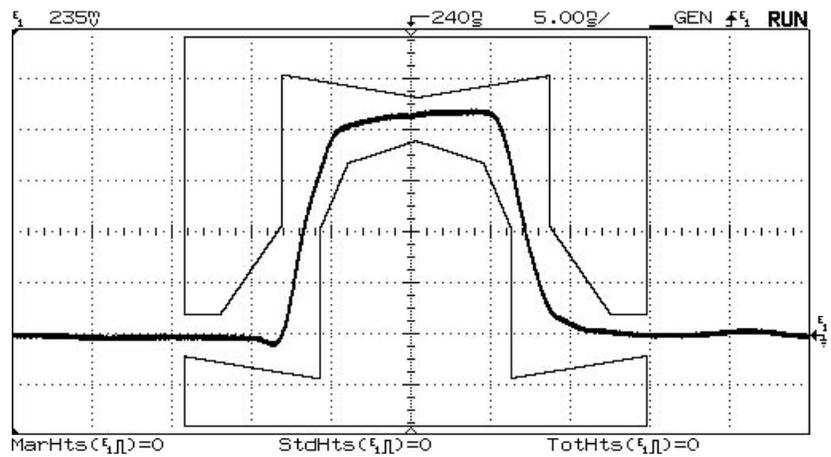
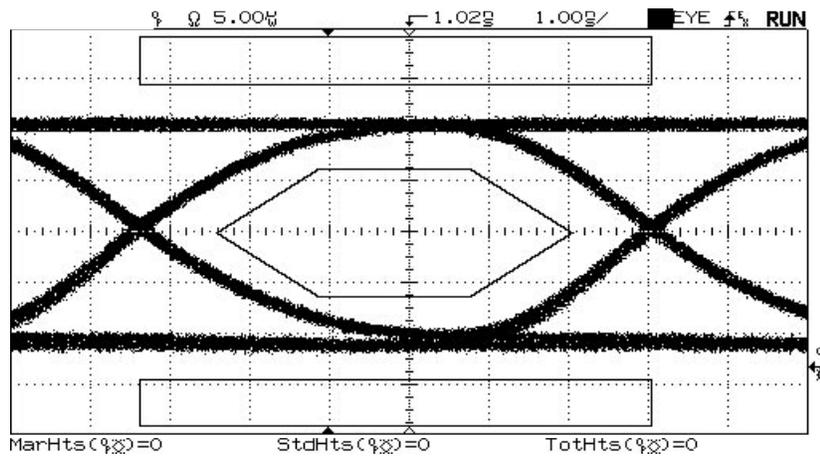


Communication waveform measurements

Product Note 83475-1



Introduction

The HP 83475 provides a comprehensive set of measurement capabilities specifically geared for digital communications applications. This product note will review some of the basic measurements performed by the HP 83475. Specific examples for analysis and conformance waveform measurements are provided.

Communications measurements

Development and manufacturing of digital communications components and equipment require extensive testing of performance characteristics. A subset of these characteristics can be tested and monitored through physical layer waveform measurements. These measurements serve to characterize the time-domain response of a communication system or component and play an important role in assuring sufficient operational margin and transmission quality. Communications standards, such as SDH and SONET, require several waveform measurements to assure equipment compliance to standard specified performance limits. The HP 83475 measures many of the time-domain characteristics of digital data and performs several of the standard required waveform measurements.

Communications standards

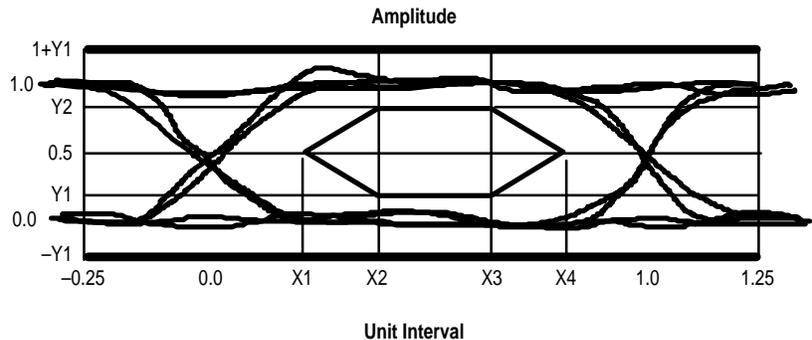
Telecommunications and Data-communications standards, such as SDH, SONET, and FDDI, require stringent operating characteristics from compliant equipment. This allows for compatibility between equipment from different manufacturers. Intensive testing and analysis are required to gain conformance to the standard specifications and to eventually obtain the required equipment performance.

Standards are typically specified in accordance with the ISO OSI Network Model which divides different network tasks into layered modules. Each layer requires different types of testing. The lowest layer in the OSI Network Model is referred to as the physical layer. The layer specifications are essentially concerned with issues involved in bit transmission. For example, physical layer standards specify signal levels and shape, cable connectors, and cable. Several of

the physical layer parameters can be measured or verified with a digital sampling oscilloscope and a wide-band, DC-coupled optical-to-electrical (O/E) converter.

Conformance measurements

Typically done in component and equipment manufacturing, a standards-driven measurement is mask and/or template waveform compliance. Standards such as SDH, SONET and Fibre Channel require transmitter time-domain response compliance to specified geometries known as waveform templates or masks. A pulse or eye-diagram mask test combines many of the pulse parameters in a single test and in some cases may come closer to specifying what is needed for proper circuit operation than the individual pulse or eye parameter. Such tests are done at the transmitter output and provide a final check to assure that the system or component has sufficient margin for proper operation under real operating conditions.



	STM-1 (155.52 Mb/s)	STM-4 (622.08 Mb/s)
X1/X4	0.15/0.85	0.25/0.75
X2/X3	0.35/0.65	0.40/0.60
Y1/Y2	0.20/0.80	0.20/0.80

	STM-16 (2.48832 Gb/s)
X3-X2	0.2
Y1/Y2	0.25/0.75

Figure 1. Eye-diagram mask definition for SDH/SONET.

A standard defined O/E reference receiver is required, by standards such as SDH and SONET, when performing a mask or template test on lightwave transmitters. The frequency response of this reference receiver is tightly controlled and is specified as that of a fourth-order Bessel-Thomson filter with a 3 dB frequency at 0.75 times the appropriate bit rate. This heavy filtering serves to integrate the average power within the bit period, reducing the effects of overshoot and noise. Thus, more consistent measurement results can be typically obtained.

A nominal extinction ratio on lightwave transmitters is also required by standards such as SDH, SONET and Fibre Channel. This measurement can be conducted on the eye-diagram response of the transmitter through the use of a sampling oscilloscope and a DC-coupled reference O/E receiver. The average optical power of an SDH/SONET transmitter is another important parameter that must comply with standard specifications. Other physical layer measurements related to the time-domain response of communications equipment include jitter and Bit Error Ratio (BER). BER is the fundamental performance characteristic of a communications system or component and is typically measured with a Bit Error Ratio Test (BERT) system.

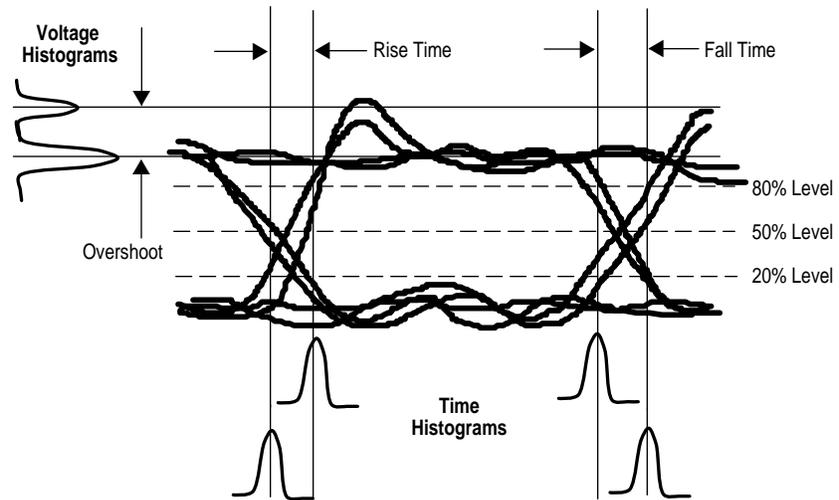


Figure 2. Eye-diagram characterization

Waveform analysis

Beyond standard-defined measurements, further analysis is typically performed by using physical layer waveform measurements. The time-domain response, usually in the form of an eye diagram, provides valuable insight into the performance of a communication transceiver or system. In development, waveform analysis through parametric measurements can be very useful as a first step in understanding system or component performance. As an example, eye-diagram waveform parameters, such as noise, jitter, and rise time, can provide insight into system or component performance limitations. In order to obtain maximum accuracy, these parameters are often characterized using the histogram statistical functions of a sampling oscilloscope and are performed at the highest possible bandwidth (BW).

The HP 83475 Lightwave Communications Analyzer

The HP 83475 Lightwave Communications Analyzer introduces a convenient and cost effective solution that fits into many of the applications where an oscilloscope and external O/E have been traditionally employed. The instrument is based on a portable frame with an analog look and feel. It provides very fast update rates at all sweep speeds to give immediate feed-back when the waveform under analysis changes. Within this platform, the HP 83475 introduces an integrated and calibrated optical channel that allows for peak and average optical power measurements.

