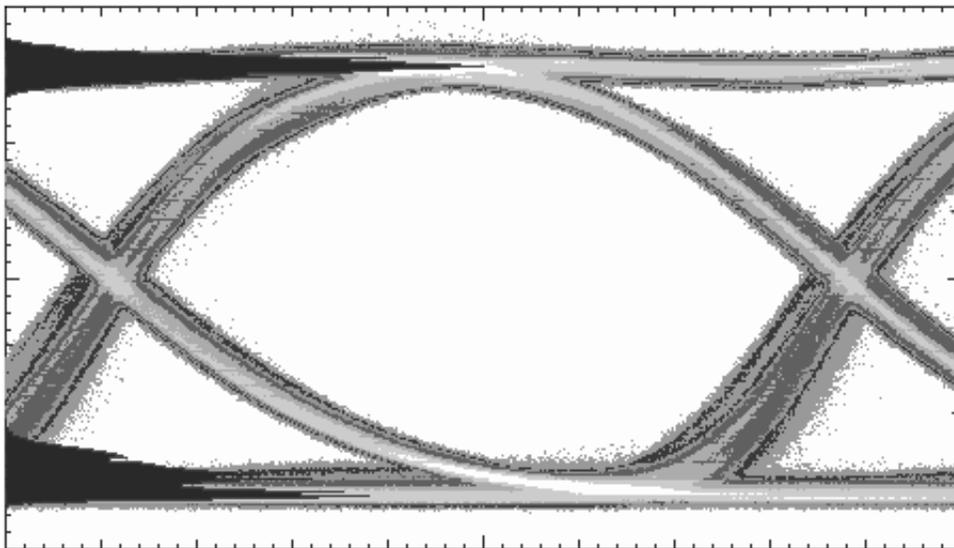
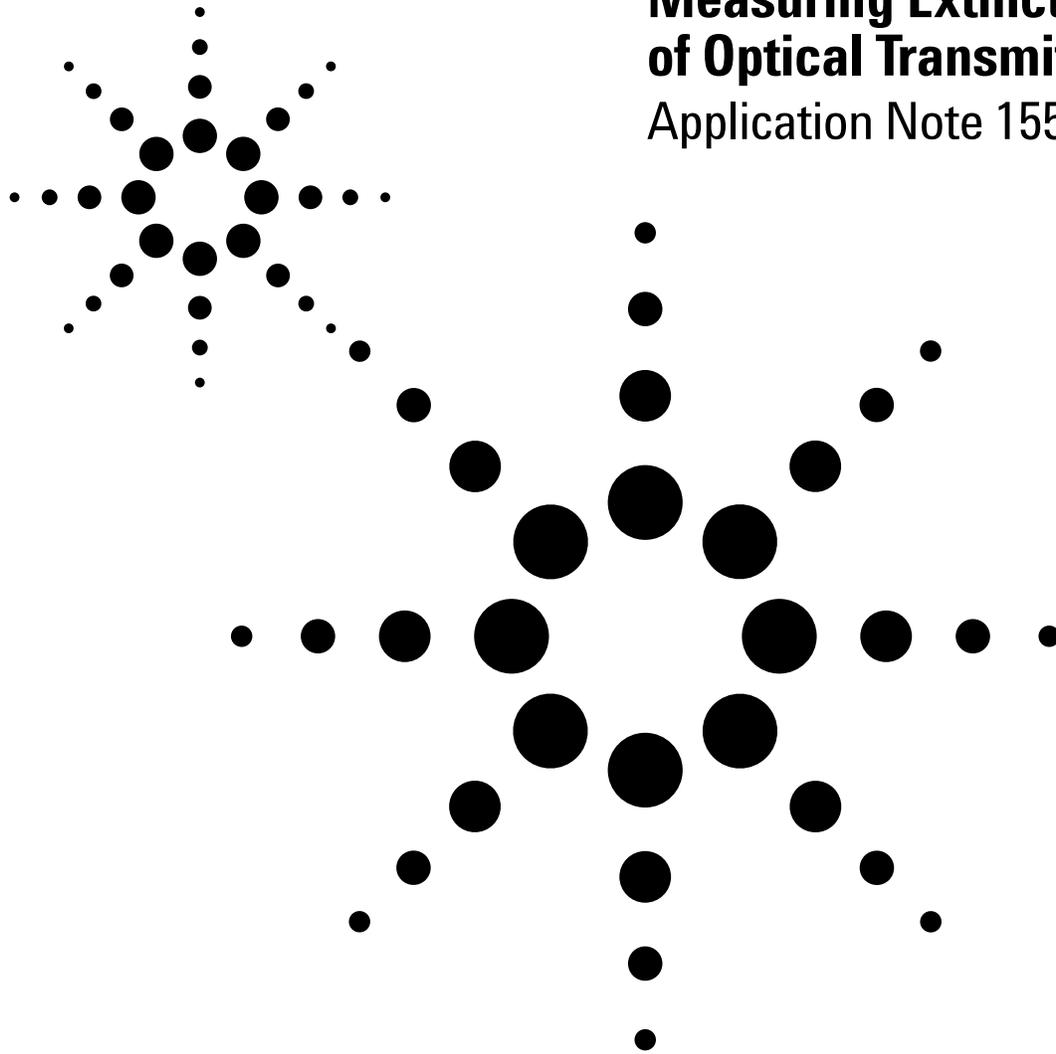


Measuring Extinction Ratio of Optical Transmitters

Application Note 1550-8



Agilent Technologies
Innovating the HP Way

Introduction

Optical transmitters used in high-speed digital communication systems are typically required to maintain a specific set of performance levels. One parameter, extinction ratio, is used to describe optimal biasing conditions and how efficiently available laser transmitter power is converted to modulation power. Although specifications are defined by industry standards and test methodologies loosely described, historically it has been difficult to achieve accurate and repeatable extinction ratio measurements.

The intent of this application note is to describe the intent of the measurement, the process used to make an extinction ratio measurement, and a methodology to achieve the best possible measurement results. The note is divided into several sections. (To begin making measurements immediately, proceed to section 4).

1. What is extinction ratio and why measure it, pages 3-5.
2. Extinction ratio measurement processes, pages 6-9.
3. Understanding and maximizing extinction ratio measurement accuracy and repeatability, pages 10-18.
4. The step-by-step procedures for making an extinction ratio measurement using the Agilent 83480A or 86100A Digital Communications Analyzer are found in pages 19-28.

1. What is extinction ratio and why measure it?

Extinction ratio, when used to describe the performance of an optical transmitter used in digital communications, is simply the ratio of the energy (power) used to transmit a logic level '1', to the energy used to transmit a logic level '0'. For a graphical description, the eye-diagram is commonly used as shown in Figure 1.

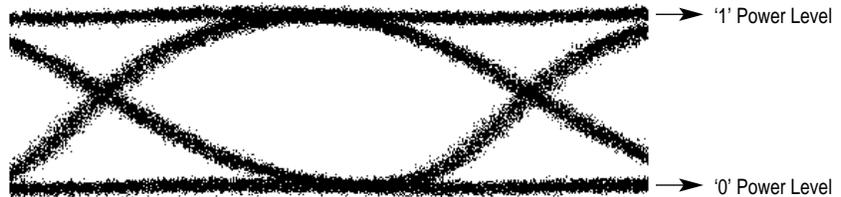


Figure 1. Definition of extinction ratio

Extinction ratio can be determined from the eye-diagram, defined as a linear ratio, in decibels, or as a percentage:

$$\text{Extinction ratio} = \frac{\text{'1' power level}}{\text{'0' power level}}$$

$$\text{Extinction ratio (dB)} = 10 \log_{10} \frac{\text{'1' power level}}{\text{'0' power level}}$$

$$\text{Extinction ratio \%} = \frac{\text{'0' power level}}{\text{'1' power level}} \times 100$$

Thus if the '1' power level was 1000 microwatts, and the '0' power level was 50 microwatts, the extinction ratio would be 20, 13 dB, or 5% depending upon which definition is preferred.

How does transmitter extinction ratio affect system performance?

The parameter that best describes the overall health of a communication system is bit-error-ratio (BER). Virtually any well designed digital communications system is capable of achieving virtually error-free communication if transmitter powers are kept high enough and system loss (i.e. fiber attenuation) is kept low enough. To minimize the need for costly amplifiers or regenerators, it is desirable to have the longest span possible between the transmitter and receiver. Lengthening the transmission span too far will eventually degrade the system BER, as signal levels drop and noise becomes a dominant component of the signal at the receiver. However, transmitter extinction ratio will also impact the allowable length of a transmission system. Figure 2 shows BER power penalty as a function of extinction ratio. For example, if the extinction ratio is 8.2 dB, approximately 1 dB of additional power would need to be transmitted to achieve the same BER obtained if the extinction ratio were instead 13 dB. In other words, a signal with 0 dBm average power and 13 dB extinction ratio should achieve the same BER as a signal with 1 dBm average power and 8.2 dB extinction ratio. Similarly, compared to an extinction ratio of 8.2 dB, an additional 1.5 dB of power would be required to maintain the BER level if extinction ratio were reduced to 5 dB.

