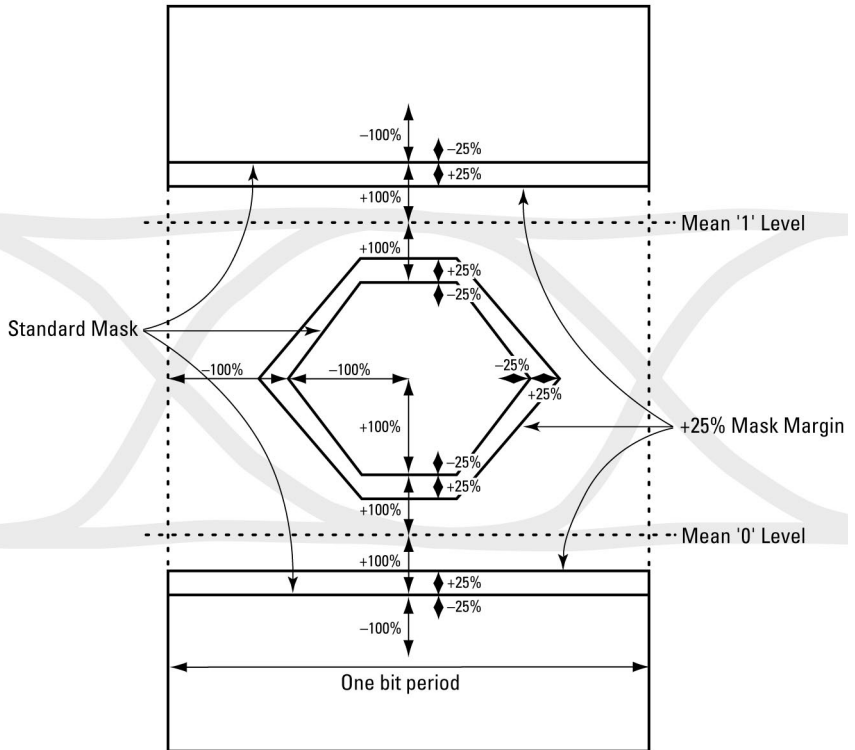


Figure 5:
Mask Margins.

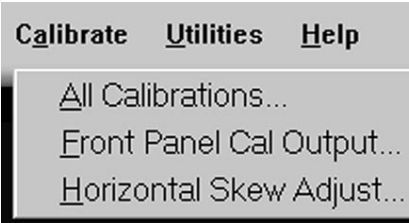
Mask margins are defined according to their largest and smallest possible dimensions in both the positive (+100%) and negative (-100%) directions. For example, the horizontal width of the central polygon (hexagon or square) in the middle of the eye is defined relative to the crossing point of the perfect bit period for the positive margins and relative to the center point of the middle polygon for negative margins. That is, the +100% mask margin extends the horizontal axis of the central polygon to the crossing points both before and after the eye being tested (making the horizontal axis one full bit period wide). Negative margins use the distance from the centerpoint of the center polygon to the horizontal edge of the standard mask as -100% and smaller negative margins distances are scaled proportionately to this distance. To create a mask margin of 25%, the horizontal axis of the margin is created by establishing points which are an additional 25% of the horizontal distance outside of the mask (see Figure 4). To create the upper and lower boundary of the central polygon, the distance between the upper line on the center polygon and the average one level is defined as 100% and a mask margin of 25% extends the upper border of the central mask by 25% of this distance. The lower boundary of the central polygon is created the same way relative to the average zero level. The vertical distances for negative mask margins are created just like the horizontal distances with the -100% distance being the distance from the standard mask to the central axis of the polygon.

For the upper and lower polygons, both the positive and negative 100% distance is defined as the distance from the regular mask boundary to the average one level (upper polygon) or average zero level (lower polygon). The polygons are either extended or withdrawn the appropriate percentage of this distance to define the positive and negative mask margins, respectively.

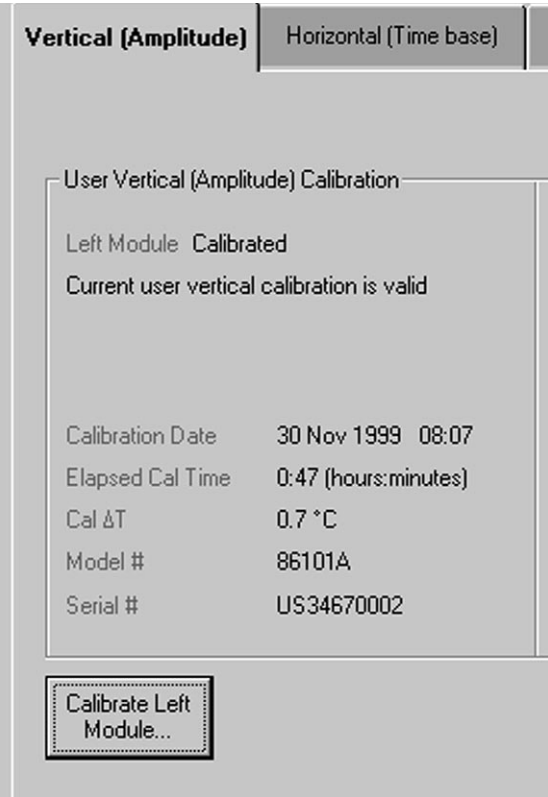
Mask Test Procedure

Note: A recent vertical calibration is necessary to obtain the best mask test results. It is recommended that a User Vertical (Amplitude) Calibration be performed after any power cycle or once every 10 hours during continuous use or if operating temp changes $>5^{\circ}\text{C}$ or a module has been removed and then reinserted into the mainframe. For the highest possible accuracy, a recalibration is recommended if the operating temperature changes by $\pm 1^{\circ}\text{C}$.