In addition, two 500 MHz electrical channels are available for general purpose circuit testing and analysis. The HP 83475 provides comprehensive communications waveform analysis capabilities with built-in automatic histogram measurements such as noise and jitter. Furthermore, the instrument also has all of the capabilities of a general-purpose 500 MHz oscilloscope.

of the internal O/E and the electrical measurement channel, a calibrated vertical Watts scale has been provided to view the instantaneous power levels of the optical waveform. The demodulated output of the integrated O/E receiver is accessible on the front panel of the instrument and can be connected to the electrical input through a BNC jumper or a filter.

Besides allowing for calibrated power measurements, the integrated optical channel can function as a fully compliant SDH/SONET or Fibre Channel reference receiver system. An optional calibration of the combined response of the integrated O/E, a hardware filter, and the electrical channel can provide measured compliance to SDH/SONET and/or Fibre Channel reference receiver specifications. The reference receiver specifications are provided in the form of a frequency response window about a fourth-order Bessel-Thomson response with a 3 dB frequency at three fourths the specified bit rate. Optical channel reference receiver options are available for SDH/SONET OC-1 (51.840 Mb/s), STM-1/OC-3 (155.52 Mb/s), and Fibre Channel 133 MBaud. A reference receiver is required for mask testing to the above standards. It is also recommended for optical extinction ratio measurements.

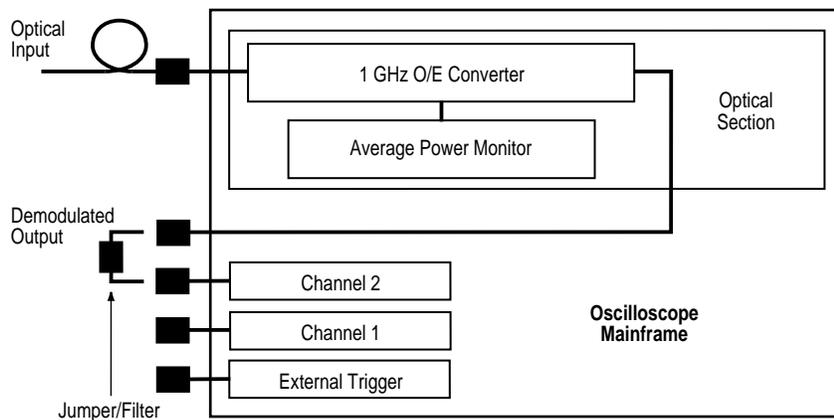


Figure 3. The HP 83475 conveniently measures both optical and electrical signals.

The lightwave technology integrated within the HP 83475 consists of a low-distortion, PIN-based 1 GHz O/E converter. The optical input provides a 62.5/125 μm multimode fiber interface. An innovative calibration procedure is implemented on the HP 83475 optical channel to provide, with a single connection, both average and instantaneous optical power measurements. By monitoring the photodiode current, a built-in average optical power meter has been implemented. In addition, through characterization

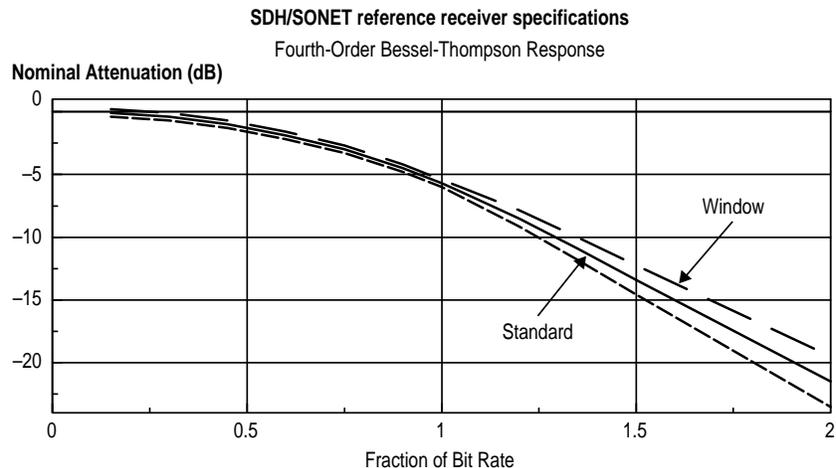


Figure 4. SDH/SONET reference receiver frequency response

Setting up the instrument

In operating the instrument, there are “hardkeys” and “softkeys.” Hardkeys reside on the instrument front panel and their functions are printed directly on the keys. These keys are denoted with bold type such as **Autoscale**. Softkeys are those that are located across the bottom of the display and whose functions are given on the instrument display. Softkeys can change depending on the selected hardkey. They are noted in brackets such as [Rise Time]. The instrument has softkeys that offer a choice of settings or functions. An example is [Opt Pmtr On Off]. In this case, you can choose “On” by pressing the softkey until “On” is highlighted, or choose “Off” by pressing the softkey until Off is highlighted. Softkey choices are noted as: [Opt Pmtr On Off] On.

Clean fiber ends and instrument test ports

It is a good measurement practice to clean fiber interfaces before making measurements and performing calibrations. Clean fiber ends and connector ports are essential for good measurements. The optical channel port and all fiber ends should be kept clean. Dirty connectors can result in reduced sensitivity. To clean the optical channel input, the connector adapter is removed from the instrument front panel, exposing the cable ferrule.

Caution: Extreme care should be taken to avoid damaging the instrument connector ferrules. Damaged connectors reduce measurement integrity and are not user serviceable.

Please refer to the connector care chapter in the instrument User’s Guide for connector cleaning and care information.

Optical or electrical

The HP 83475 can be configured with either two electrical channels or one electrical and one optical channel. Channel 1 is strictly for electrical measurements. Channel 2 can be set up as either an electrical or an optical measurement channel. To define the Channel 2 function, press: **Optical/Elec 2**, [Chan 2 Off Op E2] Op or E2. “Op” sets Channel 2 as an optical measurement channel. Note that the vertical scale is given in watts. “E2” sets Channel 2 as an electrical channel and the vertical scale is given in volts.

When “Op” is selected, the peak power of the waveform can be measured to the vertical accuracy specified for the optical channel. Vertical accuracies are specified for 780, 1310, and 1550 nm. For this and other specifications, refer to the HP 83475 Technical Specifications document (P/N 5962-7935E).

Note: The optical channel can be activated (“Op” selected) only if the Channel 2 input impedance is set at 50 Ohm.

Connecting demod output to channel 2

To make optical channel measurements, the demodulated output of the integrated O/E must be physically connected to the Channel 2 electrical input. For unfiltered measurements, a 50 Ohm BNC jumper is provided to connect the Demod output and the Channel 2 input. The nominal impedance of the O/E demodulated output is 50 Ohm. Thus, in order to achieve an impedance match, the Channel 2 input should be set to 50 Ohm. To set Channel 2 to a 50 Ohm input press: **Optical/Elec2**, [Input 50 Ohm 1 MOhm] 50 Ohm.

If the HP 83475 includes instrument options 050, 051, 052 and/or 053, the demodulated output and Channel 2 can also be connected with a reference receiver hardware filter. Reference receiver filters are required for standard defined optical eye-diagram testing. For proper filter performance, the Channel 2 input should be set at 50 Ohm.

Select operating wavelength

When using the HP 83475 optical channel, the appropriate wavelength calibration should be selected. The wavelength calibration activates the correct vertical scale and power meter calibration for the optical signal at the input. For example, if a 1310 nm signal is being analyzed, the 1310 nm vertical channel and power meter calibration should be activated. To activate the 1310 nm factory calibration, press: **Optical Cal**, [Show Deflt User] **Deflt**, 1310 nm. Standard calibrations are specified for ± 20 nm from the calibrated wavelength.

The HP 83475 allows for user calibrations at wavelengths ± 20 nm from the factory calibration wavelengths of 780, 1310, and 1550 nm. Up to three user calibrations can be performed and saved. Refer to the HP 83475 User's Guide for the user calibration procedure.

Autoscale

After connecting either an optical signal or an electrical signal to an HP 83475 input channel, the signal display can be automatically optimized by pressing the **Autoscale** front panel key. Using autoscale requires signals with a frequency range greater than or equal to 50 Hz and a duty cycle greater than 1 percent.

When you press the **Autoscale** key, the analyzer scales all channels that have signals applied and selects a time-base range based on the trigger source. The trigger source selected is the highest numbered input that has a signal applied. If a signal is connected to the external trigger input on the HP 83475, then it is selected as the trigger source.

Selecting the measurement type

The HP 83475 can make automatic measurements either on eye diagrams or pulse waveforms. The instrument must be configured to make the desired measurement type. The measurement algorithms are different depending on the type of waveform that is to be analyzed. If an eye diagram is to be analyzed, access the eye-diagram measurements by pressing **Power/Voltage**, [Meas Type Genl Wvfm Eye:NRZ] **Eye:NRZ** or **Time**, [Meas Type Genl Wvfm Eye:NRZ] **Eye:NRZ**. If a pulse measurement needs to be made, under the [Meas Type Genl Wvfm Eye:NRZ] softkey, make sure that "Genl Wvfm" has been selected.

Only one type of measurement can be made at a time. If measurements of a given type are active, and the measurement type of the active measurement is changed, the measurements are automatically deactivated and the results section displays "Genl off" or "Eye off."