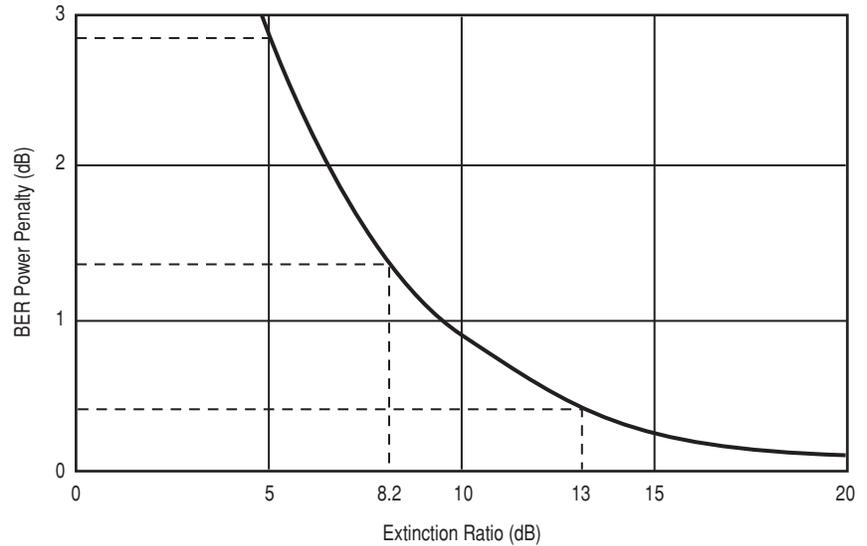


Figure 2. BER power penalty versus extinction ratio

How does extinction ratio describe transmitter performance?

Good bit error ratio (BER) performance is achieved when there is significant separation between the power level used to transmit a logical '1' and the power level used to transmit a logical '0'. The difference between these two power levels describes the modulation power of the transmitted signal. The larger the modulation power, the easier it will be for the system receiver to accurately determine what signal level is present.

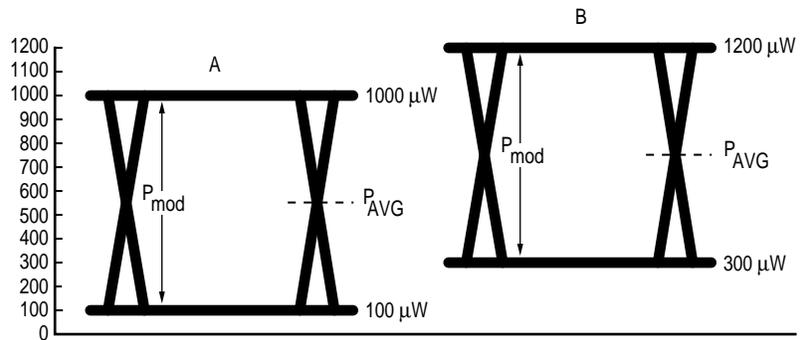


Figure 3. Relationships between average power, modulation power, and extinction ratio

Consider the two eye diagrams of Figure 3. Both signals have the same modulation power of 900 microwatts (the difference between high and low levels). Assuming the noise levels for either signal are the same, the BER's achieved with either transmitter A or transmitter B are likely to be similar. Which condition is superior? Note that the average power for transmitter A and B are 550 microwatts and 750 microwatts respectively. Transmitter B is required to produce 200 microwatts additional average power above transmitter A with no apparent performance improvement.

Ideally, an optical transmitter would be turned off (zero output power) in the transmission of a logical '0'. However, as a directly modulated laser approaches or drops below the lasing threshold, system BER performance is degraded due to transmitter wavelength shift (chirp) and waveform distortion (overshoot and ringing). Thus in Figure 3, neither transmitter A or B is biased and modulated in a manner that causes the laser to operate below the lasing threshold. Transmitter A generates 100 microwatts to transmit a logical '0', 300 microwatts for transmitter B. While both conditions then use some power to transmit a '0', using 300 microwatts to transmit a logical '0' can be considered an inefficient use of available laser power.

While modulation power described the difference between '1' and '0' power levels, it yields no measure of how efficiently laser power is used. However, the ratio of the '1' and '0' power levels, known as extinction ratio, is an indication of efficiency. The extinction ratio for transmitter A is 1000/100 or 10, whereas the extinction ratio for transmitter B is 1200/300 or 4. In the limit, extinction ratio can become infinite. In this case all the available laser power is converted to modulation power. (However, this would require the laser to be turned off for the transmission of a '0', and as mentioned above this would result in a degraded BER). Extinction Ratio values in the range of 8 to 20 (9 and 13 dB) are common for high-speed, directly modulated lasers.

For the examples of Figure 3, transmitter A would have an extinction ratio of 10, 10 dB, and 10%. Transmitter B would have an extinction ratio of 4, 6 dB, and 25%.

2. Extinction ratio measurement process

Industry standards have been developed to set minimum requirements for extinction ratio values and to define a methodology for making extinction ratio measurements.

ITU G.957: This document defines the physical requirements for Synchronous Digital Hierarchy (SDH) transmitters. Extinction ratio minimums of 8.2 dB to 10 dB are required depending upon the application.

Bellcore GR-253-CORE: Defines requirements for Synchronous Optical Network (SONET) systems. Similar to SDH transmitters, extinction ratio minimums of 8.2 dB to 10 dB are required.

IEEE 802.3Z: Defines requirements for Gigabit Ethernet transmitters. Extinction ratios greater than 9 dB are specified using test methods from TIA/EIA-526-4A

ANSI X3.230-1994/X3.297-1997: Defines requirements for Fibre Channel transmitters. Extinction ratios greater than 9 dB are specified using test methods from TIA/EIA OFSTP-4A.

TIA/EIA (Telecommunications Industries of America/ Electronics Industries of America) 526-4A (OFSTP-4A): This document describes measurement procedures for digital communications eye-diagrams including extinction ratio.

Extinction Ratio measurements are typically performed on eye-diagrams using digitizing oscilloscopes. Referring to OFSTP-4A, the receiver block diagram for eye-diagram extinction ratio measurements is shown in Figure 4. The key elements of the test system are an optical receiver and a digitizing oscilloscope. The optical receiver consists of a photodiode followed by a fourth-order Bessel-Thomson low-pass filter. The frequency response of the photodiode/filter combination is precisely specified for both SDH and SONET testing and is shown in Figure 5. This specification assumes that the oscilloscope does not contribute to the frequency response rolloff.

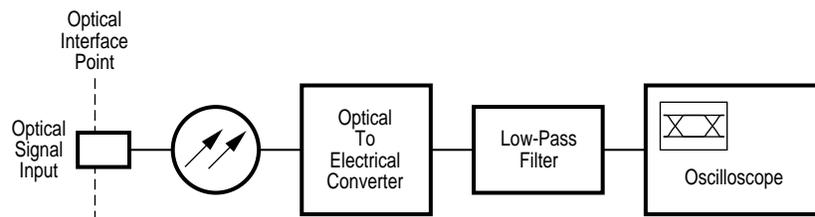


Figure 4. Test system for measuring extinction ratio

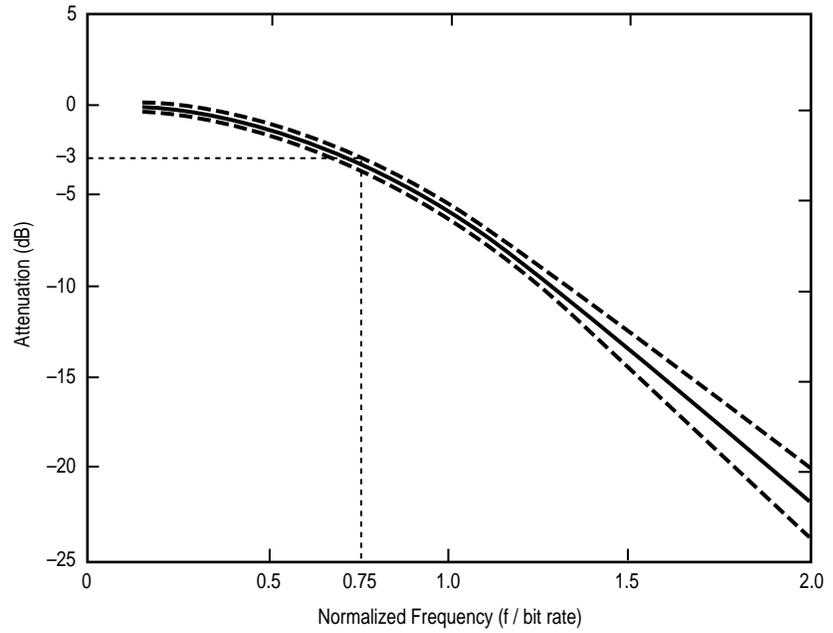


Figure 5. Frequency response requirements for the filtered optical receiver

The frequency response specification provides a consistent measurement method for characterizing optical transmitters. For example, the waveform viewed with a very broad bandwidth system is likely to appear different than when viewed with a reduced bandwidth (filtered) system. See Figure 6. This is a critical issue for eye-diagram mask testing, which is used to define allowable waveform shape. In addition, a reduced-bandwidth (filtered) receiver will behave similarly to the receivers typically used in an actual transmission system. That is, system receivers generally have the minimal bandwidth required to accurately operate at a given data rate. Extinction ratio measurements can be made with or without a filtered receiver. In practice, SDH and SONET compliance measurements, including extinction ratio are typically made in a filtered bandwidth as the filter performs an integrating effect to simulate the signal that will be seen by a decision circuit.