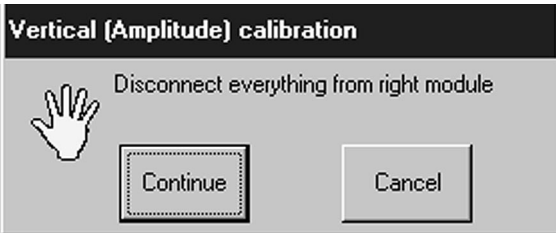
1. Connect an optical signal to the optical input, turn the appropriate channel on, and press the Auto Scale hard key to the right of the display. The autoscale will search for an appropriate trigger level, and set the horizontal and vertical scales to achieve a good eye diagram.
2. Pull down the Calibrate main menu at the top of the display window and select All Calibrations



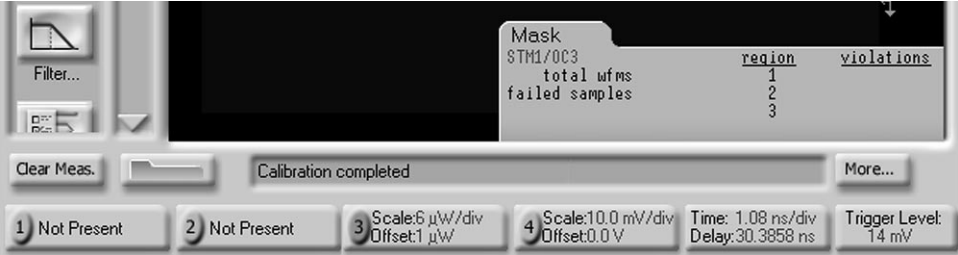
3. Select the Vertical (Amplitude) index tab



4. Determine which module will be used, then push the Calibrate Left Module or Calibrate Right Module soft key
5. Disconnect everything from the module and press Continue



6. The routine takes approximately one and a half minutes to complete
7. After the completion of the vertical calibration the message “Calibration complete” is displayed in the message bar.



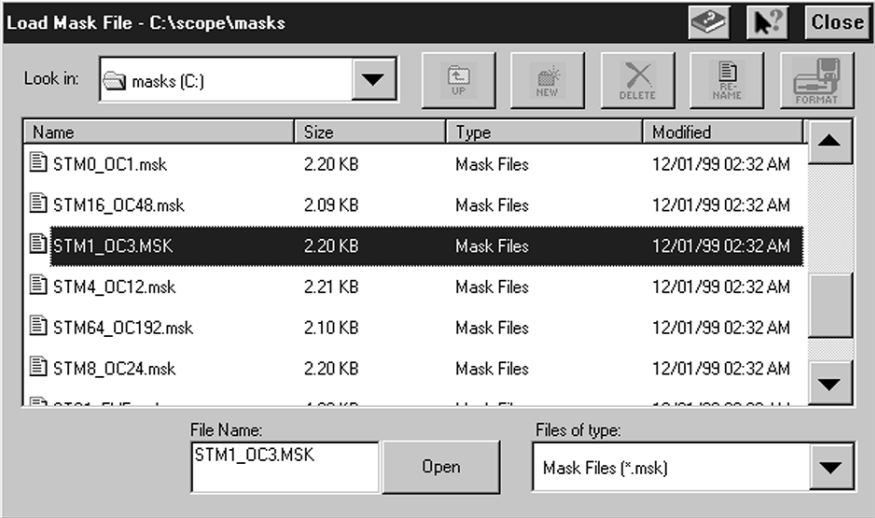
8. Reconnect the optical signal to the optical input and then press the Clear Display hardkey (near the floppy disk drive)
9. Press the Eye/ Mask Mode hard key on the front panel to the right of the display
10. Touch/click the Mask Test soft key in the top of the vertical window on the left of the display



11. Touch/click Select Mask& This will bring up a dialog box with a list of all the mask formats.



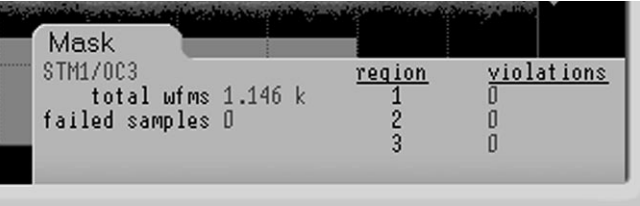
Select the appropriate mask from the list of files and press the Open soft key in the lower part of the window



12. Touch/click Start Mask Test.



13. The mask will automatically align to the waveform and the measurement results will appear in the measurement tab window. Waveforms which were taken prior to the start of the mask test are included in the results. To clear all waveforms and start a mask test with entirely new data press the Clear Display hardkey (near the floppy disk drive). If you would like to scale or position the mask manually, push the Mask Test Scaling soft key in the scroll window on the left.

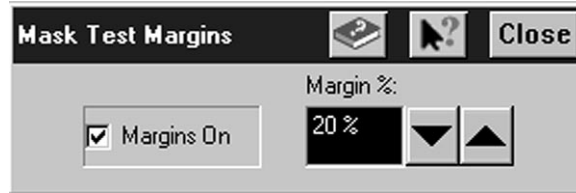


Mask Margins

14. Start the mask test as described in steps 1 through 13 above. Then touch/click the soft key in the scroll window on the left of the display.



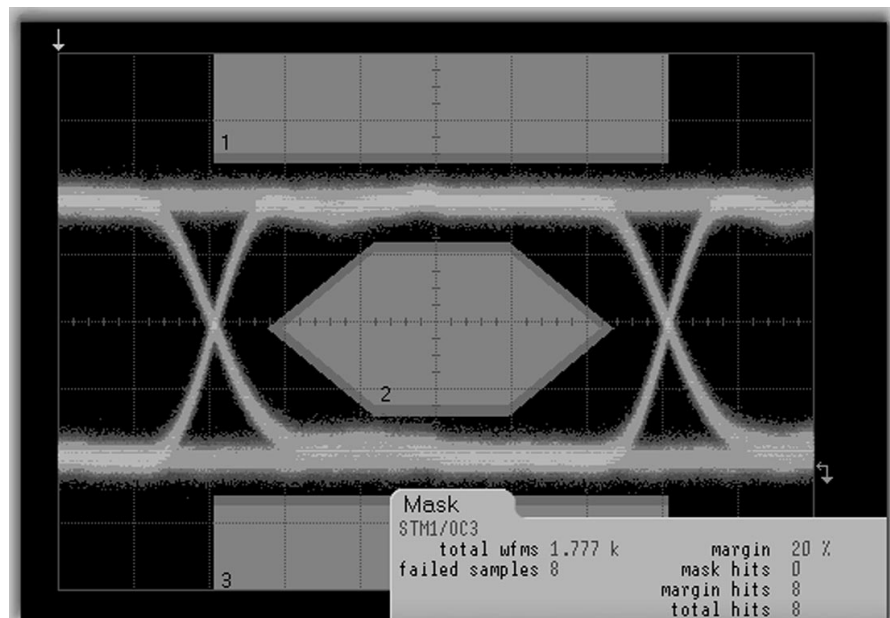
15. Touch/click the checkmark in the dialog box to turn on your mask margins and then choose the percentage mask margin that you want.