Setting the sample size for statistical measurements

Several of the measurements made by the HP 83475 are based on values obtained from a statistical distribution of data accumulated at a particular waveform location. The data can be arranged, for statistical analysis, into what is called a histogram. A histogram is a graphical representation of the data distribution. Parameters such as mean and standard deviation can be obtained from a histogram. These parameters can be used as a basis for waveform analysis. For example, the standard deviation of a time histogram taken at the eye-diagram crossing point is typically identified as the signal jitter. The HP 83475 also uses histograms to obtain eye-diagram parameters which are used for mask positioning and scaling. The eye-diagram crossing points and mean "1" and "0" levels are statistically determined and used to scale and position a mask to an eye diagram.

For eye-diagram measurements, the HP 83475 allows the user to set the number of histogram samples used in the determination of statistical measurements and mask scaling. There are two types of histograms acquired by the HP 83475, time and amplitude histograms. You can independently set sample sizes for both types of histograms. Figure 5 illustrates the locations of the time and amplitude histograms relative to the waveform.

Note: The HP 83475 uses histograms to make several of the waveform measurements. However, the histograms are not shown on the instrument display.

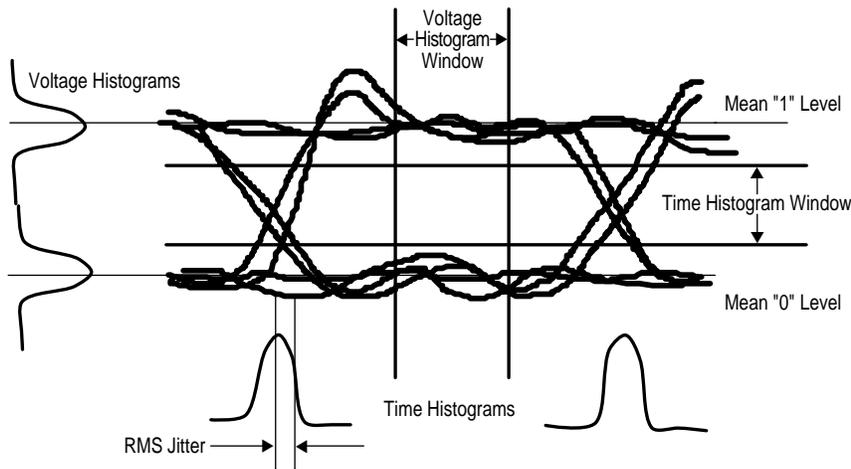


Figure 5. Time and amplitude histograms on an eye diagram

You can set the number of amplitude histogram samples by pressing: **Power/Voltage**, [More 1/4], [More 2/4], [More 3/4], [Ampl Samp]. Use the general-purpose knob to set the number of amplitude samples to be acquired in the determination of the eye-diagram vertical parameters. Typically, a sample size of around 1000 is sufficient to get good accuracy and scaling time.

You can set the number of time histogram samples by pressing: **Time**, [More 1/4], [More 2/4], [More 3/4], [Time Samp]. Use the general-purpose knob to set the number of time samples to be acquired in the determination of the eye-diagram crossing points. Typically, a sample size of around 300 is sufficient to get good accuracy and scaling time.

Note: Statistical measurement time is very sensitive to the number of selected time samples. This is due to the very narrow histogram windows required for the acquisition of time or horizontal samples.

Large sample sizes lead to very accurate results. However, measurement time is significantly increased. Typically, a time sample size of around 300 is sufficient for good accuracy in the determination of eye-diagram crossing points.

Triggering

The trigger source for the HP 83475 can be specified as Channel 1, Channel 2, External Trigger, or Line. Triggering on a signal applied to Channel 1 or 2 allows for triggering on a data stream whenever a reference clock is unavailable. The external trigger allows for triggering on a reference or recovered clock signal. Line triggering selects an internal signal, of the same frequency as the power line signal (50 to 60 Hz), as the trigger source.

Triggering on the data, by using the Channel 1 or 2 internal trigger, is both a practical and common practice. Depending on the test objectives, useful information is available through this method. However, under this condition, accurate analysis of timing information cannot be obtained. Triggering on the data

stream is similar to re-timing the data because the signal or data jitter is greatly attenuated around the triggering point. In addition, when analyzing eye diagrams, triggering on the data does not provide a worst case or true representation of the signal eye pattern. When triggering on data, only a subset of all of the possible transitions is represented by the eye diagram. This subset is representative of the sections on the data stream that provide the required conditions for a trigger; namely a rising or falling edge with sufficient signal energy. If a rising edge is selected as the trigger condition, for example, sections of the data pattern containing long strings of high and/or low levels, such as 11110000, are not captured on the eye pattern.

To analyze signal jitter and/or obtain a more accurate representation of the signal-eye pattern, it is recommended that an external reference signal be utilized as the trigger. The reference signal can be obtained from the data source or through a clock recovery device. The data signal can be connected to one of the two data channels and the trigger signal can be connected to the other available data channel or to the external trigger input. The HP 83475 has a viewable external trigger input. When both Channel 1 and 2 are being utilized, the reference trigger signal can be connected to the external trigger. This signal can be displayed for analysis and timing measurements between data channel and trigger. To view the external trigger signal press: **Source**, [Ext], [Menu], [Ext Trig View On Off] On.

Transceiver conformance measurements

Measuring average optical power

Average power is a fundamental measurement for any lightwave communications system or transmitter. It is a parameter that is directly related to BER performance. In order to assure a nominal system BER performance, standards such as SDH and SONET require that the nominal mean launched power of a compliant transmitter be within a certain range. There are several mean launched power ranges depending on transmitter application. The SDH and SONET standards define two types of applications. These are intra-office and inter-office. The inter-office application is sub-divided into short-haul and long-haul implementations. Transmitter and system parameters are specified for all of these.

The mean launched power ranges are provided such that system BER performance is maintained over the physical distance targeted for the given application. For example, for intra-office, 155 Mb/s, 1310 nm applications, the typical link distance is less than 2 Km and the mean launched power range required for 10^{-12} BER performance is -15 to -8 dBm.

Note: Fixed single mode (9/125 μm) attenuators can provide unexpected power readings when interfaced with the 62.5/125 μm multi-mode HP 83475 input. Some single mode attenuators achieve signal dampening through leakage into the 125 μm fiber cladding. This signal content can be detected by a multi-mode 62.5 μm fiber core.

In contrast, for inter-office long-haul 1310 nm applications, the typical repeater link distance is around 40 km and, consequently, the mean launched power range increases to between -5 dBm and 0 dBm. Typically, in commercially available transmitters, a margin is included in transmitter launch power accounting for end of life performance. In effect, short haul transmitters could be manufactured for at least -8 dBm launch power. This provides a 7 dB end-of-life margin.

By monitoring the photodiode current on the integrated PIN photodiode, the HP 83475 measures average optical power at the push of a button. After selecting the correct operating wavelength calibration and connecting a signal to the HP 83475 optical input, you can measure average power by pressing: **Power/Voltage**, [Opt Pmtr Off On] **On**.

At 1310 and 1550 nm, the HP 83475 optical power meter has a dynamic range of -24 to -3 dBm. To accurately measure power levels above -3 dBm, an

external attenuator should be used in conjunction with the internal attenuation correction of the HP 83475. First, you must determine the attenuation value of the attenuator and make sure that you have the optical channel activated. Then, to correct the external attenuation, press: **Optical/Elec2**, [More 1/2], [Ext Attn]. Use the general-purpose knob below the **Cursors/Masks** front panel key to dial in the external attenuation. This will compensate for the external attenuation to provide an accurate reading of the average power.

Note: In addition to the power meter reading, the external attenuation correction also corrects the optical channel vertical scale and all automatic amplitude power measurements.

Caution: To avoid damage to the analyzer, make sure the average optical power level of the signal into the OPTICAL INPUT is less than $+4$ dBm (2.5 mW).

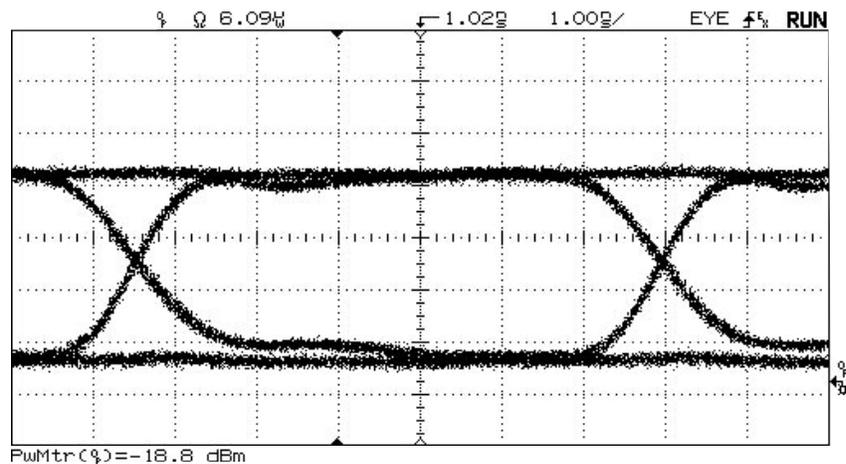


Figure 6. HP 83475 optical power measurement

Lightwave transmitter mask test

Fiber-optic communications standards such as SDH, SONET, and Fibre Channel require that the transmitter time-domain response, usually in the form of an NRZ uni-polar eye diagram, have a particular shape. This shape is specified in terms of a mask or template which dictates regions where the wave-form should not reside. In the manufacturing of standard compliant equipment, optical transmitter ports must be tested for mask compliance as a final check of proper operation. Typically, each rate within a standard's hierarchy has its own mask geometrical specifications.