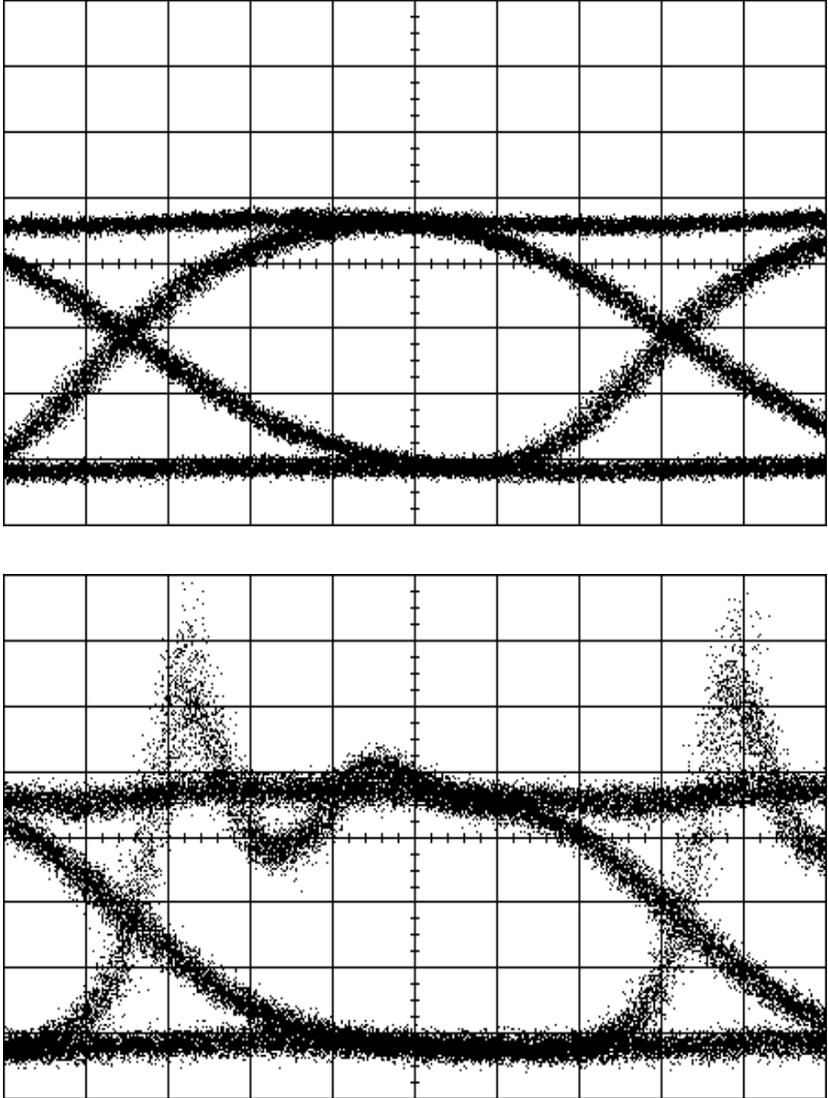


Figure 6. Waveform measured in a filtered and unfiltered bandwidth

The extinction ratio measurement is made through a statistical analysis of the eye-diagram. OFSTP-4A recommends that the mean value of the logical '1' signal and the mean value of the logical '0' signal be determined at the center of the eye. Again, the ratio of these two values yields the extinction ratio.

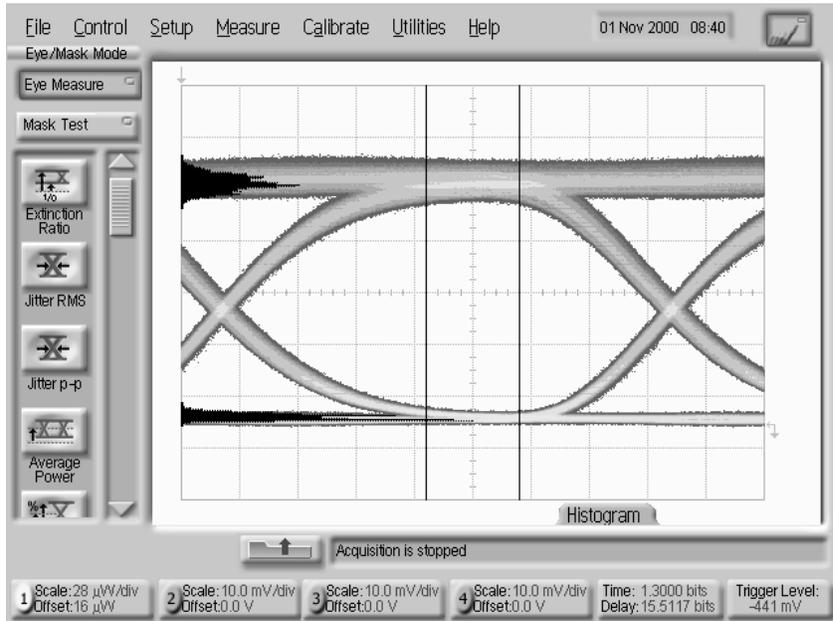


Figure 7. Using histograms to determine extinction ratio

A histogram analysis is used to determine the '1' and '0' levels. Figure 7 shows an eye-diagram with a histogram constructed along the vertical axis for the central 20% of the eye-diagram. As expected, the histogram is bimodal. The majority of the time the waveform exists at either the logic 1 level or the logic 0 level. To determine the mean values discussed above, the histogram is split in half vertically. The mean value of each of the two histograms is then determined. Ideally this should be sufficient information from which to determine the extinction ratio. But as is the case with many measurements, there are factors which can lead to measurement uncertainty and inaccuracy.

3. Understanding and maximizing extinction ratio measurement accuracy and repeatability

There are several factors which can potentially degrade an extinction ratio measurement. These factors can be grouped into the following categories:

- Offset/spurious signals generated by the instrumentation
- Distortion of the waveform caused by the instrumentation
- Precision of the instrument in measuring the amplitudes of the waveform

To minimize measurement degradation, the following strategy should be implemented:

- Use a histogram-based measurement algorithm that is robust even when error producing situations are present
- Understand the causes of waveform distortion and use instrumentation that yields high waveform fidelity
- Understand and where possible stay within the measurement limitations of the instrument

Offsets

It is a common occurrence for photodiode receivers to generate a non-zero output voltage when no light is present at the input. This can occur due to photodiode dark currents, or can be generated by electrical amplifiers following the photodiode. Also, offsets can be generated by the oscilloscope following the photodiode. Consider the simple eye-diagram of Figure 8. With a '1' level of 1 milliwatt and a '0' level of 50 microwatts, the extinction ratio is 20, 13 dB, or 5%. If this signal is passed through a receiver with an optical to electrical conversion gain of 500 Volts per Watt and a 'dark' or offset voltage of 10 millivolts, how will the waveform on an oscilloscope appear?

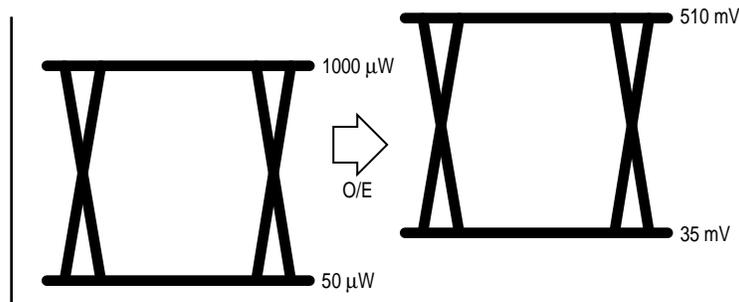


Figure 8. How offsets can affect measurement accuracy

At the receiver output the '1' level will be shifted from an ideal value of 500 millivolts to 510 millivolts. The '0' level will be shifted from an ideal value of 25 millivolts to 35 millivolts. The apparent extinction ratio would be 14.6, 11.6 dB, or 6.9%. With the offset unaccounted for, the measurement error would be:

$$\text{measurement error} = ((20-14.6)/20)*100 = 27\%$$

When measuring transmitters with higher extinction ratios, an even larger measurement error will be experienced as the offset error approaches and may even dominate the true '0' level. In this specific example, without removing the offset error, the highest extinction ratio that can be measured (for a constant 500 millivolt '1' level) would be 510/10 or 51 (17 dB, 2%), even if the true extinction ratio was infinite. Note also that a negative offset will potentially cause an extinction ratio measurement result to appear to be much larger than the true value.

Another issue arising from offsets occurs if the offset fluctuates. The result is an extinction ratio measurement that has variation as well as inaccuracy.

Reducing measurement error due to instrumentation offsets

Both the HP Agilent 83480A and Agilent 86100A Digital Communications Analyzers provide simple and straightforward ways to decrease extinction ratio measurement error due to offsets. In the Agilent 83480A this process is referred to as dark calibration or "dark cal". In the Agilent 86100A the process is referred to as an extinction ratio calibration. In either instrument the procedure is essentially the same. The instrument requests that any source of light be blocked from entering the optical receiver. The instrument will then measure any residual signals present when there is no input to the receiver. When an extinction ratio measurement is performed, the instrument will mathematically remove the offset from the extinction ratio calculation.

Both the Agilent 83480A and 86100A have integrated optical receivers which are designed to minimize and stabilize internal offset signals. If external optical receivers are used, the calibration algorithms are still valid when performed on an electrical channel to which the receiver is attached. It is important to ensure that the external receiver be attached and active when the calibration is performed. In this way any offsets generated by the receiver will be accurately characterized.

Effects of instrumentation frequency response

The frequency response of the measurement system, including the photodiode O/E converter, any amplification, filtering, and the measuring oscilloscope can potentially lead to waveform distortion and an eventual degradation of extinction ratio measurements.

TIA/EIA OFSTP-4A recommends that the frequency response of the receiver, including filtering, follows the response window previously shown in Figure 5. The allowable tolerances are very tight and can be difficult to achieve in practice. However, it is possible that a receiver approaching these tolerances can have a frequency response that results in an extinction ratio measurement with significant inaccuracy.