16. Close the dialog box and touch/click the Start Mask Test in the vertical scroll window on the left of the display.



17. Note that the mask hits and the mask margin hits are tallied separately.



Extinction ratio

Extinction ratio is defined as the ratio of the mean one level divided by the mean zero level of an eye diagram. Extinction ratio can be expressed in one of three ways:

- dB

$$\text{Extinction ratio dB} = 10 \log_{10} \left[\frac{\text{One level} - \text{Dark level}}{\text{Zero level} - \text{Dark level}} \right]$$

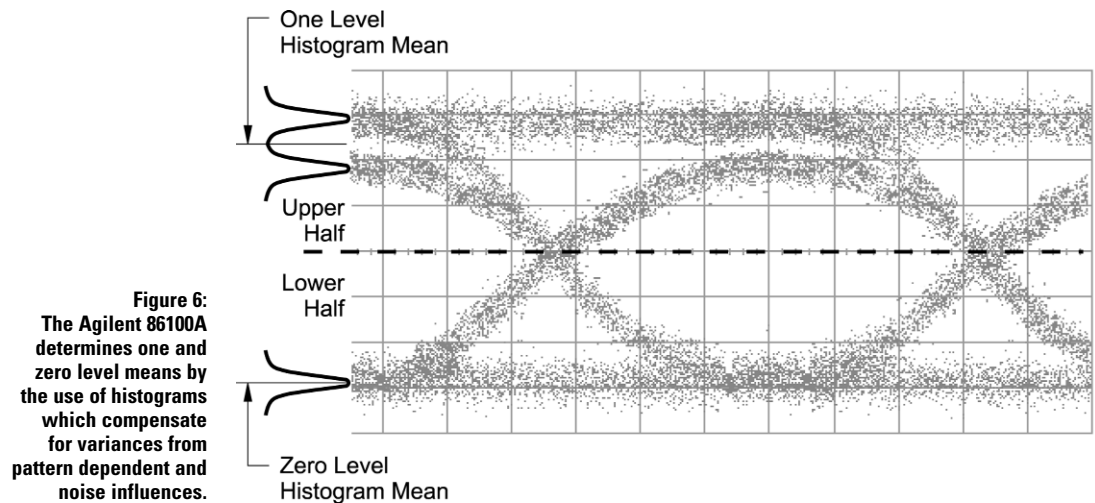
- %

$$\text{Extinction ratio percent} = 100 \left[\frac{\text{Zero level} - \text{Dark level}}{\text{One level} - \text{Dark level}} \right]$$

- ratio

$$\text{Extinction ratio} = \frac{\text{One level} - \text{Dark level}}{\text{Zero level} - \text{Dark level}}$$

While this measurement is simple in concept, it is difficult to achieve with high accuracy since the measurement is a ratio with the denominator being the mean zero level. When the mean zero level approaches absolute 0, small variations in the measurement of the mean zero level translate into large variations in the extinction ratio measurement. What this means is that the dark level¹⁰ within the oscilloscope must be subtracted from both the mean one and the mean zero measurements. Since dark levels can vary depending upon the vertical scale of the oscilloscope, it is important that the dark level be measured at the actual vertical scale level used to make the extinction ratio measurement. The Agilent 86100A will automatically prompt the user to make an extinction ratio calibration whenever the vertical scale has been changed or the operating temperature or measurement plug-in module has changed.¹¹

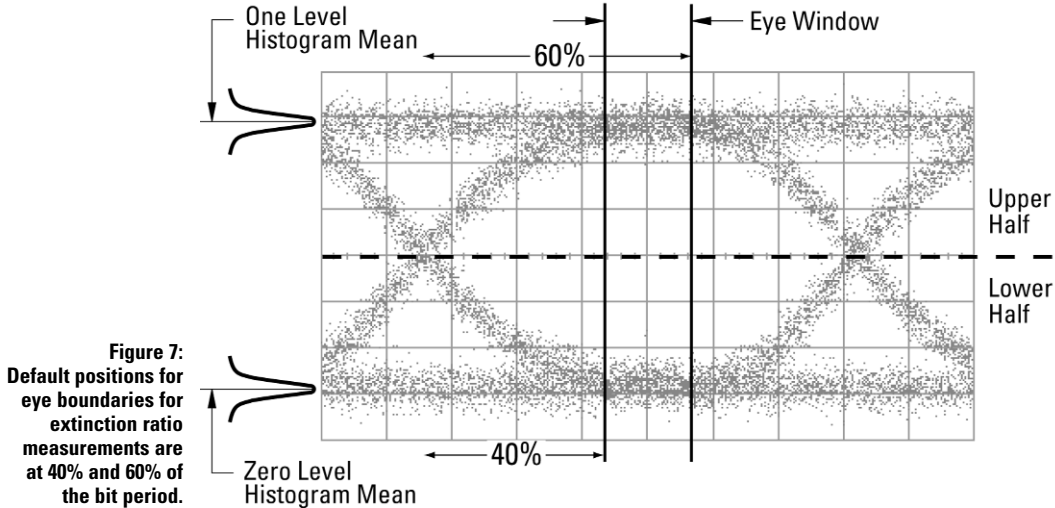


In order to make accurate extinction level measurements, the reference receiver must have a flat frequency response all the way back to DC. Even a system which is compliant with the standard Bessel-Thomson frequency response window may exhibit a DC gain “rise” or “fall” which will shift the eye diagram and result in inaccurate extinction ratio measurements.