The HP 83475 can automatically test waveform compliance to a variety of optical mask standard specifications. In addition, through an external controller, custom masks can be down-loaded into the HP 83475. This allows for compliance testing to user-defined mask specifications. The available optical standard mask tests are:

SONET/SDH
(ITU-T G.957 and
Bellcore GR-253-CORE):
OC-1, 51.84 Mb/s
OC-3/STM-1, 155.52 Mb/s

ANSI X3.88:
Fibre Channel 133 MBd
Fibre Channel 266 MBd

The following steps show you how to use the analyzer to perform an SDH/SONET STM-1/OC-3 (155 Mb/s) mask test:

1) Obtain a stable eye-diagram display. Adjust the vertical scale so that the displayed eye diagram is around four divisions peak to peak. Adjust the vertical offset so that the eye diagram is centered about the middle of the vertical scale. Horizontally, make sure that at least two crossing points are displayed. For a 155 Mb/s signal, the horizontal sweep time should be set to around 1 ns/div. Adjust the delay to center the eye diagram on the display.

2) Select the standard mask test by pressing: **Cursors/Masks**, [Select Mask], [OC3/STM1], [done].

3) Define the test parameters by pressing: [Define Test]. In this softkey menu, you can define test parameters by pressing the following softkeys:

- [Test for X sec], Press this key and use the general-purpose knob to set the test time. The test time is directly related to the number of waveforms which are tested to the optical mask. Typically, 2 seconds is sufficient to obtain a good representation of the transmitter eye diagram.

- [Margin], Press this key and use the general-purpose knob to adjust the test margin. The test margin makes the conformance test either more difficult or easier to pass. It is fundamentally, a linear expansion or reduction of the mask. A positive margin can be used to set a test performance limit for process control. A negative margin can be used to better analyze the performance limitations of non-conforming transmitters.

- [Max Hits], Press this key and use the general-purpose knob to set the maximum allowed number of mask hits for a pass condition to take place. Typically, this parameter is set to a value of zero hits.

- [On Pass CONT PRINT STOP], Press this key to toggle through three action choices which are triggered on a pass test condition. CONT causes the analyzer to continue normal acquisition, PRINT causes the analyzer to send a hard copy of the test results to an external printer, and STOP causes the analyzer to stop data acquisition and freeze the test results on the display.

- [On Fail CONT PRINT STOP], Press this key to toggle through three action choices which are triggered on a fail test condition. CONT causes the analyzer to continue normal acquisition, PRINT causes the analyzer to send a hard copy of the test results to an external printer, and STOP causes the analyzer to stop data acquisition and freeze the test results on the display.

4) Once test parameters have been set, the mask test can be performed by pressing: [Previous Menu], [Do Test].

The analyzer will scale and position the mask on the eye diagram and then go into infinite persistence mode while acquiring data points for the specified test time. Once the data has been acquired and tested against the mask, the test result will flash on the lower part of the screen and the specified test action will be performed. The test result is also provided below the [Do Test] softkey.

The second option is to press [Show Mask Only Once Continuous Off] Continuous. In other words, toggle the key until “Continuous” is displayed.

In Continuous mode, the analyzer will continuously acquire histogram data to scale the mask to the eye diagram. If the eye diagram changes or the instrument settings are changed, the mask will automatically be scaled to the displayed eye diagram. The scaling will work only if both eye-diagram crossing points and the data high and low levels are

shown in the instrument display. The scaling time will depend upon the selected number of amplitude and time histogram samples.

Custom mask testing

Beyond the automatic standard mask tests, the HP 83475 can measure compliance to user-defined mask geometries. Through HP-IB or RS-232 remote control, up to two custom masks can be downloaded into the HP 83475 non-volatile memory. Each mask can be defined to have up to eight separate geometrical regions or a total of 120 points, whichever limit is reached first. The custom masks also support all of the automatic testing algorithms, such as scaling and positioning, employed with the built-in standard masks. For details on creating and performing custom mask tests, please refer to the HP 83475 User's Guide (Revision November 1995).

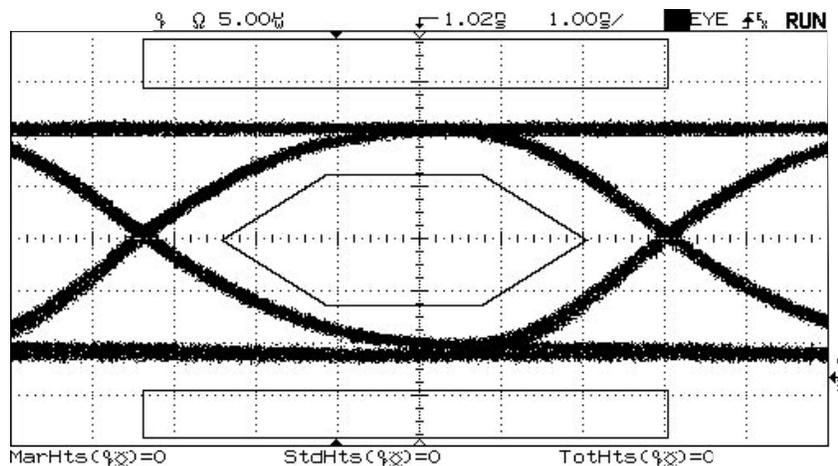


Figure 7. STM-1/OC-3 test results

If the eye-diagram shape changes (ie., laser bias is changed) or if the vertical or horizontal instrument settings are changed, the mask will no longer be scaled to the eye diagram. Two options exist to rescale the mask. One is to perform another test through the [Do Test] softkey. This can take some time depending on the settings of the test parameters.

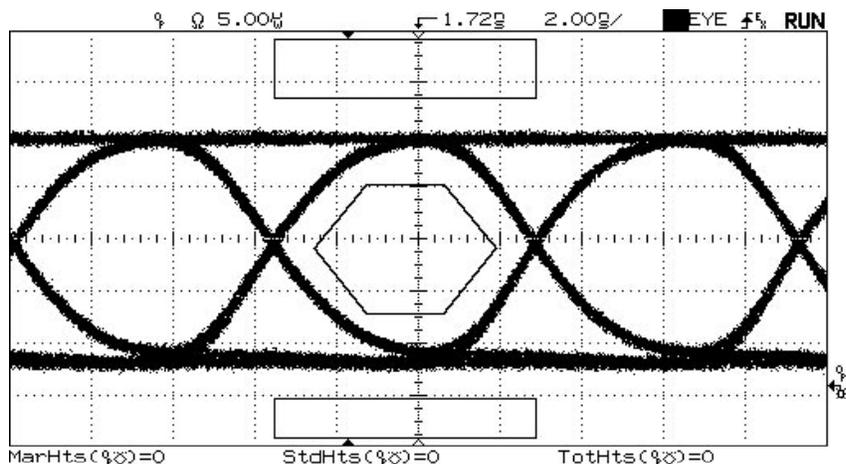


Figure 8. Rescaled STM-1/OC-3 optical eye mask

Electrical telecom pulse mask testing

Typically, lightwave transmitter signal shape is dictated by standard specified eye-diagram masks. Electrical telecom transmitters have similar requirements. However, the signal shape for electrically transmitted signals is typically specified in terms of a pulse mask or template. The pulse template, like an eye-diagram mask, seeks to combine many pulse parameters in a single test. The specified shape is geared to provide proper circuit operation and to allow for multi-vendor network equipment matching at different network interfaces.

Pulse matching characteristics are defined by industry standards and recommendations such as ITU-T Recommendation G.703, ITU-T Recommendation I.430, ANSI T1.102-1987, the current revision of T1.102-199X, and the T1.403-1988. The ITU-T (formerly CCITT) recommendations refer to what is typically known as the PDH (Plesiochronous Digital Hierarchy) network. These standards are typically used in most of the world with the exception of North America. The ANSI standards deal with the specifications for the North American network.

Though most of the electrical signal masks/templates are for pulse shape specification, some of the masks are for eye-diagram shapes. The electrical side of the Bellcore SONET standard, for the 51.84 Mb/s (STS-1) and 155 Mb/s (STS-3) line rates, specifies both eye-diagram and pulse masks to test signal characteristics. The

eye-diagram masks are provided for versatility and convenience. As will be explained, an eye-diagram test needs less sophisticated measuring technology as it utilizes the entire signal.

Signal characteristics in time division multiplexing (TDM) equipment

There are two types of data encoding techniques typically encountered in electrical telecommunications transmission. These are Alternate Mark Inversion (AMI) and Coded Mark Inversion (CMI). The most commonly used is AMI. CMI is typically utilized for the higher digital hierarchy line rates, such as the PDH 139.264 Mb/s rate (commonly known as E4). Electrical, unipolar signals are converted to either AMI or CMI before transmission.

AMI is a 3-level non-return-to-zero (NRZ) code for which, in its

simplest form, logic "1s" are represented by alternating the 1's polarity and logic "0s" are represented by a zero amplitude space. An example is shown in Figure 9.

AMI meets the objective of minimizing the DC component in the signal. The voltage summation of all the pulses on a well-balanced AMI coded line will be zero.

CMI is a 2-level, bipolar non-return-to-zero (NRZ) code in which the logic 0 is coded so that both amplitude levels, A1 and A2, are attained consecutively, each for half the unit time interval ($T/2$). Similar to AMI, the logic "1s" are coded such that the amplitude alternates, between A1 and A2, for consecutive logic "1s." An example is given in Figure 10. Note that for the logic "0" there is always a positive transition at the midpoint of the binary unit time interval.