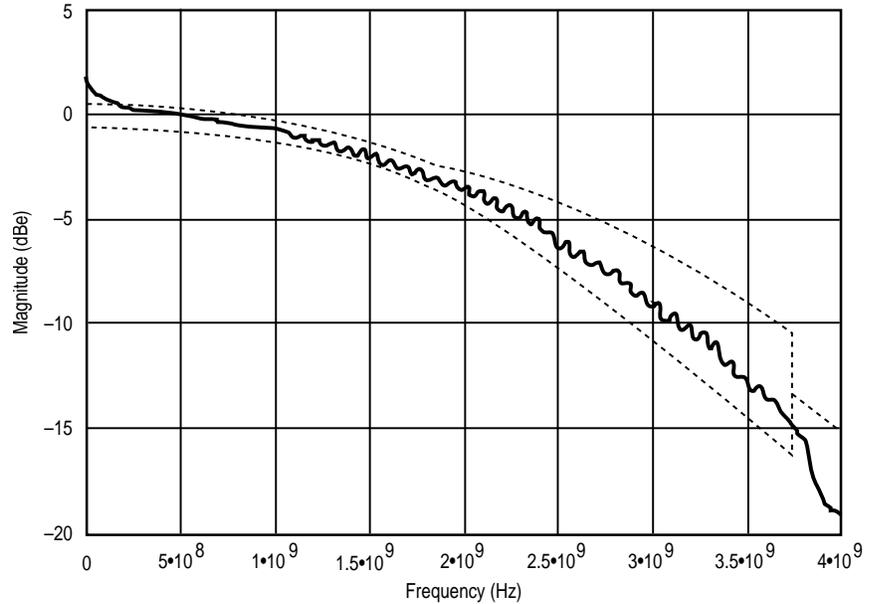


Figure 9. Receiver frequency response causing extinction ratio measurement inaccuracy

Consider a receiver with a frequency response similar to that shown in Figure 9. It almost falls within the required specifications for a SDH/SONET reference receiver and might then be used for extinction ratio compliance measurements. Note that the frequency response appears well behaved, except at the very low frequency range, where a distinct uplift occurs approaching 1 dB. The implication of this response is that very low frequency signal components will experience amplification relative to the middle and high frequency components of the data signal. Increased low frequency gain is a common phenomenon of GaAs amplifiers used in high-speed, wide-bandwidth O/E receivers or off-axis coupling of light to the photodiode.

When a waveform such as the signal shown in Figure 10 is passed through a measurement system with the frequency response similar to Figure 9, it will experience distortion as the low frequency components will be amplified relative to the rest of the signal. A transmitter with an approximate 10 dB extinction ratio is measured at 5.48 dB. The easiest way to view the impact this has on an extinction ratio measurement is to classify the low frequency components as simply the DC or average power and the high frequency components as the AC modulation or information bearing element of the signal.

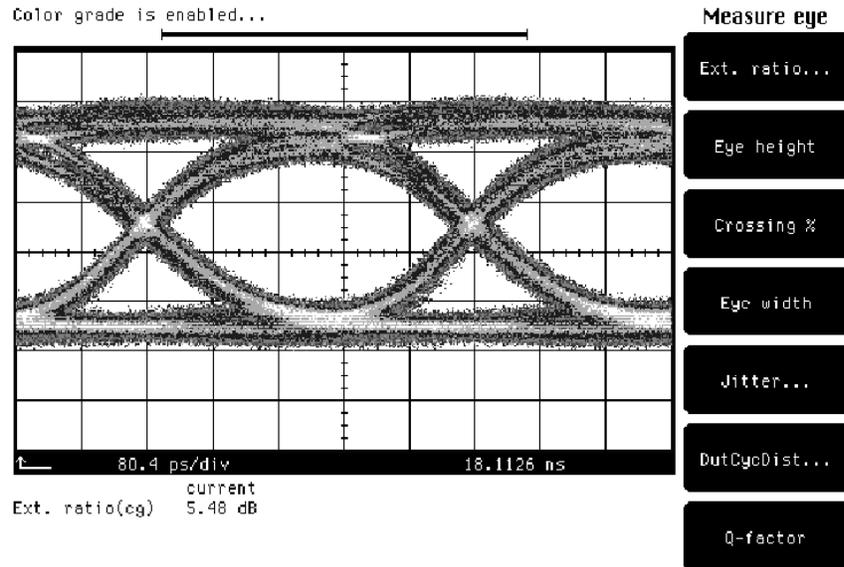


Figure 10. Waveform distortion due to imperfect frequency response

The effect of this offset is similar to that caused by dark levels (see Figure 8). As true extinction ratios become high, the measurement error can increase significantly. However, unlike dark levels, there is no simple technique to remove offsets due to the frequency response of the receiver. This is because the correction required is dependent upon the frequency content specific to the signal being measured.

The best technique for minimizing extinction ratio measurement errors due to frequency response imperfections is to use a measurement system designed to minimize this effect*. Caution should be used when measurements are made with amplified receivers. Receivers that are not amplified, or that employ carefully designed amplification are preferred for accurate extinction ratio measurements.

Receivers used for making extinction ratio measurements including the Agilent 83481A, 83482A, 83485A, 83485B, 83486A, 83487A, 86101A, 86103A, 86105A, 86106A, and 86109A are designed to have well behaved frequency responses that yield very accurate extinction ratio measurements. An example of the frequency response of the Agilent 83485A is shown in Figure 11.

* In limited cases, frequency response error at a single bit rate can be removed using the technique described in Appendix 1)

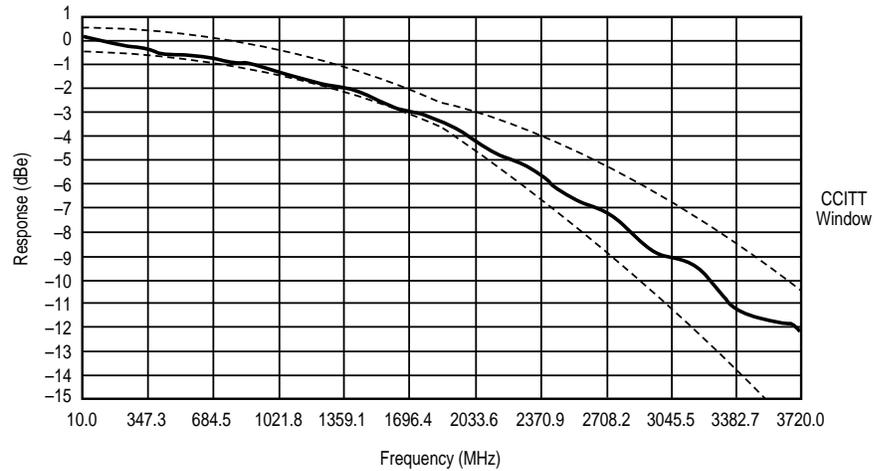


Figure 11. Frequency response of the Agilent 83485 Optical receiver

Extinction Ratio measurement algorithms

The process used by the Agilent 83480A for automatically measuring extinction ratio consists of the following elements:

1. Remove internal offset effects through a dark calibration
2. Set up the instrument in an infinite persistence database mode (This is a 3 dimensional database of number of samples vs. time and amplitude. This is displayed in a color graded mode where color represents the number of samples measured at a given display pixel.)
3. Perform a histogram analysis of the eye-diagram to determine the '1' and '0' levels of the eye diagram
4. Calculate the extinction ratio and report the results

The algorithms used for making extinction measurements have evolved over time. When the Agilent 83480 was introduced in 1994, there was not a strong consensus within the industry on what region of the eye diagram should be used for analysis. Some felt the measurement should be made over the full bit period of the eye. Others felt that only data from the central 20% of the eye should be used. To make the instrument as flexible as possible, it was designed to be configurable to measure any region of the eye the user desired.

When wide regions are analyzed, the rising and falling edges of the eye may potentially influence the measurement even though these portions of the waveform are not typically considered part of the actual '1' or '0' levels. If data from the rising and falling edges of the eye diagram are included in the histogram, they will tend to raise the apparent mean '0' level and lower the apparent '1' level. Thus early algorithms were designed to isolate data from the rising and falling edges.

This feature of the extinction ratio measurement algorithm would sometimes cause problems with eye diagrams that exhibited pattern dependency. For example the '1' levels following another logic '1' might be consistently higher than '1' levels preceded by a logic '0'. The eye diagram would then exhibit 2 discrete '1' levels. The histogram for the '1' level would then exhibit two distinct modes. To the analyzer, this has a similar signature to the histogram for the '1' level when using data from the full bit period of an eye due to data from rising and falling edges. The analyzer would then sometimes "lock" onto one of the discrete modes of the bimodal histogram when in reality it should have found the overall mean of the entire data set. This might occur even if only the central region of the eye was being analyzed. If neither of the modes were dominant, the analyzer might momentarily lock onto one mode and then lock onto the other. The effect would be seen in the reported value of extinction ratio. It would bounce back and forth between two values. (If the instrument markers were tracking the measurement, they would also jump in position.)

Since 1994, the industry has generally concluded that an extinction ratio measurement should be made over the central region of the eye diagram. Because of this, the measurement algorithm for extinction ratio has been optimized for this case. The new algorithm will simply find the overall mean of the data within the measurement boundaries (typically the central 20% of the eye). It does not try to interpret whether any of the data is from a rising or falling edge. There are two distinct benefits from this change. First, eye diagrams with pattern dependency no longer suffer from measurement "bounce". Second, measurement results are achieved much quicker and with significantly better repeatability and stability. The updated measurement algorithm has been implemented in firmware revision 7.0 for the Agilent 83480A and for all revisions of the Agilent 86100.

Regardless of the measurement algorithm, the following issues are important to consider:

- Will noise degrade the measurement?
- What is the smallest signal level that can be measured accurately?
- What portion of the eye is analyzed?
- What constitutes an adequate amount of data from which to construct histograms?

Instrumentation noise and measurements of small signals

Instrumentation noise can also lead to extinction ratio measurement error. However, because the measurement is histogram based, it can be very robust even as noise levels approach the magnitude of the signal being measured. For example, the RMS noise level of the Agilent 83480A when using the Agilent 83485A optical receiver plug-in or Agilent 86100A with the 86105A plug-in is typically 8 microwatts (-21 dBm). This noise level will be seen on both the '1' and '0' levels for a combined RMS level of 16 microwatts.

Transmitter signals at average power levels of lower than 40 microwatts (-14 dBm) at an extinction ratio on the order of 10 can still be accurately measured even though the eye pattern begins to close.