¹⁰ Dark level or dark signal refers to signals that are generated within the oscilloscope even when there is not an external signal being input. Dark signals can be generated by photodiode dark currents, offset voltages from electrical amplifiers in the O/E receiver circuit, and other circuitry within the oscilloscope.

¹¹ If the Agilent 86100A and the HP 83480A show different results when measuring extinction ratio, it is recommended that the measurement from the Agilent 86100A be given preference. The Agilent 86100A utilizes an improved algorithm that results in more thorough and consistent analysis of extinction ratios.

The Agilent 86100A allows you to define the boundaries of window which is used to make the extinction ratio measurement. The default value for the eye window is the central 20% of the bit period. You can change the position of the boundaries that define the eye window setting in the Configure Measurement dialog box (under the Measure drop down menu). This setting determines what portion of the eye will be measured. The default values for the boundary positions of the eye window are the 40% (Eye Boundary 1) and 60% (Eye Boundary 2) sections of the bit period.



Changes in extinction ratio measurements for the Agilent 86100A Infiniium DCA in comparison to the Agilent 83480A

Users of the HP/Agilent 83480A who begin making extinction ratio measurements on the new Infiniium DCA will likely notice that the measurements are reported faster, the reported values are extremely stable, and if the device under test itself is stable, the measurement results are very repeatable (e.g., an initial measurement is made and then a new measurement is performed either by clearing the display or setting up and making a measurement hours or even days later.)

The algorithm used for extinction ratio in the Infiniium DCA has been altered from what most users have experienced with the HP 83480A. To explain the differences it is worthwhile to review the history of the HP 83480A. When this product was introduced in 1995, there was not a strong industry consensus on how an extinction ratio should be performed. Specifically, in constructing histograms to determine the logic 1 and 0 levels, some engineers proposed using the peak values of histograms while others proposed mean values. Also, some proposed using data over the entire bit period of the eye diagram while others proposed using the central portion of the eye. In order to try to satisfy everyone, the algorithm used in the HP 83480A was designed to be both flexible and robust over a variety of test conditions.

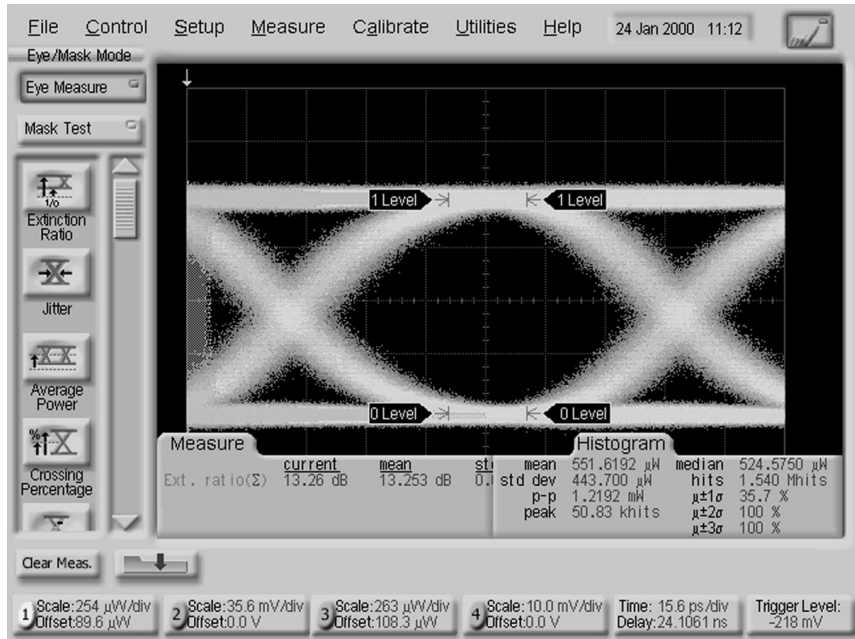


Figure 8:
The Agilent 86100A has an improved extinction ratio algorithm.

Gradually the industry gravitated towards using the mean value of the eye diagram histograms from the central 20% of the eye diagram. However, to better satisfy the entire customer base of users, the HP 83480 maintained its flexible algorithm until recently¹². If someone wanted to test over the full bit period of the eye diagram, the algorithm needed to be "smart" enough to ignore the rising and falling edges of the eye, as they are not good indicators of the true on and off levels of the transmitter. Although the rising and falling edges of the eye should not affect the extinction ratio measurement when made at the center of the eye, the generic algorithm could get fooled when an eye diagram had significant or even subtle pattern dependency resulting in multiple 1 or 0 levels. For example, if the 1 level had two discrete modes, one of the levels could get confused as being a rising/falling edge. Thus the algorithm could incorrectly lock on to the other mode as the true 1 level. If the densities of the modes were close to equal, the algorithm might even jump back and forth, first locking onto one mode and then another. The result would be an extinction ratio value that would jump in value, sometimes in excess of 1 dB.

The Infiniium DCA has updated its extinction ratio algorithm to better match the way industry is currently making extinction ratio measurements. It has been optimized to accurately determine the mean 1 and 0 levels over the central portion of the eye diagram. It should not be adversely affected by pattern dependencies, subtle or strong.

In addition, the processing power of the new instrument allows very fast calculation of the measurement results from the acquired data. The combination of processing power and a modified algorithm are the key to the fast, stable and repeatable extinction ratio measurement now available in the Infiniium DCA.

Extinction Ratio Measurement Procedure

Note: A recently performed user vertical calibration and extinction ratio calibration is necessary to obtain the most accurate extinction ratio measurement readings. The extinction ratio calibration will automatically check to see if a vertical calibration is needed.

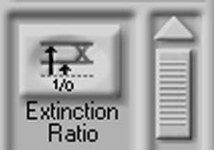
¹² The updated algorithm has been incorporated into the 83480A in firmware revision 7.0 and higher.

The vertical scale setting affects the magnitude of the dark level offset. Perform the extinction ratio calibration at the vertical scale at which you will make your measurement. Increasing the vertical scale sensitivity for a large eye diagram display typically yields a more accurate measurement.