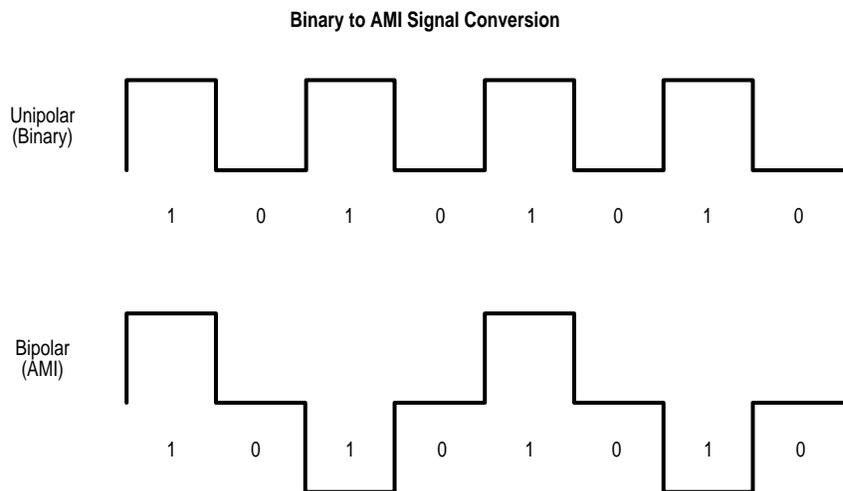


Figure 9. Unipolar binary sequence and its equivalent AMI sequence

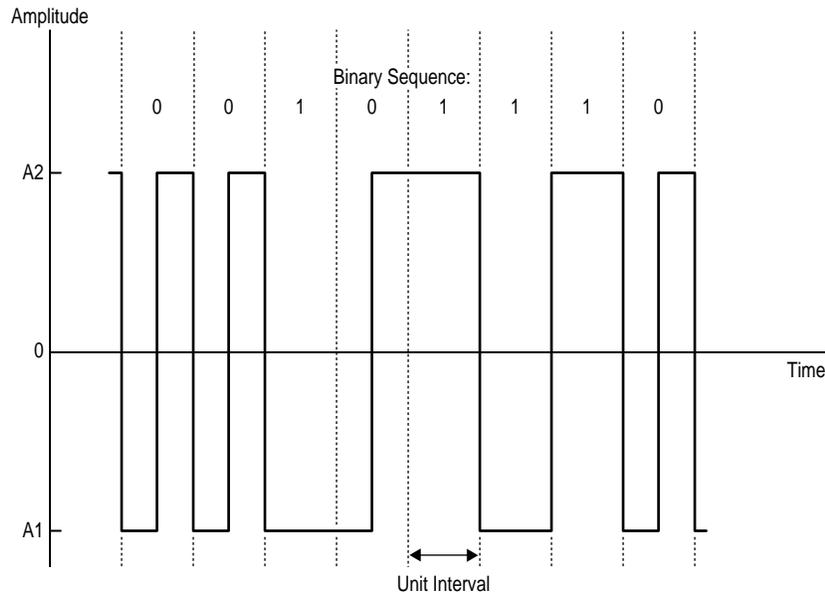


Figure 10. CMI coded binary signal

Zero substitution

Timing information must be derived from transmitted data by the receiving equipment. Receiving equipment must phase lock to the transmitted data in order to recover information. For this reason, it is important that the data on a telecommunication line not remain in the zero state for an extended period of time. Equipment is designed so that, for AMI signal transmission, the extended strings of zeros are replaced by “1s” pulses. Receiving equipment, in turn, must be able to identify the zero substitutions and remove the inserted 1s to restore the original information. When zero substitution is executed, the AMI coding scheme is violated. In other words, the inserted pulse is of the same polarity as the previous logic “1” pulse. This AMI code violation flags receiving equipment so that it can remove the zero substitutions.

There are several zero substitution algorithms typically utilized in the telecommunications transmission. A very simple code which is typically used for the PDH 2, 8 and 34 Mb/s (E1, E2, E3) line rates is High Density Bipolar of order 3, also known as HDB3. In HDB3, each block of four consecutive zeros is replaced by 000V or B00V, where V is an AMI code violation and B represents an inserted pulse conforming to the AMI rule. The choice of 000V or B00V is made so that the number of B pulses between consecutive V pulses is odd. In other words, successive V pulses are of alternate polarity so that no DC component is introduced.

Given the coding scheme, CMI codes do not require any zero substitution. There are no spaces (or zero amplitude time intervals) in a CMI encoded binary sequence and there are plenty of transitions for receiving equipment to recover clock and synchronize.

Isolated ones

An isolated 1 pulse is a pulse unaffected by intersymbol interference or corrupted by noise. In most cases, due to line coding constraints, an ideal isolated pulse can only be approximated. Typically, an isolated pulse is approximated by a pulse that is preceded by and followed by zero states. The ANSI and Bellcore pulse mask standards, for AMI coded signals, are written for a positive isolated pulse. The pulse mask will always span more than one pulse time slot. It is important that the pulse characteristics preceding and following the isolated pulse be evaluated. The characteristics of the pulse as well as the settling before and after the pulse must be considered.

The isolated 1s standards are written for leading and trailing zero states. Extended zero states do not normally exist in live traffic (random data) because of the zero substitution algorithms discussed previously. Leading and trailing zero requirements vary depending on the mask in use. The Bellcore STS-1 51.84 Mb/s pulse mask test requires a pulse preceded by at least two zeros and followed by at least one zero.

Fixed voltage versus normalized amplitude templates

The amplitude of pulse templates is typically specified either in fixed volts or in normalized amplitude. The North American Bellcore and ANSI template specifications are typically given in normalized amplitude. In other words, the template amplitude specifications are provided as a fraction of the peak pulse amplitude. The ITU-T PDH amplitude specifications, on the other hand, are typically given in fixed voltage levels. This seeks to incorporate an amplitude test with the pulse shape test. The HP 83475 accommodates both types of specifications. The Bellcore specified pulse mask tests scale to the normalized pulse while the PDH templates scale to the absolute amplitudes given by the standard.

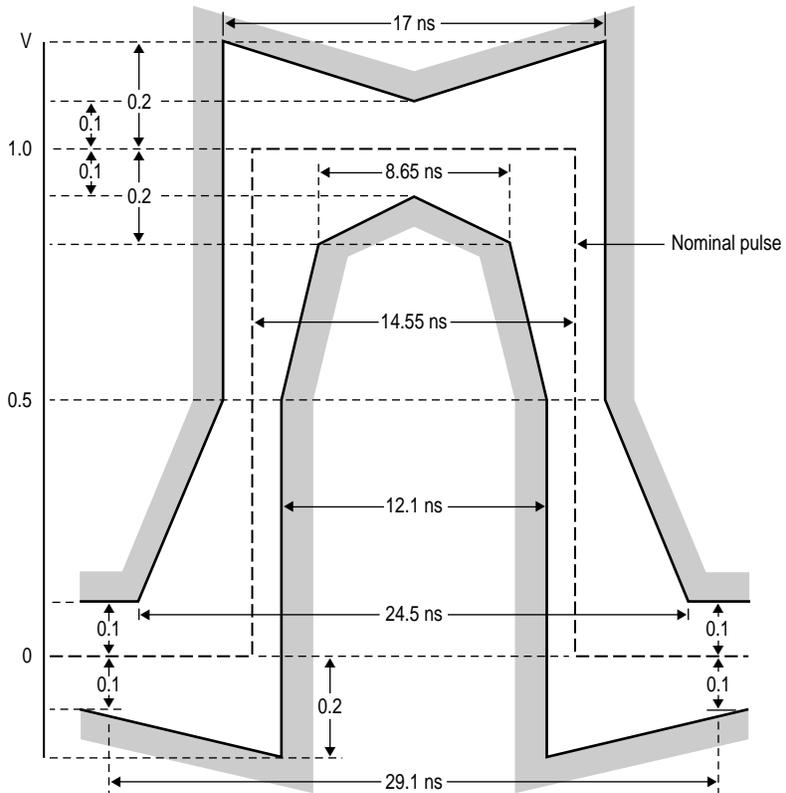
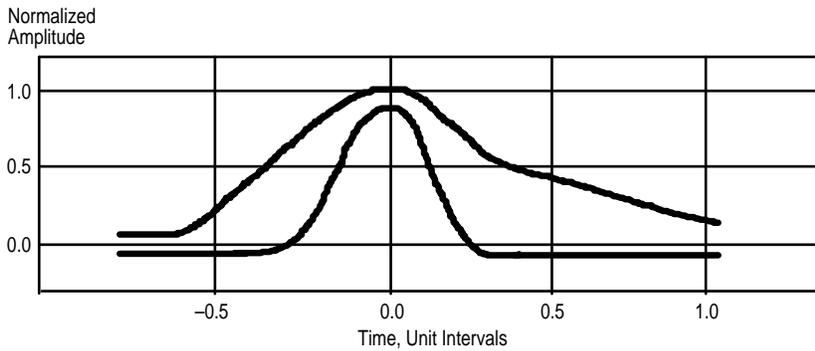


Figure 12. PDH E3, 8.448 Mb/s pulse mask definition



Normalized Amplitude Equation	Time Axis Range (UI)
Upper Curve	Upper Curve
$-0.85 < T < -0.68$	0.03
$-0.68 < T < -0.36$	$0.5(1+\sin[(\pi/2)(1+T/0.34)])+0.3$
$0.36 < T < 1.4$	$0.08+0.407\exp\{-1.84(T-0.36)\}$
Lower Curve	Lower Curve
$-0.85 < T < -0.68$	-0.03
$-0.68 < T < -0.36$	$0.5(1+\sin[(\pi/2)(1+T/0.34)])+0.3$
$0.36 < T < 1.4$	-0.03

Figure 11. Bellcore DS-3, 44.736 Mb/s pulse mask definition

Negative pulse testing

For AMI-coded signals, only the positive masks have been standardized. However, users typically also test for negative 1s' pulse performance. One way to do this is to use the channel inverting function of the HP 83475 and apply the positive pulse mask to the inverted negative pulse. The HP 83475 inversion is done through software, not hardware. In other words, an inverting amplifier is not used. The software inversion minimizes amplitude uncertainties to provide for a good measurement for negative pulse template conformance.