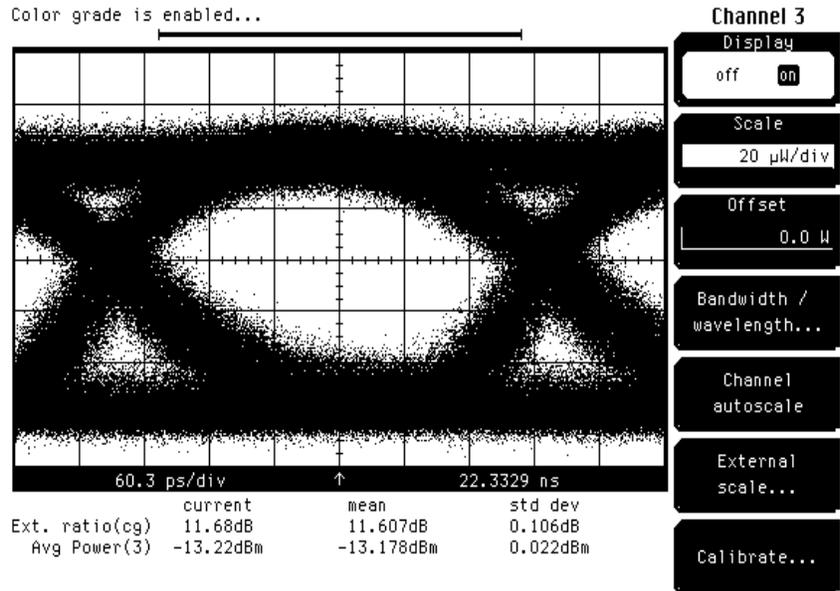


Figure 12. Extinction Ratio measurements with low signal-to-noise ratios

Using the automatic histogram capabilities of the instrument, the mean '1' and '0' levels from which extinction ratio is calculated are easily determined. In the case of Figure 12, the eye height (difference between '1' and '0' levels)-to-RMS-noise ratio approaches 10, where the RMS noise is 16 microwatts (double 8 microwatts) and the signal power is approximately 100 microwatts (roughly double the average power when the extinction ratio is greater than 10). As this ratio goes much below 5, the extinction ratio measurement algorithm will eventually fail as the instrument can no longer differentiate the components of the eye diagram as required to set up the location of the histograms.

There is a large family of receiver plug-ins compatible with the Agilent 83480A and 86100A, each with their own noise characteristic. The Agilent 83481A, 83486A, 83487A, 86101A, and 86103A exhibit typical RMS noise levels of less than 1.5 microwatts, allowing extinction ratio measurements on signals as low as 10 microwatts (-20 dBm avg.). The Agilent 83485B and 86106A RMS noise levels are typically less than 15 microwatts, allowing extinction ratio measurements on signals as low as 100 microwatts (-10 dBm). Although extinction ratio measurements can be made with low SNR's, it should be noted that mask testing of eye-diagrams require an SNR on the order of 12 or greater. For example, when using the Agilent 83480A and 83485A (RMS noise of 8 microwatts on both '1' and '0' levels) the signal power should exceed 200 microwatts (average power in excess of 100 microwatts, -10 dBm) for mask testing.

Determining what portion of the eye to measure

OFSTP-4 recommended that the histogram from which the extinction ratio data is extracted include data from a full bit period of the signal or in other words one complete “eye”. An advantage of this methodology is that it allows for simplified alignment of the histogram window. As long as the horizontal width of the window is one full bit period, the horizontal positioning of the window is trivial. The Agilent 83480A and 86100A allow the histogram to be taken from any portion of a bit period. For example, the default setting of the Agilent 83480A and 86100A is to measure the central 20% of the eye.

The central 20% of the eye is used for two reasons. First, the most recent revision of OFSTP-4A specifies that extinction ratio measurements be made here. Second, this is the portion of the filtered eye that represents the true mean ‘1’ and ‘0’ powers of the unfiltered eye waveform. If measurements are to be made on a portion of the eye other than the central 20%, this parameter can be modified in the Agilent 83480A under the DEFINE MEAS, Color Grade, Eye window menu. In the Agilent 86100A this parameter can be altered under the Measure, Config Measure, Eye Boundary setting.

Acquiring an adequate database

Measurements based upon statistical sampling and histogram analysis are generally improved as the sample size is increased. With firmware revisions earlier than 7.0 for the Agilent 83480A, measurements would tend to fluctuate and then eventually stabilize as the number of waveforms displayed in infinite persistence (color grade mode) increased.

Figure 13 shows the general shape of the vertical histogram for the case where a single waveform has been acquired versus the case where 50 waveforms have been acquired. Note that with a single waveform the histogram is rather coarse, and with 50 waveforms the histogram is very smooth indicating a well-filled sample space.

The 83480 (firmware revision 7.0 and higher) and 86100 are designed not to report an extinction ratio result until at least one pixel on the display has been hit at least 15 times. 20 or more waveforms may need to be acquired to reach this density of data. The 83480A allows this parameter to be altered through DEFINE MEAS, Color Grade, # Hits. The 86100 allows this to be altered only through remote command.

As the extinction ratio measurement algorithms have been improved, accurate and stable measurement results can be achieved for just a few waveforms. This can be examined by reducing the # Hits parameter and observing the stability of the reported measurement as just a few waveforms are initially collected versus a large number of waveforms. In general, histograms from even small sample sizes yield an accurate assessment of the mean ‘1’ and ‘0’ levels.

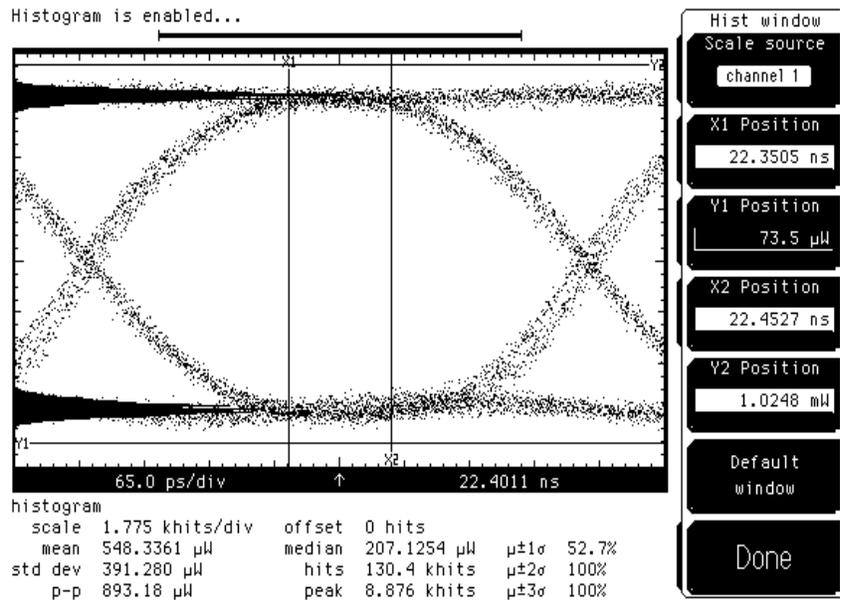
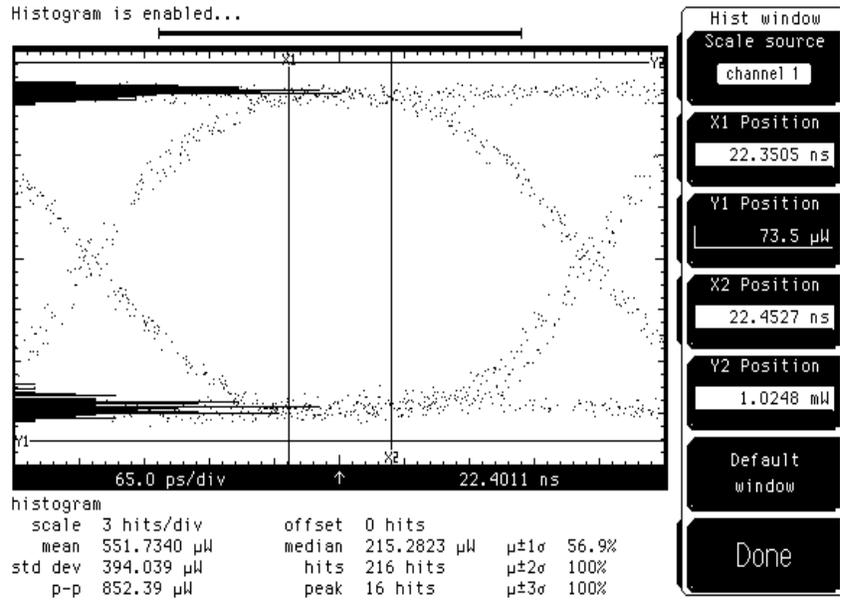


Figure 13. Extinction ratio histograms for small and large sample spaces.

4. Procedure for measuring extinction ratio using the Agilent 83480A or 86100A Digital Communications Analyzer

The following section discusses the step-by-step procedure for making an extinction ratio measurement using the Agilent 83480A and 86100A Digital Communications Analyzers. Following these guidelines will provide optimum measurement results.

Start with a known instrument configuration

To begin the procedure from a known instrument state, the instrument can be placed into a default setup condition by pressing SETUP (83480 only) and the Default Setup softkey. Note that this will revert any customized instrument configurations back to their default conditions. While the default setup is not required to perform an extinction ratio measurement, it does guarantee that unusual instrument configurations will not impact the results.

Getting the signal on the instrument display

The Agilent 83480A and 86100A, like all very wide-bandwidth “equivalent-time” digitizing sampling oscilloscopes, requires an external trigger for a timing reference. The best trigger signal is a clock signal that is synchronized with the data. For example, if a 2.5 Gbit/s waveform is to be measured, the best trigger signal is the 2.5 GHz clock signal used to generate the signal to be measured. This timing signal could come from the pattern generator used to produce the data that modulated the laser, or a clock signal extracted from the data. Subrate clock signals may also be used if they are integer divisions of the actual data rate (i.e. a divide by 4 or divide by 10 clock, 622.08 or 248.832 MHz for a 2488.32 Mbit/s waveform). The trigger signal must be phase-locked or phase coherent to the data waveform. Since all measurements are made relative to the trigger event, any relative phase instability between the trigger signal and the data will be seen as waveform instability on the instrument display.