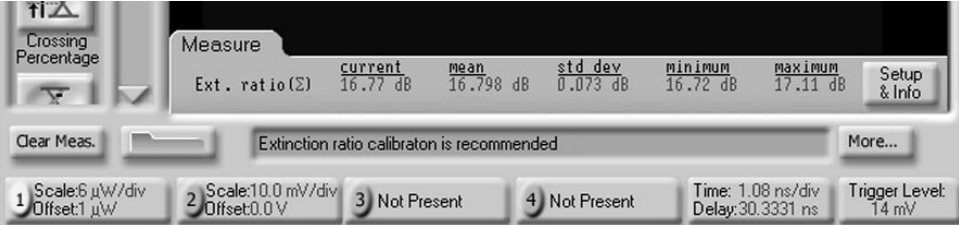
1. Connect an optical signal to the optical input and turn the appropriate channel on
2. Press the Eye/Mask Mode hard key on the instrument's front panel (or open the Setup menu and click/touch Eye/Mask Mode)
3. Click/touch the Eye/Measure soft key (in the upper left corner of the display)



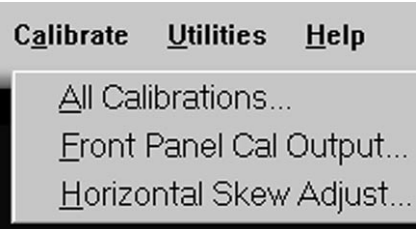
4. Press the Autoscale hard key on the front panel (right side of display), wait for its completion
5. Press the Extinction ratio soft key in the vertical scroll window on the left side of the display



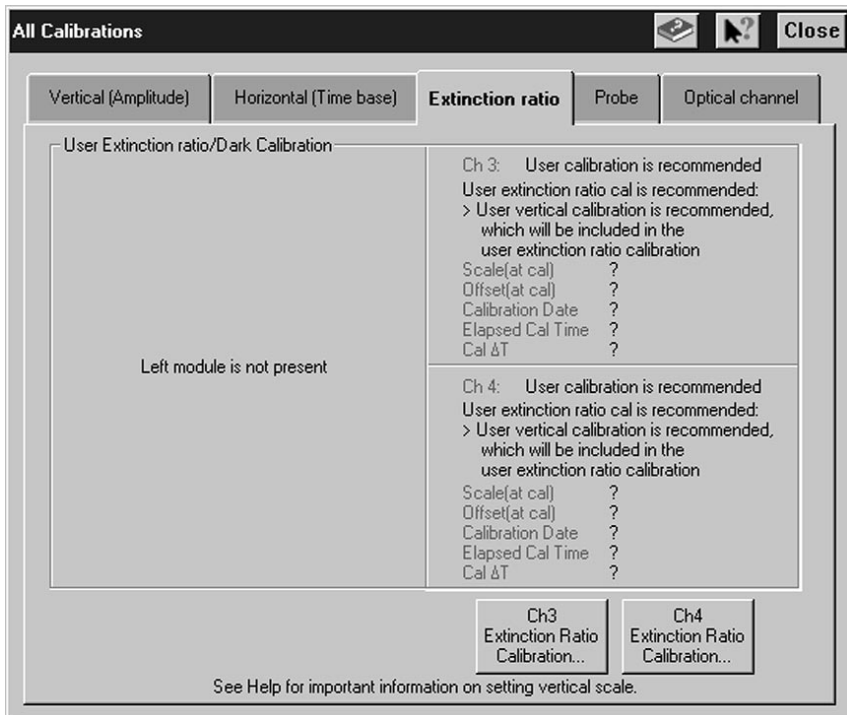
6. Look in the message window at the bottom of the display. If an extinction ratio calibration is recommended, perform the following steps.



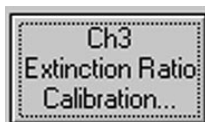
7. Pull down the Calibrate menu main menu and select All Calibrations



8. Select the Extinction Ratio index tab

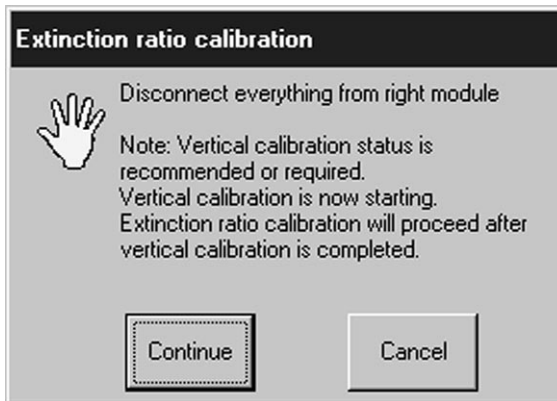


9. Touch/click the Extinction Ratio Calibration button for the optical channel which you are using

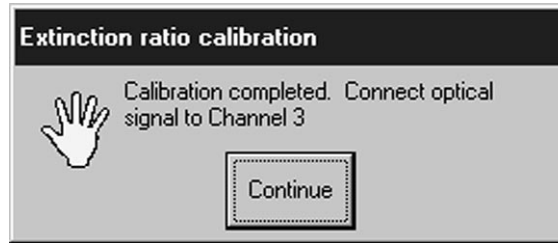


10. Follow the on-screen instructions. If vertical calibration is needed, it will automatically be started. A vertical calibration will take approximately 1.5 minutes, the extinction ratio routine takes a few seconds to complete.

11. Disconnect everything from the module and press the Continue softkey

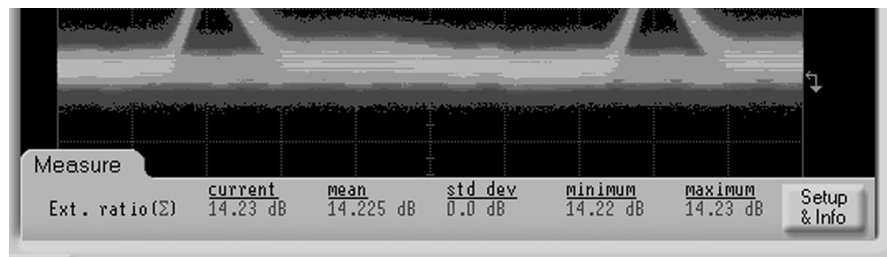


12. After the completion of the user calibrations the message “Calibration complete” is displayed in the message bar



13. Reconnect the optical signal to the calibrated optical channel and then press the Continue soft key **only after** you have reconnected the optical signal and it has stabilized.