Another way to test a negative pulse is to invert the positive pulse mask and apply it to a negative pulse. The HP 83475 also provides this option for fixed voltage amplitude templates.

Electrical interfaces

Data transmission through electrical media is typically accomplished through either twisted pair or coaxial cable. The twisted pair cables are typically of 100, 110, or 120 Ohm impedance while the coaxial cables are of 75 Ohm impedance. When doing a pulse mask test, these impedances must be interfaced with the oscilloscope input. The input impedance of modern, high-bandwidth digital sampling oscilloscopes is typically 50 Ohms. Some oscilloscopes can switch between 50 Ohm and 1 MOhm inputs. External accessories must be used to minimize the mismatch between the oscilloscope input impedance and the typical telecommunication equipment test port.

Two options exist to interface the HP 83475 with a 75 Ohm coaxial test port. The HP 83475 can switch between 50 Ohm and 1 MOhm input impedances. With the input impedance set to 50 Ohm, one option is to use a 50 Ohm to 75 Ohm minimum loss matching pad. The other is to set the input impedance to 1 MOhm and use a 75 Ohm feedthru termination.

The HP 11852B minimum loss pad provides a 50 Ohm to 75 Ohm match with better than a 21 dB return loss over a dc to 2 GHz bandwidth.

In addition, matching pads and feedthru terminations can be obtained from a series of manufacturers. For example, Pasternack Enterprises of Irvine, California provides both parts with the following model numbers:

BNC matching pad, 50 Ohm male to 75 Ohm female, model number: PE7006

BNC 75 Ohm feedthru termination, model number: PE6008-75

Both of the above parts specify a 21 dB (1.2:1 VSWR) minimum return loss over the DC to 1 GHz frequency range. This performance is quite adequate for the testing of electrical signals up to the 155 Mb/s bit rate.

When interfacing a symmetrical or twisted pair port to the HP 83475, a wideband 100 Ohm twisted pair to 50 Ohm BNC transformer gives the greatest versatility. The transformer twisted pair leads can be soldered to any twisted pair cable assembly to configure a test probe. Wide band transformers are available from several manufacturers. One such transformer is from North Hills Signal Processing in Syosset, New York:

Wideband 100 Ohm balanced to 50 Ohm unbalanced (BNC) transformer, model number: NH13734, Frequency range: 0.1 to 300 MHz

The specified frequency range is quite adequate for testing pulses at bit rates up to 25 Mb/s.

When using a minimum loss matching pad or a wide band transformer at the HP 83475 electrical input, the vertical scale can be corrected for the external attenuation. This is useful when measurements of pulse amplitude are desired or when a PDH pulse mask test is being performed for the E1, E2, E3 and E4 line rates. The correction is similar to the probe correction feature available in many digital sampling oscilloscopes. If, for example, a 3 dB matching pad is being used at the input, the 3 dB correction can be entered and the voltage vertical scale is multiplied by 1.414. The displayed voltage is then the voltage at the input of the matching pad. To correct for attenuation on Channel 1 or 2 press: **Elec 1** or **Optical/Elec 2**, [More 1/2], [Ext Attn]. Use the general-purpose knob to dial in the external attenuation.

Making a pulse mask test with the HP 83475

The HP 83475 can perform tests to a variety of industry-specified electrical interface masks. The electrical mask tests available with the HP 83475 are:

SONET, Bellcore GR-253-CORE:

- STS-1 eye, 51.84 Mb/s
- STS-3 eye, 155.52 Mb/s
- STS-1 pulse, 51.84 Mb/s
- STS-3 one pulse, 155.52 Mb/s
- STS-3 zero pulse, 155.52 Mb/s

ANSI T1.102:

- DS-1, 1.544 Mb/s
- DS-1c, 3.152 Mb/s
- DS-2, 6.312 Mb/s
- DS-3, 44.736 Mb/s

ITU-T G.703 + SDH:

- E1, 2.048 Mb/s
- E2, 8.448 Mb/s
- E3, 34.368 Mb/s
- E4 one pulse, 139.264 Mb/s
- E4 zero pulse, 139.264 Mb/s
- STM-1 one pulse, 155.52 Mb/s
- STM-1 zero pulse, 155.52 Mb/s

The fundamental requirement for a pulse mask test is a stable pulse display. The conditions required to obtain this with the HP 83475 are:

1) The signal under analysis must be repetitive. For example, the signal could be a repeating PRBS, a repeating section of an SDH/SONET frame, an all ones AMI pattern, or just a repetitive, NRZ "1010" sequence.

2) A trigger signal must be available. Two conditions are possible for trigger, depending on the waveform under analysis, which provide a stable sequence of pulses:

a) If the signal under analysis provides a rising or falling edge at a fixed rate, (ie., an NRZ 1010 sequence) the instrument can be triggered from the data. In other words, the internal channel trigger can be used to obtain a stable sequence of pulses on the instrument display.

b) If the waveform under analysis is a repeating long pattern, for example, a repeating $2^{23}-1$ PRBS

pattern, a trigger signal must be obtained which is synchronized with the repetition rate of the pattern and this signal must be used as the input to the HP 83475 external trigger channel. For example, if a 128 bit pattern is the data under analysis, a trigger signal that repeats every 128 bits (or a multiple of this) must be used as the external trigger.

3) Once a stable trigger is achieved and a stable sequence of bits is obtained on the display, the horizontal time/div and the delay must be adjusted to obtain the desired pulse to which the pulse mask can be scaled.

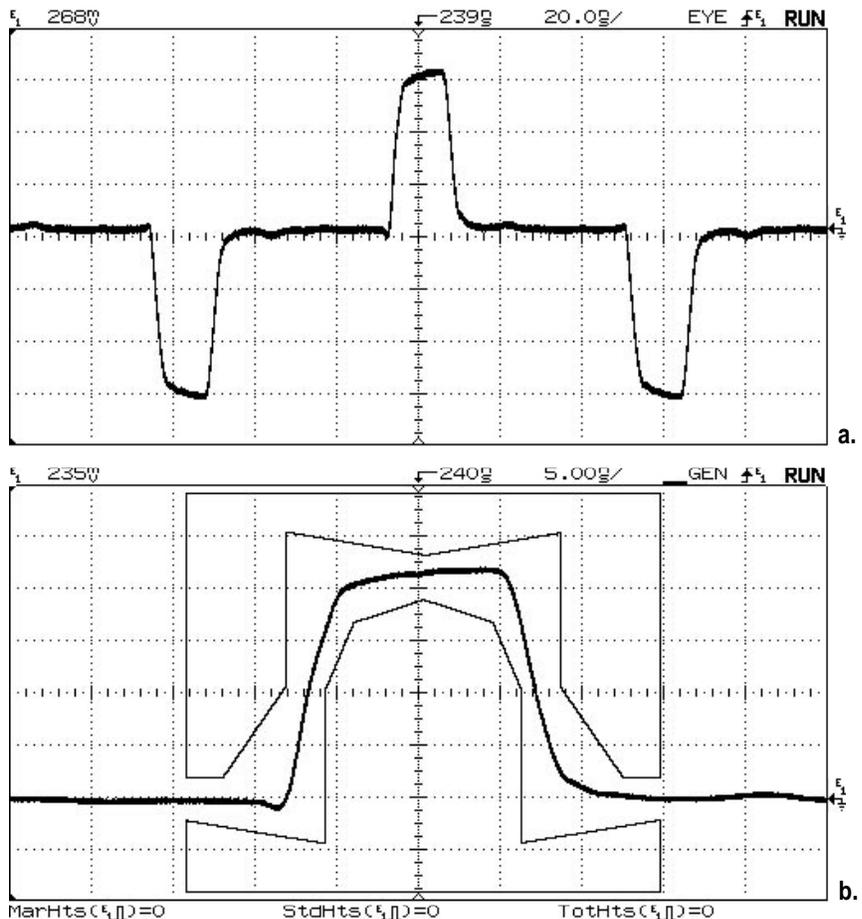


Figure 13. Stable sequence of bits from an AMI signal (a). PDH E1 (2 Mb/s) pulse mask test results (b).

In addition, if there is external attenuation at the electrical channel input, this can be corrected by pressing: **Elec 1** or **Optical/Elec 2**, [More 1/2] [Ext Atn]. Use the general-purpose knob to enter the correction. Adjust the Volts/div setting so that the pulse is around 4 to 5 divisions peak to peak.