In general, extinction-ratio measurements are not sensitive to mild trigger vs. data instability (jitter) in that the measurements are made on signal amplitudes. A mask test on the other hand can be severely impacted by jitter.

When measuring optical waveforms, a high-integrity connection should be made to the optical receiver. Poor connections can cause amplitude fluctuation and degrade measurements. Make sure that the fiber ferrule of both the instrument receiver and signal fiber are clean and in good mechanical condition. Once the connection is made, the instrument can be configured for the extinction ratio measurement.

Extinction ratio measurements require that only a single channel be active. Turn off the other channels by selecting the Channel SETUP key (found above the input connectors on Agilent 8348X plug-in modules) and turning the channel OFF for each channel besides the one to be measured. With the Agilent 86100A, extinction ratio measurements are made while operating in the “EYE/MASK” mode. Pressing the Eye/Mask button to the right of the instrument display activates this mode. When this is selected, the instrument automatically will turn off all input channels but one and put the instrument in an infinite persistence mode.

Filtered or unfiltered?

Extinction ratio measurements can be made in either a filtered or unfiltered bandwidth (although unfiltered measurements do not comply with the OFSTP-4A test method). In the Agilent 83480A, the filter configuration can be setup by pressing the Channel SETUP key, Bandwidth/Wavelength (softkey), Filter (on or off). In the Agilent 86100A, the filter can be activated by selecting the Setup dialog and selecting the appropriate channel, or by pressing the appropriate channel button below the display graticule. Some plug-in modules have dual filters for two data rates. If the filter is on, make sure the correct filter has been selected.

Setting the vertical and horizontal scales

The measurement should be made with a complete eye-diagram on the instrument display. Thus the vertical and horizontal scales should be adjusted to achieve this. Using the Agilent 86100A, scaling is easily achieved by simply pressing the autoscale key. Although the Agilent 83480A has an autoscale function, it is not designed to optimally display an eye-diagram. The following can be used to display the eye.

Press the CHANNEL SETUP key on the plug-in for the channel to be measured. Press the Channel Autoscale softkey. This will do a vertical scaling without altering the timebase settings. Press the Timebase key. Set the time base [Time/Bit period] key to bit period. Set the Bit Rate key to match the data rate of the signal (such as 2488 Mb/s STM-16/OC-48) either by using the knob or arrow keys to scroll through the built-in standard rates, or enter the data rate through the numeric keypad. Set the Bit Period to a value between one and two bits. Then adjust the Position value to center the eye-diagram on the screen.

Activating the color graded database

Extinction ratio measurements are made using a histogram analysis of the eye-diagram. Using the 86100A the database for histograms is simply any data on the infinite persistence display that is automatically activated when the instrument is placed in Eye/mask mode. For the 83480A, the database from which the histogram is derived is the color graded database. Thus the instrument must be placed in the color graded display mode. This is accomplished by pressing the DISPLAY key and then the Color Grade softkey (turning it “on”). As soon as Color Grade is activated, the database will begin to accumulate data. However, for both the 83480A and 86100A when any of a variety of settings are altered on the instrument (examples include vertical or horizontal scaling), the database will be refreshed and begin to build again.

Setting up the extinction ratio measurement

Agilent 83480A

The extinction ratio measurement is found under the Meas Eye menu (located as a “shift” function of the Acquisition key below the instrument display). When extinction ratio is selected, the extinction ratio menu will appear. First select the format for reporting results, either linear ratio, decibels, or as a percentage.

Agilent 86100A

The extinction ratio measurement is available as one of the automatic eye measurements found on the left side of the display when the Eye/Mask mode is activated (key found to the right of the display). With an eye diagram on the display, the extinction ratio is reported after pressing the “extinction ratio” measurement key. In its default state, the 86100A reports extinction ratio in decibels. To change to linear or percentage results, press “setup and info” on the measurement results tab (to the right of the reported extinction ratio value). Then press “extinction ratio” and “configuration”. The extinction ratio format can then be changed.

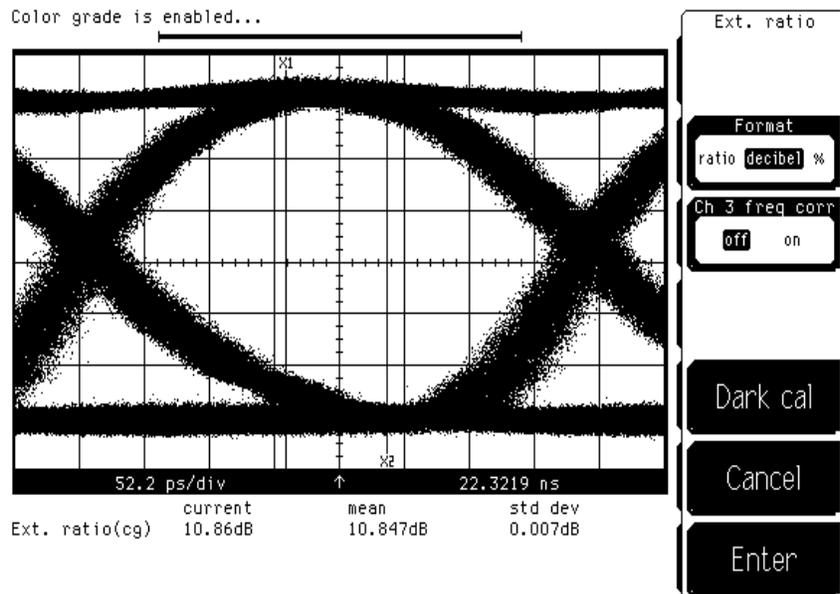


Figure 14a. Extinction ratio menu for the 83480A

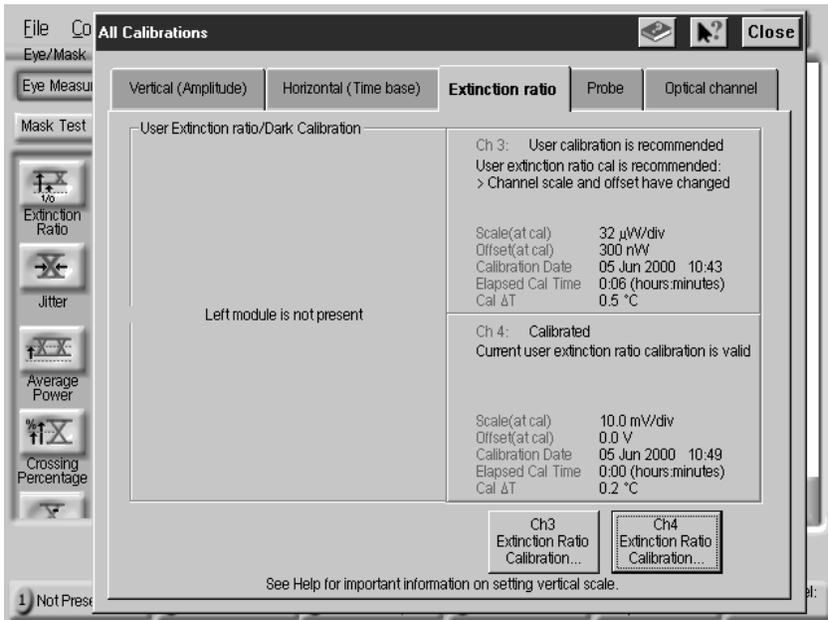


Figure 14b. Extinction ratio menu for the 86100A

An extinction ratio or “dark” calibration should then be performed to allow internal offsets (either of an integrated optical channel or an external O/E converter and electrical channel) to be removed from the measurement. However, prior to performing the dark cal some discussion on vertical scale and offset is required. The Agilent 83480A and 86100A are a digitizing oscilloscopes. Measured signal levels are converted to digitized levels. To obtain the highest accuracy in the digitizing process, the vertical scale and offset should be adjusted so that the eye-diagram covers most of the instrument display. On the other hand, when measuring the dark signal level (the signal level of the instrument when no signal is applied) during an extinction ratio or dark cal, the vertical scale and offset must be such that the dark level is also visible on the instrument display.

To satisfy both of these conditions, first adjust the vertical scale and offset to present the largest eye possible while leaving about half of a vertical graticule between the bottom of the eye and the bottom of the instrument display. Specific vertical scale values such as 80 microwatts/div will likely need to be entered through the numeric keypad instead of the 50/100/200....settings achieved through the arrow keys or knob. Disable the light source to be measured by either turning it off or disconnecting it from the instrument. Verify that the dark level is on the screen. It should appear as a flat horizontal line, and should be located near the bottom of the screen. If it is not on screen, or is perhaps difficult to see due to the display persistence still showing the eye-diagram in the ‘on’ condition, the vertical scale or offset should be adjusted until the dark level is visible. The vertical scale adjustment process can then be repeated until the largest eye diagram is visible while still being able to display the dark level when the light source is disabled. See Figure 15.