14. The measurement results will appear in the measurement window



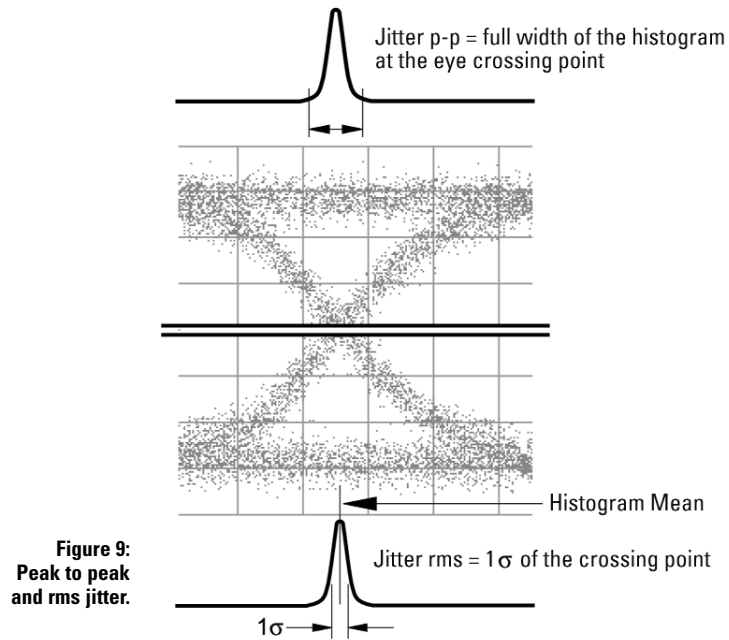
Jitter

In order to fully characterize a device as standards compliant, the standards require additional specialized equipment for jitter testing. The SONET/SDH standards require that the device be tested for jitter generation, jitter transfer, and jitter tolerance with a test setup such as the Agilent 71501C jitter analysis system.¹³ The Fibre Channel and the Gigabit Ethernet standards require measuring jitter with a bit error ratio test set using a defined test pattern.¹⁴ One of the main reasons that the standards require additional testing is that, due to the sampling techniques used, a communications analyzer cannot guarantee whether or not a device actually passes the jitter standard. With that being said, it is common practice to take jitter measurements using a digital communications analyzer with a source clock or a recovered clock since this is a quick test which usually gives a faithful indication of the jitter present on the signal. As mentioned earlier, the quality of the trigger signal can greatly affect the jitter measurement results.

A jitter measurement on an oscilloscope or digital communications analyzer refers to the measurement of the time variances of the rising and falling edges of an eye diagram as these edges affect the crossing points of the eye. Jitter is measured as either peak to peak jitter, which refers to the full width of the crossing point of the eye, or as rms jitter which is defined as one standard deviation from the mean of the crossing point histogram.

¹³ For more information on testing jitter on SDH systems, see ITU-T O.171: Timing jitter and wander measuring equipment for digital systems which are based on the pliesochronous digital hierarchy (PDH) and ITU G.957. For jitter testing of SONET OC-48 and OC-192 transmission, see Bellcore GR-253-CORE: Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria, and GR-1377-CORE: SONET OC-192 Transport System Generic Criteria.

¹⁴ See IEEE Std 802.3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications; ANSI X3.297-1997: Fibre Channel - Physical and signaling Interface-2 (FC-PH-2); and the National Committee for Information Technology Standardization (NCITS) T11.2/Project 1230 Fibre Channel - Methodologies for Jitter Specification.



The 86100A creates histograms to find the crossing point of the eye diagram and then takes a very narrow sample in the horizontal axis at the vertical level of the crossing point. The time difference between the end samples of this sampling window constitute the peak to peak jitter measurement. The rms jitter is found by constructing a histogram of the samples between the end samples and determining the mean and standard deviation of the distribution of the samples.

Rise time

Rise times are generally performed in the unfiltered mode in order to use the full bandwidth of the communications analyzer to get the most accurate measurement. Gigabit Ethernet allows an exception to this procedure by taking the rise time measurement in the filtered mode and then removing the effects of the filter mathematically by the following formula:

$$T_{\text{rise, fall}} = \sqrt{(T_{\text{rise, fall_measured}})^2 - (T_{\text{rise, fall_filter}})^2}$$

It should be noted that this method might adversely affect the accuracy of the rise or fall time measurement since the filter will limit the oscilloscope's ability to capture the high frequency components which create the faster edge speeds.

Therefore, the recommended procedure is to measure the rise or fall time with the full unfiltered bandwidth.

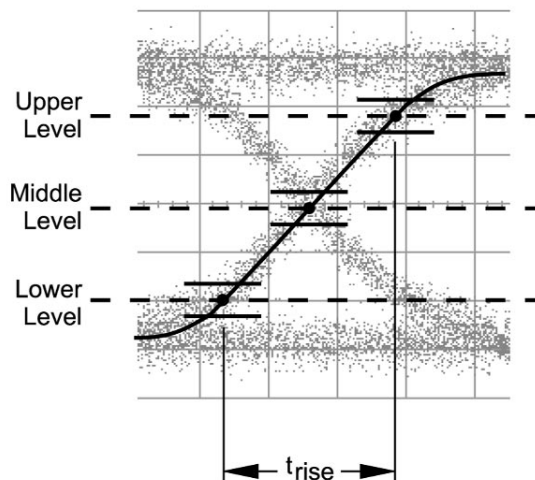


Figure 10: Rise time.

Rise and fall times are usually defined as 20% to 80% or 10% to 90%. The Agilent 86100A first creates a histogram to define the mean location of the crossing points of the rising zero to one and one to zero transitions of the eye diagram. Histograms are then created for the one and zero levels and a mean one level and mean zero level is determined. The instrument then calculates the upper threshold level (usually 80% or 90% of the difference between the mean one and mean zero levels) and the lower threshold level (usually 20% or 10% of the difference between the mean one and mean zero levels). Histograms are created at these levels and an upper and lower threshold mean is determined. A line is drawn from the lower threshold mean through the eye crossing mean to the upper threshold mean. The rise time is calculated as the difference between the lower threshold mean and the upper threshold mean. Likewise, fall time would be measured the same way with the measurement being the difference between the upper threshold mean and the lower threshold mean.