With the desired pulse centered on the display, the pulse mask test can be performed. The test key sequence is essentially identical to the sequence used for testing a lightwave transmitter. However, under **Cursors/Masks**, [Select Mask], the appropriate line rate pulse mask specification must be selected. For the step-by-step procedure, refer to the "Lightwave Transmitter Mask Test" section of this document.

Isolated "1s"

The ANSI T1 and Bellcore standards require that pulse mask testing be performed on isolated "1" pulses. An isolated "1" pulse can be captured by the HP 83475 as long as the conditions explained under "Making a pulse mask test with the HP 83475" are met. If the signal under analysis is not repetitive but rather random, the HP 83475 can still trigger on the data and display an eye diagram, but a stable sequence of pulses will not be displayed. In effect, a pulse meeting the isolated "1" conditions will not be obtained and, thus, the appropriate test cannot be performed.

Lightwave transmitter extinction ratio measurements

Definition

Extinction ratio is a lightwave transmitter parameter controlled by communications standards such as SDH, SONET and Fibre Channel. This parameter is directly related to system power budget which in turn is related to BER performance. In order to understand its definition, it is important to first review how a typical fiber-optic digital link transmits and receives data.

For a typical, directly-modulated digital laser transmitter, the incoming electronic digital data directly controls the bias on a laser diode. A digital "1" logic level causes the laser to be biased fully on, resulting in maximum light transmission. A logic "0"

level biases the laser nearly off, so that very little light is transmitted. (For reasons we will describe in a moment, lasers are almost never biased fully off, so a small amount of light is transmitted even during a logic "0" pulse.)

Extinction ratio is defined as the ratio of the average optical power in a logical 1 signal to the average optical power in a logical 0 signal. This definition is used because it is representative of how an actual operating system works. A typical photon-counting receiver integrates the received signal over the entire bit period. Values above a preset threshold are identified as "1s", and values below the threshold are identified as "0s." The greater the difference in power levels, the easier it is to make the correct decision in the presence of noise.

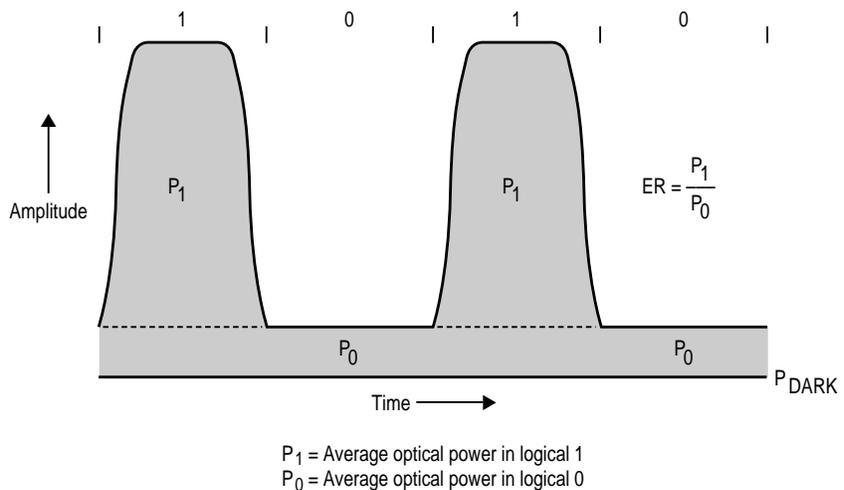


Figure 14. Extinction ratio definition

Why not infinite extinction ratio ?

If the strongest signal occurs with maximum difference between the 1 and 0 powers, why is the laser not biased completely off during the transmission of a logic 0 pulse? The problem is that in this condition the transmitter suffers from several turn-on related effects. Relaxation oscillations cause serious overshoot, ringing, and jitter. Frequency chirp also causes significant broadening of the spectral line-width. When taking into account the common dispersive effects of standard transmission media, these waveform characteristics can significantly impact system BER performance.

At the other extreme, too small an extinction ratio is not good either. For a BER of 10^{-12} , an extinction ratio of 8.2 dB causes a power penalty of 1.3 dB compared to an infinite extinction ratio (ignoring jitter and relaxation oscillation problems). Current SDH and SONET specifications require a minimum of 10 dB extinction ratio for most applications, with 8.2 dB being acceptable in certain instances.

Extinction Ratio Equivalent Definitions:

$$XR \text{ (dB)} = 10 \log P_1/P_0$$

$$XT \text{ (%) } = 100 \times P_0/P_1$$

The SDH/SONET standards specify extinction ratio in dB. The parameter is also typically specified in %.

Standards for extinction ratio

Extinction ratio is specified by several telecommunications and datacommunications standard documents. ITU-T G.957 and Bellcore GR-253-CORE define the minimum extinction ratios required by SDH and SONET systems while ANSI X3.88 does the same for Fibre Channel systems. TIA/EIA OFSTP-4 recommends parameter measurement procedures and makes several key recommendations that go a long way toward removing measurement ambiguity.

The key points of OFSTP-4 are that extinction ratio should be measured at the full bit rate using an oscilloscope and a reference O/E receiver with a specified filtered response and, secondly, that the average one and zero power levels should be measured as the most prevalent values over the full bit period or eye window. In essence, the measurement of the most prevalent one and zero levels should be done on an eye diagram which overlaps all possible data transitions. For best results, it is also recommended that the measurement be made using the statistical histogram capabilities available on modern digitizing oscilloscopes.

One important point to consider is that extinction ratio is often used to estimate the transmitter's effect on system power penalty. For the estimate to be realistic, the measurement needs to be made on a data pattern at the data rate representative of actual use. As might be expected, a laser

produces different extinction ratios at different data rates and patterns, so it is important that the data rate and pattern of the measurement be reported along with the extinction ratio.

The OFSTP-4 recommended optical reference receiver must have a fourth-order Bessel-Thomson response with a 3 dB cutoff frequency at 0.75 times the bit rate. A tight tolerance window is specified around the ideal response. The filtered response approximates the integrating technique used by photon-counting receivers and, at the center of the eye, provides for a good approximation of the average optical powers of the "1" and "0" levels.

Measurement algorithm

In order to calculate extinction ratio, the average power of the logic "1" and "0" levels must be calculated. If a reference receiver is used, the integrating effect of the filtering receiver will provide for a good approximation of the average power in the "1" and "0" levels at the center of the eye. Thus, for extinction ratio calculations, the ideal approach is to determine the 1 and 0 levels at the center of the filtered eye. Internal histogram capabilities in many digital oscilloscopes make the measurement fairly easy to do. There are essentially two problems with this ideal approach. First, within the industry, there is no agreement on the width of the window.

Second, any misalignment of the window with respect to the true eye center would cause measurement inconsistencies or differences due to the different contributions of the rising and falling edges. The OFSTP-4 committee took an alternative approach to recommend the measurement be made across the full eye. This eliminated the effect of any slight misalignment. Instead of finding a simple mean, they recommended using the most prevalent 1 and 0 values. Most prevalent values, in essence, represent the location of the 1 and 0 level histogram peaks. These, quite often, do not coincide with the mean of the distributions. However, in principle, these should be very close to the true average 1 and 0 powers.

In practice the use of most prevalent values and a full bit window is somewhat less than ideal. Typically, the difference between

measuring mean values at eye center and most prevalent values across the full eye can be one-half dB or more. HP currently recommends measuring mean values while using a narrow window, around 20 % of the bit period, about the eye center. The HP 83475, however, can be set to measure over any desired portion of the bit. The measurement of mean 1 and 0 values at the center of the eye provides for an extinction-ratio measurement that can be more realistically applied to power penalty calculations. Fundamentally, the integrating effect of the reference receiver will provide a good approximation of the "1" and "0" level average powers at the center of the eye. In addition, the mean level calculations provide for a more repeatable and physically meaningful measurement in relation to the actual extinction ratio definition.

DC-offset correction

Another practical problem in measuring extinction ratio is that reference receivers and oscilloscope inputs rarely have exactly zero offset voltages over all temperature and operating conditions. To avoid error, the measurement algorithm should subtract offset voltage from the measured 1 and 0 voltage values. This is done by blocking the light to the optical receiver and measuring the residual offset. Offset voltage can change rapidly with temperature, so re-calibration should be performed whenever temperature varies more than a few degrees from the previous calibration.

Sources of measurement uncertainty

Though extinction ratio has a simple definition, it is a parameter that has caused much controversy throughout the industry. Differences in measurement technique often cause a laser or LED to appear within specifications on one system and out of specifications on another system. This is a particular problem when one system is in the transmitter supplier's outgoing test department and the other is in the customer's incoming inspection department. It has been determined that the most prominent cause of measurement inconsistencies is differences in the frequency response of measurement systems. In effect, differences in the frequency response of oscilloscope and O/E systems provide for inconsistent and, sometimes, incorrect results.