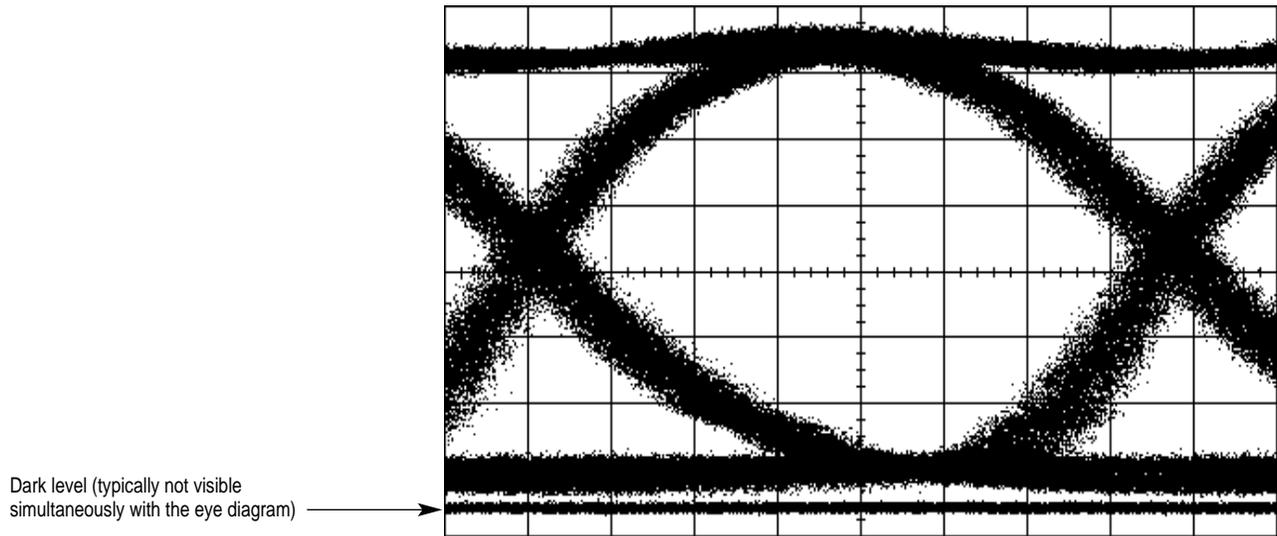


Figure 15. Optimum vertical scale displays the dark level and the largest eye possible.

Setting the vertical scale to maximize the size of the eye-diagram is not a rigorous requirement for an accurate extinction ratio measurement. It is a recommendation for the best possible measurement accuracy. Valid, accurate results will still be obtained for eye-diagrams with as little as 3 graticules of vertical display magnitude.

Performing an extinction ratio or “dark” calibration

Extinction ratio calibration for the Agilent 86100A

The Agilent 86100A will report an extinction ratio value, even without a valid extinction ratio calibration. However, for best accuracy an extinction ratio calibration should be performed. Once an extinction ratio calibration has been performed, it will remain valid as long as the temperature of the instrument does not vary more than $\pm 1^\circ\text{C}$ or less than 10 hours has elapsed since the calibration was performed. Thus the calibration should be performed after the instrument has warmed up, typically achieved after one hour. Also, the calibration should be performed at the vertical scale setting at which the measurement will be made. If the scale setting is changed more than one major scale setting, a new extinction ratio calibration is recommended. (For example, if the scale was $200 \mu\text{W}/\text{division}$ when the calibration was performed, this calibration is adequate for scale settings from $100 \mu\text{W}/\text{division}$ to $500 \mu\text{W}/\text{division}$).

To perform an extinction ratio calibration, select the calibration pull down menu at the top of the display. This will then display a page that includes all the available calibrations for the instrument. Select the tab for extinction ratio. The display should appear as Figure 16a.

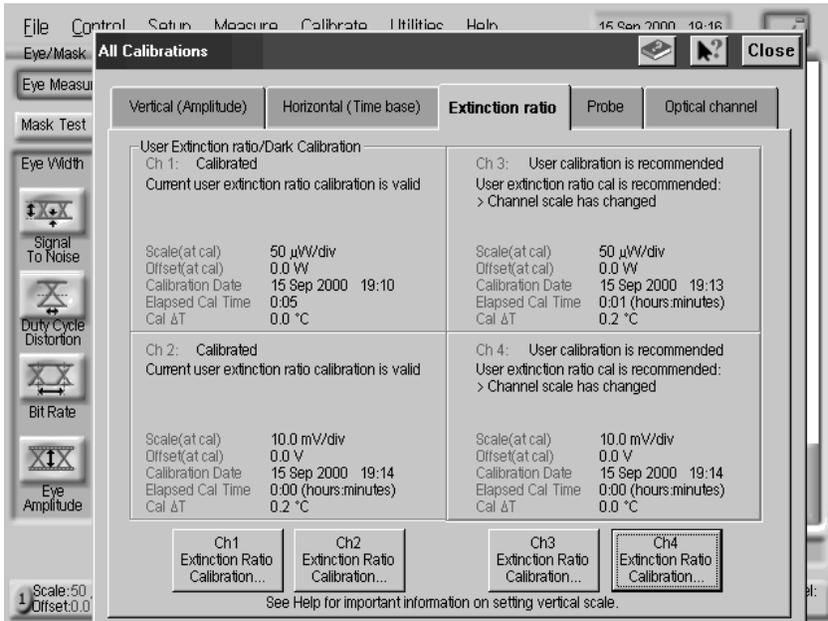


Figure 16a. Calibration status of the plug-in channel in the 86100A

The extinction ratio calibration page will indicate whether a calibration is recommended, why it is recommended, and the conditions under which any current calibrations have been performed. To execute a calibration, select the “Ch X Extinction Ratio Calibration” button.

When the calibration is selected, the user is instructed to remove any signals present at the input to the instrument. It is best to block any light going into the receiver, as stray ambient light can corrupt a calibration, particularly those with large core diameters. If external optical receivers are used, the receiver should be attached to the electrical channel of the instrument and be in an active state.

If the plug-in module does not have a valid vertical calibration, the extinction ratio calibration will automatically invoke a vertical calibration. This will take one to two minutes. Once the vertical calibration is performed, or a valid vertical calibration already existed, the extinction ratio calibration is performed. This takes less than two seconds. (This is the reason that sometimes extinction ratio calibrations take one to two minutes or just one or two seconds.)

Extinction ratio calibration for the Agilent 83480A

A dark calibration is required to allow the instrument to remove any internal offset signals from the extinction ratio calculation. If a valid dark calibration has not been performed, the instrument will not report any extinction ratio results. If a dark calibration has been performed and the instrument is turned off, the dark calibration is invalidated. A similar condition will occur if the ambient temperature of the instrument changes more than 5 degrees C.

A dark calibration is performed under the MEAS EYE/Extinction Ratio/Dark Cal key sequence. When Dark Cal is pressed, the instrument instructs the user to remove all signal connections to the plug-in. The intent is to have no optical signal power going into the instrument so that what is measured is only due to internal offsets. In the case where an external receiver is used, offsets due to both this receiver and the Agilent 83480A are measured. When using receivers with large core diameters such as the Agilent 83486A/7A, ambient light can be significant enough to corrupt the calibration. Therefore the input to the receiver should be blocked so no light can enter.

For best accuracy, the dark cal should be performed after the instrument has warmed up. A one hour warm-up time is sufficient. A plug-in calibration will also ensure best accuracy. This is easy to perform and is achieved under the UTILITY/Calibrate/Calibrate Plug-in key sequence. (A plug-in cal should be performed whenever the ambient temperature of the instrument has deviated more than 5 degrees C from the temperature value when the last plug-in cal took place, or the plug-in module has been removed from the mainframe. The temperature status can be seen by selecting SETUP CHANNEL near the measurement channel input and selecting the Calibrate/Cal Status softkeys and turning the Cal Status "ON". See Figure 16b. Note that in this example the temperature deviation from when the plug-in calibration (not the mainframe calibration) was performed is 0 degrees C. Once the plug-in cal has been performed, a dark cal will still be required.)

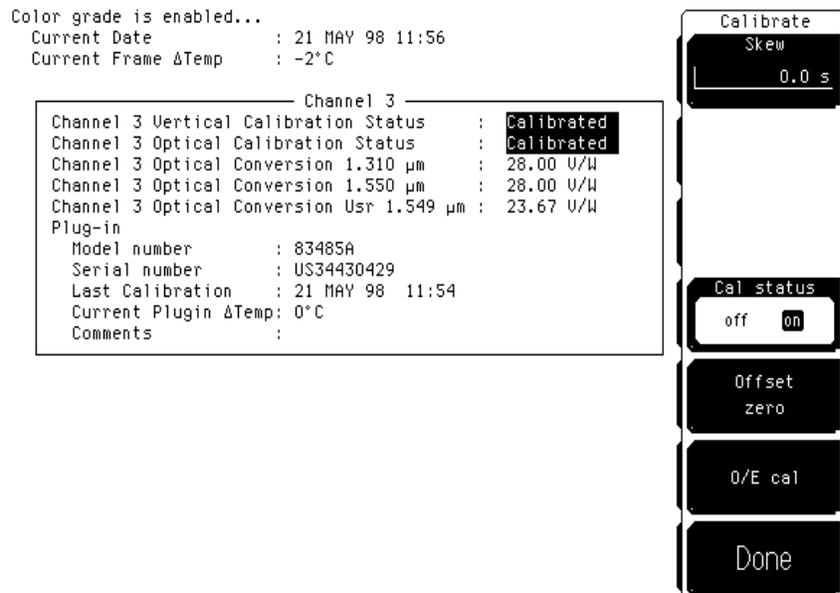


Figure 16b. Calibration status of the plug-in module in the 83480A

When the dark cal is first performed with an integrated optical channel, two procedures take place. An O/E offset calibration is executed. In this process a partial vertical calibration for the plug-in module takes place which will minimize any internal offsets from the internal optical receiver and the following electronics. Second, the actual dark level after offset adjustment is measured. This procedure takes approximately 35 seconds. If the dark cal procedure is performed a second time, the O/E offset calibration is not required and only a dark level measurement is performed. In this case, the dark cal process takes less than 2 seconds. Note that for best accuracy, the dark cal should be performed with the same vertical scale and offset values that will be used when the extinction ratio measurement is made. If signal levels change (example, a second transmitter with lower power is tested), the dark cal should be repeated once the vertical scaling has been adjusted appropriate for the new laser under test. If a dark calibration is not repeated, the measurement results are still valid and accurate. Repeating the dark calibration simply guarantees the best possible accuracy.