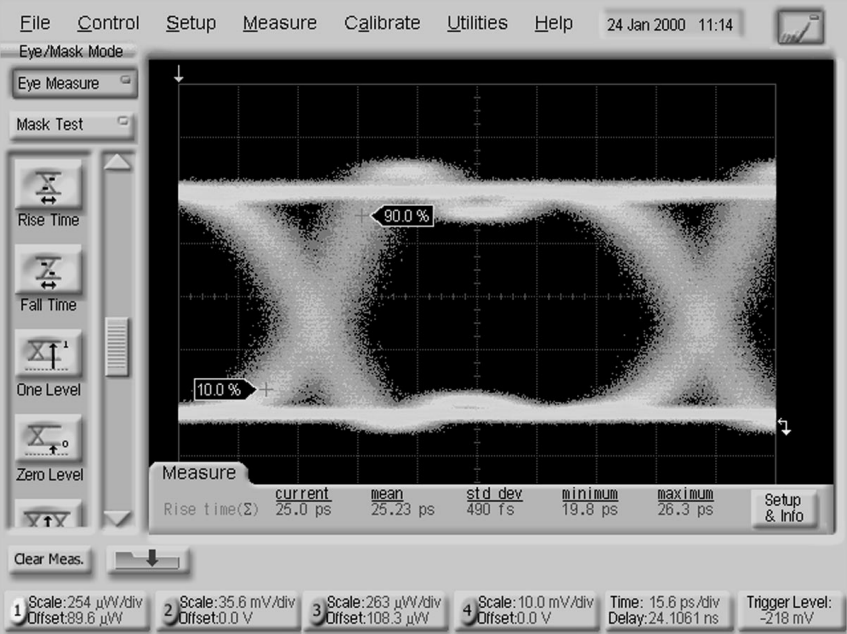


Figure 11:
Agilent 86100A rise
time measurement.

Average power

The Agilent 86100A, when used with its integrated O/E plug-in modules, has a built-in true optical power meter (the optical power is measured independently, not calculated from the waveform). The internal photo detector converts the optical signal to an electrical signal and the instrument measures the DC component of the electrical signal. The average power is calculated according to:

$$\text{Average Power} = \text{dc component of photo detector current [amps]} / \text{photo detector responsivity } (\lambda) \text{ [amps/watt]}.$$

To ensure accuracy, the photodetector responsivity is determined for the wavelength being measured and the appropriate factor is used to calculate average power. The operator can choose to have the average power meter report readings in dBm or uWatts.

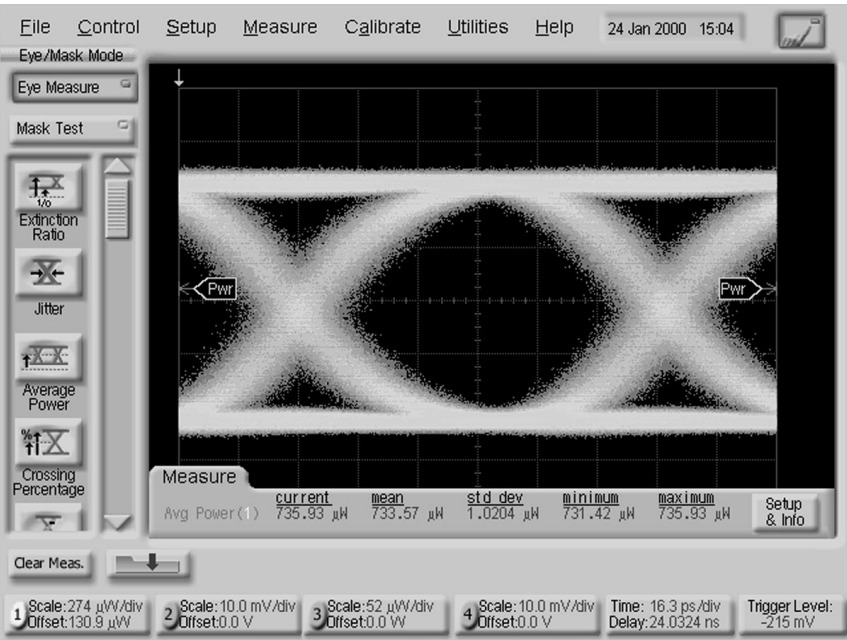


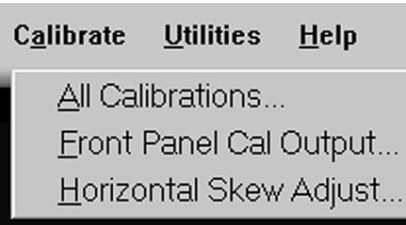
Figure 12:
Average power measurement with Agilent 86100A.

Average Power Procedure

Note: A recent vertical calibration is necessary to obtain the most accurate average power reading. It is recommended that a User Vertical (Amplitude) Calibration be performed after any power cycle or once every 10 hours during continuous use or if operating temp changes $>5^{\circ}$ C or a module has been removed and then reinserted into the mainframe.

For the highest possible accuracy, a recalibration is recommended if the operating temperature changes by $\pm 1^{\circ}$ C.

1. Pull down the Calibrate main menu at the top of the display and select All Calibrations

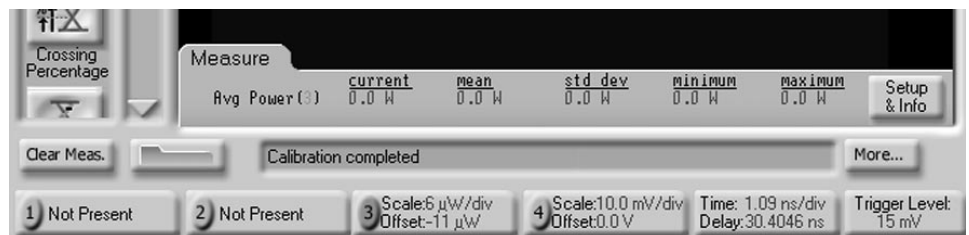


2. Select the Vertical (Amplitude) index tab

- Determine which module will be used, then push the Calibrate Left Module or Calibrate Right Module



- Disconnect everything from the module and press Continue
- The routine takes approximately one and a half minutes to complete
- After the completion of the vertical calibration the message “Calibration complete” is displayed in the message bar.