Once a dark cal has been executed, the instrument instructs the user to reconnect the laser. Because the instrument has likely acquired data before the laser is reconnected, the database should be refreshed to ensure that it contains data only from the active laser signal. This is achieved by pressing CLEAR DISPLAY once the laser signal has stabilized. To complete the procedure, press DONE in the Extinction Ratio menu and the measurement result should then be reported.

General issues with extinction ratio calibrations

It is important to note that the calibration does not remove or “zero out” any offset signals. It only quantifies them and allows for them to be mathematically removed from the measurement calculation.

As discussed in an earlier section (page 17), the Agilent 83480A allows the user to set the minimum number of “hits” or samples that must be acquired before a valid extinction ratio measurement is calculated. For example, if the minimum number of hits is set to 15, at least one of the display pixels must be hit at least 15 times before the extinction ratio is calculated and displayed. This forces the database to build up to a significant sample size prior to reporting results. This limit is user defined and can be adjusted under DEFINE MEAS/ Color grade/ # Hits. The default value is 1, meaning that measurement results are yielded immediately (upon display of the first color grade waveform). If the # Hit limit is set to a small value there will possibly be fluctuation in the measurement results as the database will initially be small. However, as data is continuously acquired, the extinction ratio measurement should quickly converge to a final value.

In the Agilent 86100A, controlling the #hits is currently only achievable through GPIB control. The default value is 15 hits. Depending upon the signal distribution of typical signals, it is likely that stable, repeatable measurements can be achieved with a #hits setting much lower than 15. The result is that fewer waveforms and less time is required to perform the measurement.

If a laser under test is being actively tuned, then the database will need to be periodically refreshed so that data taken under previous tuning levels/old operating conditions does not impact the current measurement. Refreshing the database is achieved through executing a CLEAR DISPLAY.

How accurate are the results?

The accuracy of the extinction ratio measurement made by the Agilent 83480A is dependent upon the actual level of extinction ratio. As extinction ratio levels become high, eventually the instruments ability to make an accurate measurement is limited by its dynamic range. In these cases the instrument is required to simultaneously measure a very large level and a very small level. The vertical accuracy for this type of measurement is described by the “DC accuracy” or the accuracy in making a measurement of a specific signal level. For example, using the Agilent 83485A plug-in, the DC accuracy is $\pm 25 \mu\text{W} \pm 2\%$ of the measured level. If the logic ‘1’ level is $1000 \mu\text{W}$, and the ‘0’ level is $100 \mu\text{W}$, the measurement extremes (ignoring offsets) would be:

$$(1000*1.02 + 25)/(100*0.98 - 25) = 14.32 \text{ (11.6 dB) to}$$

$$(1000*0.98 - 25)/(100*1.02 + 25) = 7.52 \text{ (8.8 dB)}$$

If the same analysis is used on a 16 dB (40:1) extinction ratio, the measurement uncertainty for a $1000 \mu\text{W}$ ‘1’ level and a $25 \mu\text{W}$ ‘0’ level becomes:

$$(1000*1.02 + 25)/(25*0.98 - 25) = (\text{Infinite}) \text{ to}$$

$$(1000*0.98 - 25)/(25*1.02 + 25) = 18.9 \text{ (12.8 dB)}$$

The above analysis ignored offsets. However, the precision with which offsets are measured will also impact the final result. To compute extinction ratio, the internal offset determined through the dark cal is subtracted from both the logic ‘1’ and logic ‘0’ levels of the eye diagram. When the logic ‘0’ level is very small (as is the case when extinction ratio is high), removing the offset requires the subtraction of a small number from another small number. Again, because both the logic ‘0’ level and dark level are measured with a vertical scale setting that also allows the logic ‘1’ level to be measured, the digitization process for the small signals has a comparatively low level of precision (subject to quantization error). Thus the value that dominates the extinction ratio measurement, the offset adjusted logic ‘0’, can be subject to significant measurement uncertainty.

The above analysis would tend to cause a general distrust of extinction ratio measurements. In reality, measurements are significantly better than that implied by a worst case uncertainty analysis. The situation is alleviated in large part through the use of histograms. Histograms tend to smooth out some of the effects of quantization error and yield an effective improvement in measurement accuracy. To give a practical assessment for measurement accuracy, the following tables show “measured versus actual” performance for a variety of Agilent 83480A and 86100A configurations.

Table 1. Agilent 83480A Extinction Ratio Measurement Accuracy

	Actual Extinction Ratio (dB)		
	8 to 11	11 to 14	14 to 16
Plug-in Module	Measurement error		
Agilent 83485A			
Agilent 86105A			
Agilent 86106A	-0.6 to 0	-1.5 to 0	-2 to 0
Agilent 83481A			
Agilent 83486A			
Agilent 83487A	-0.4 to 0	-1.2 to 0	-2 to 0
Agilent 86101A			
Agilent 86103A			

Notes: Measurements based upon a color graded database with 50 waveforms, 2⁷-1 PRBS data. Measurements made over the central 20% of the eye-diagram. Eye-diagrams typically scaled to approximately 6 or more vertical divisions. Horizontal scale set to show approximately 1.3 bit periods. Measurements made in a filtered bandwidth (SDH/SONET or Gigabit Ethernet Filtering according to the data rate). Valid plug-in vertical calibration and extinction ratio dark calibration. Average power levels from -4 dBm to -14 dBm for the Agilent 83485A plug-in module. Average power levels from -10 dBm to -18 dBm for the Agilent 83481A, 83486A and 83487A plug-in modules. Measurement uncertainties may be different for waveforms with unusual waveshapes leading to poorly shaped vertical histograms. These results are not instrument specifications, but are intended to give expected measurement performance levels.

What levels of extinction ratio can be measured?

Although in theory extinction ratio can be infinite, the measurement of very high extinction ratios is difficult to achieve with any precision due to the measurement uncertainties discussed above. Depending upon the data rate and instrument configuration, Table 1 should give an indication of both measurement range and accuracy.

A technique developed to extend extinction ratio measurement range has been implemented in the Agilent 83480A and is discussed in Appendix 1. This technique is currently not available in the Agilent 86100A.

Appendix 1: Extending extinction ratio measurement range

If a transmitter with an adjustable extinction ratio was measured by the Agilent 83480A, and transmitter adjustment produced a higher and higher extinction ratio, eventually the extinction ratio reported would reach a maximum even if the true extinction ratio continued to increase. If this measurement limit can be determined, the Agilent 83480A will allow a user-entered adjustment to increase the useable measurement range. A laser source with an adjustable, very high extinction ratio is required. The procedure is as follows:

1. Perform all the steps required for an extinction ratio measurement as described in this application note. When selecting the format for the measurement result, select % as opposed to linear or dB.
2. Beginning with an extinction ratio in the range of 10%, systematically adjust the extinction ratio for a lower and lower % level. (Recall that as extinction ratio goes up, extinction ratio percentage will go down). After each laser adjustment, execute a CLEAR DISPLAY to refresh the database.
3. At some point, the reported extinction ratio percentage will no longer change. Either the instrument has reached a measurement limitation or the laser has reached maximum adjustment. To determine which is the case, one tool that can be used for a directly modulated laser is to monitor the average power (Shift/More Meas (on the numeric keypad)/Avg Power). If the average power continues to change but extinction ratio does not, it is likely that the instrument is at its limit. The waveform could also be observed to see if it continues to change with adjustment.
4. When the measurement limit for the instrument has been determined, document this value. This may be somewhere between 1 and 4% and will depend upon the instrument configuration and the data rate being measured.
5. In the extinction ratio menu (MEAS EYE/Extinction ratio) there is a key titled "Ch 'x' freq corr". Select this key and through the numeric keypad enter the percentage value obtained in step 4. For example, if the measurement limit is 1.5%, press 1, '.', 5 and enter on the keypad.

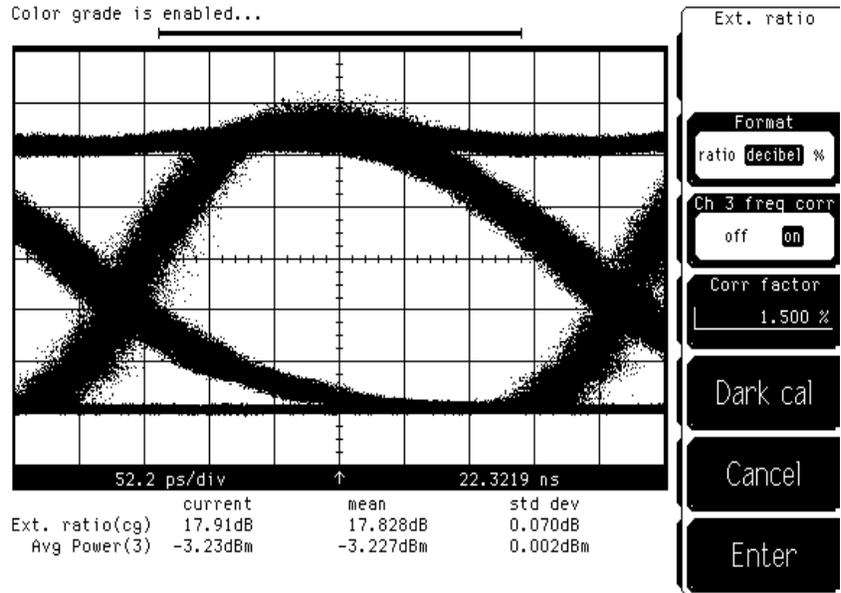


Figure 17. Frequency correction menu

Subsequent extinction ratio measurements will be offset to account for the measurement floor of the instrument. The format can be returned to linear or dB if desired and still use this correction. Note that this correction factor is only valid for the conditions for which it was determined. That is, the frequency content of the data should be constant. If a PRBS data sequence is used, the pattern length and data rate must be held constant. For a detailed explanation of the theory behind this procedure, refer to “Accurate Optical Extinction Ratio Measurements”, IEEE Photonics Technology Letter, Vol. 6, No. 11, November 1994, P.O. Andersson and K. Akermark.

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