- Connect an optical signal to the optical input

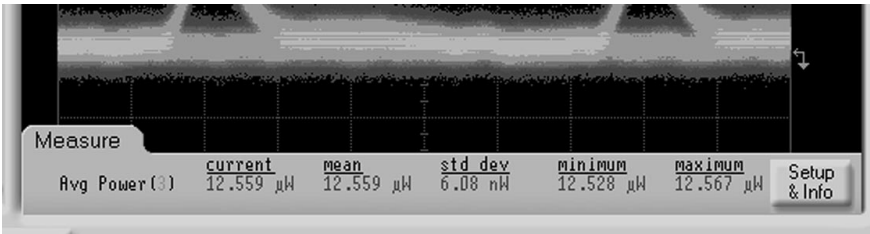
8. If you are in Oscilloscope Mode, select the Amplitude measure button.
Click/touch Average Power



9. If you are in Eye/ Mask Mode, select Eye Measure button. Click/touch Average Power



10. Press the Clear Display hard key on the front panel (near the floppy disk drive)
11. The measurement results will appear in the measurement window



Summary

High-speed fiberoptic transmitters are considered standards compliant if they pass criteria, which are published by the American National Standards Institute, Telcordia (Bellcore), the Telecommunications Industry Association, and the International Telecommunications Union. Digital Communications Analyzers are wide bandwidth digitizing oscilloscopes with specialized measurements built-in. Digital communications analyzers are used with optical reference receivers for testing high-speed optical transmitters to determine whether or not the transmitter is compliant with the physical layer specifications defined by the appropriate standards.

The Agilent 86100A, with its integrated architecture, superior performance and intuitive Windows user interface, is the next generation digital communications analyzer from the Agilent Technologies Division of the Hewlett Packard Co. By following the appropriate standards documents and using the procedures and recommendations outlined in this application note, the R&D or Manufacturing Engineer can ensure that their products are standards compliant.

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GR-253-CORE: *Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria*, Revision 2. Telcordia (formerly Bellcore), January, 1999.

IEEE Std 802.3: CSMA/CD Access Method and Physical Layer Specifications. Institute of Electrical and Electronics Engineers: 1998.

ITU-T Recommendation G.957: Digital Sections and Digital Line Systems - Optical Interfaces for Equipments and Systems Relating to the Synchronous Digital Hierarchy. Telecommunication Standardization Sector of International Telecommunications Union (ITU-T): July, 1995.

LeCheminant, Greg. *Methodologies for Accurate Extinction Ratio Measurements of High-Speed Laser Transmitters*. Symposium Paper: Hewlett Packard's Optical Network Interface Design Symposium, 1998. (<http://www.semiconductor.agilent.com/seminar/onids.html>)

OFSTP-4A Optical Eye Pattern Measurement Procedure, TIA/EIA Standard, November, 1997.

Shi, Hong and Greg LeCheminant. *Triggering Oscilloscopes from STM-1 STM-64 - Accurate Measurements are Not as Simple as You Expected*. Symposium Paper: Hewlett Packard's Optical Network Interface Design Symposium, 1999. (<http://www.semiconductor.agilent.com/seminar/onids.html>)

Wheeler, Brian. *Eye-Mask Testing in Giga-Baud Lightwave Systems*. Symposium Paper: Hewlett Packard's Optical Network Interface Design Symposium, 1998. (<http://www.semiconductor.agilent.com/seminar/onids.html>)

Woodward, Mark and Greg LeCheminant. *Optimizing Lightwave Components for Gigabit/second Transmission Rates*. Symposium Paper: Hewlett Packard's Optical Network Interface Design Symposium, 1997. (<http://www.semiconductor.agilent.com/seminar/onids.html>)

Appendix: Recommended Standards for Eye Diagram Analysis¹⁵

ANSI X3.230-1994/AM 1-1996: Fibre Channel - Physical and Signaling Interface (FC-PH) Amendment 1. American National Standards Institute: March 22, 1996.

ANSI X3.230-1994: Fibre Channel – Physical and Signaling Interface (FC-PH). American National Standards Institute: November 14, 1994.

ANSI X3.297-1997: Fibre Channel – Physical and Signaling Interface - 2 (FC-PH-2). American National Standards Institute: March 12, 1997.

ANSI/TIA/EIA-526-4A: OSTP-4A Optical Eye Pattern Measurement Procedure. Telecommunications Industry Association (in association with the Electronic Industries Association and the American National Standards Institute): August, 1997.

GR-1377-CORE: SONET OC-192 Transport System Generic Criteria, Issue 5. Telcordia Technologies (formerly Bellcore/Bell Communications Research): December, 1998.

GR-253-CORE: Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria, Revision 2. Telcordia Technologies (formerly Bellcore/Bell Communications Research): January, 1999.

IEC 61280-2-2 Test Procedures for Digital Systems – Optical eye pattern, waveform, and extinction ratio. International Electrotechnical Commission (IEC): November, 1998.

IEEE Std 802.3: CSMA/CD Access Method and Physical Layer Specifications. Institute of Electrical and Electronics Engineers: 1998.

ITU-T G.957 – Digital Sections and Digital Line Systems – Optical Interfaces for Equipments and Systems Relating to the Synchronous Digital Hierarchy. Telecommunication Standardization Sector of International Telecommunications Union (ITU-T): July, 1995.

T11.2/Project 1230 Information Technology – Fibre Channel – Methodologies for Jitter Specification (Working Draft). National Committee for Information Technology Standardization (NCITS): 1999.

¹⁵ These standards are the basic reference documents that the engineer should start with. Since standards are constantly evolving it is strongly recommended that the reader not consider this a comprehensive list and check with the standards organizations for additional information.

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(fax) (61 3) 9272 0749
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(fax) (64 4) 802 6881

Asia Pacific:

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