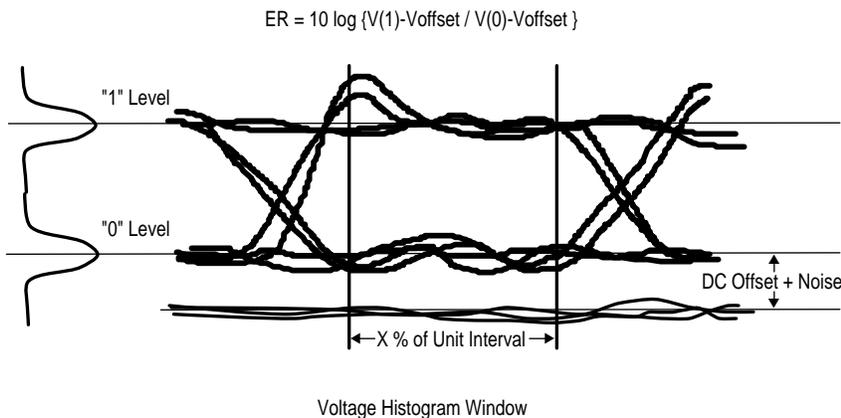
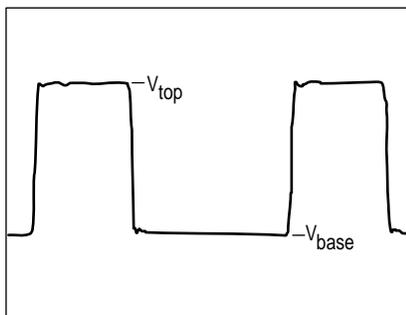


Figure 15. Extinction-ratio measurement on an optical eye diagram

As previously mentioned, when measuring extinction ratio, the use of a fourth-order Bessel-Thomson reference receiver is recommended. This ensures that there is some consistency in the frequency response of measurement systems. However, it is important that the reference receiver meet the SDH/SONET or Fibre Channel bandwidth specification throughout the entire specified bandwidth. Specifically, it is important to verify that the receiver be compliant down to DC. Low frequency gain rise effects, which provide for AC and DC gain differences, can significantly corrupt an extinction ratio measurement. Figure 16 illustrates the effect. In the time domain, a low frequency gain rise appears as a “slow tail” on the pulse. In effect, the signal DC components are amplified more than the AC components. Thus, the pulses measured at the output of the receiver are not an accurate representation of the input signal.

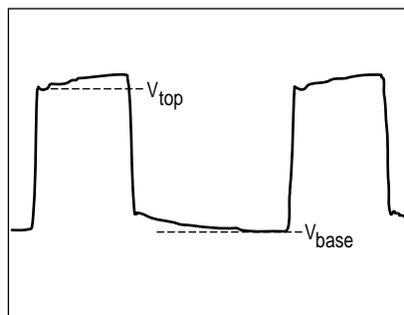


SDH compliant receiver

Other sources of error can also cause measurement uncertainty. It is important to have a good data source which provides a “clean” eye diagram as the reference signal. A well-designed reference receiver which minimizes return loss between the photodiode and filter is also important. The oscilloscope should also be very linear and channel crosstalk should be negligible. Finally, sensitivity should also be considered. The measurement system should have sufficient sensitivity to repeatably calculate the required signal parameters for measuring extinction ratio. Taking into account the system sensitivity, sufficient histogram data samples should be acquired to obtain repeatable extinction ratio measurements and minimize uncertainty due to system noise.

Measuring extinction ratio with the HP 83475

The HP 83475 automatically measures extinction ratio at the push of a button. The instrument



Receiver failing SDH spec due to low freq. gain rise

Figure 16. Slow tail effect due to low frequency gain rises on reference receiver frequency response.

uses a histogram-based algorithm to calculate the parameter on an eye diagram. Before doing the measurement, however, a DC offset calibration should be performed. Furthermore, if using the optical channel, make sure to connect the **Demod Out** to the electrical **Channel 2** input. This can be achieved through either a 50 Ohm BNC jumper or, if the instrument has the appropriate option, with a fourth-order Bessel-Thomson filter. The filter connection is recommended for best results. This makes the optical input, depending on the filter option, into a SONET/SDH or Fiber Channel reference receiver. For proper performance of the optical input, make sure that the Channel 2 input impedance is set to 50 Ohms. The procedure for executing an extinction ratio is given below.

- 1) First, make sure you obtain a stable eye-diagram display. To get the best results, the eye diagram should be obtained using a reference clock as the external trigger signal. Make sure that the eye diagram is around 4 to 6 vertical divisions in amplitude. Horizontally, you must have at least two crossing points displayed and, for best results, display only two crossing points.

2) Make sure you have the measurement type set for Eye: NRZ, the correct measurement source selected (E2, Op or E1), and select an appropriate number of time and amplitude samples. Typically, 300 time samples and 1000 amplitude samples is sufficient for repeatable measurements on signals of greater than -17 dBm average signal power.

3) Perform a DC offset channel calibration. Press **Optical Cal**, [Ext Ratio Offset Cal]. Then select the appropriate channel for calibration. To calibrate the optical channel press [Meas Op]. If you are using an external O/E with electrical Channels 1 or 2 press either [Meas E1] or [Meas E2].

Note: Before performing a DC offset calibration, it is recommended that the instrument be warmed up (activated) for at least one hour. This minimizes DC offset drift after calibration. If environmental temperature changes significantly, a new offset calibration should be performed.

4) Follow the on-screen instructions for performing an offset calibration. When the calibration is complete, press [Previous Menu].

5) To activate measurement tracking, press **Power/Voltage** [More 1/4], [Show Meas Off On] **On**. When this is activated, markers appear showing the measurement location on the eye.

6) To set the measurement display units, press [More 2/4], [More 3/4], [Select Units]. You can set the measurement units to either linear, dB, or %. Linear is simply the ratio of the one to zero levels, dB is the decibel equivalent of this ratio, and % is the inverse of the linear ratio multiplied by 100.

7) To define the measurement window, press [Previous Menu], [Define Eye Window]. Select [Measure Auto Man] **Auto** to set automatic crossing point location. Highlight the [Min] and [Max] limits by pressing the appropriate keys. Use the general-purpose knob to adjust the minimum and maximum limits to the desired locations within the eye crossings. 0% defines the left most crossing and 100 % the next crossing point to the right. For best results, when using a filtered reference receiver, it is recommended to set the minimum limit to 40% and the maximum to 60%. Press [Previous Menu] when done.

8) To measure extinction ratio, press [More 4/4], [Extinction Ratio]. The extinction ratio is shown in the results section of the display.

Transceiver waveform analysis

Eye-diagram characterization measurements are typically performed to analyze the time-domain response of communications transmitters and receivers. Distortion, jitter, and dispersion characteristics of transmitted data directly impact system performance and must be appropriately minimized and compensated. It is important to consider that characterization measurements must be done under appropriate bandwidth conditions. The test system must have sufficient bandwidth margin to minimize measurement uncertainty on high-frequency waveform characteristics. In addition, the system should have sufficient sensitivity such that measurement integrity is not compromised due to sys-

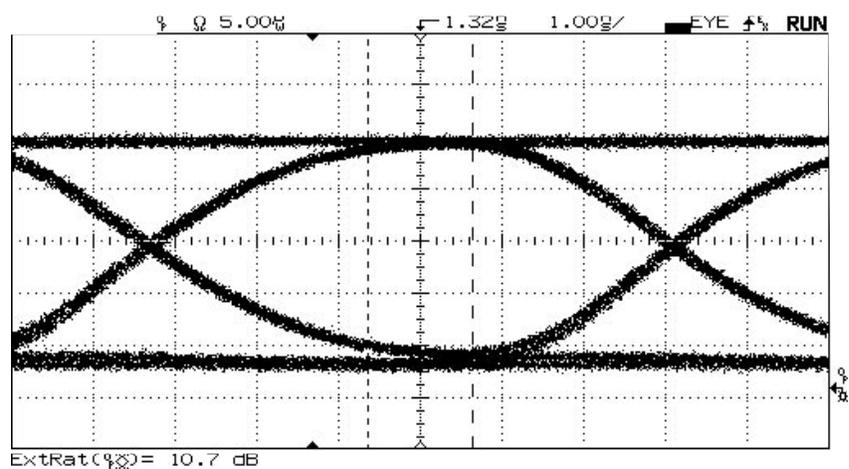


Figure 17. Eye-diagram extinction-ratio measurement results

tem noise. Furthermore, the test system should have a very flat frequency response in order to provide optimum waveform fidelity. For lightwave measurements, bandwidth margin, sensitivity, and flatness are factors which typically differ depending on the selected measurement receiver technology. It is important to consider the application and the test objectives to make the optimum selection for your measurement system.

the HP 83475 is given below for both eye diagrams and general pulsed waveforms.

Eye diagram measurements:

Time: Rise/fall time, bit rate, bit period, duty cycle distortion, jitter (rms and pk-to-pk)

Voltage/power: Extinction ratio, amplitude, overshoot, eye height, noise (rms and pk-to-pk), one level, zero level, max level, min level, eye crossing %

Eye diagram versus general waveforms

Time-domain response characterization is typically done through statistical measurements of waveform parameters. Typically, rise time, fall time, overshoot, distortion, noise and jitter are measured for the transmitter time-domain response. Jitter and distortion are typically measured at the receiver.

These measurements are typically conducted either on an eye diagram or a pulse. Eye-diagram measurements provide a composite view of all possible waveform variations and, in effect, take into account pattern-dependent effects. In essence, eye-diagram measurements can be considered to be a representation of the average or mean behavior of the device under test. In addition, given the overlap of transitions, a qualitative view of transmitter performance can be conveniently obtained by simply looking at the vertical and horizontal eye-opening characteristics. Pulse measurements, on the other hand, isolate response to a specific pattern (usually 1010) and allow for accurate focus and analysis of transition characteristics. Typically, for example, when characterizing the rise time of a transmitter, it is best to utilize a high rise time, low repetition rate (relative to transmitter bandwidth) 1010 pattern. This allows for an accurate characterization of device rise time performance.

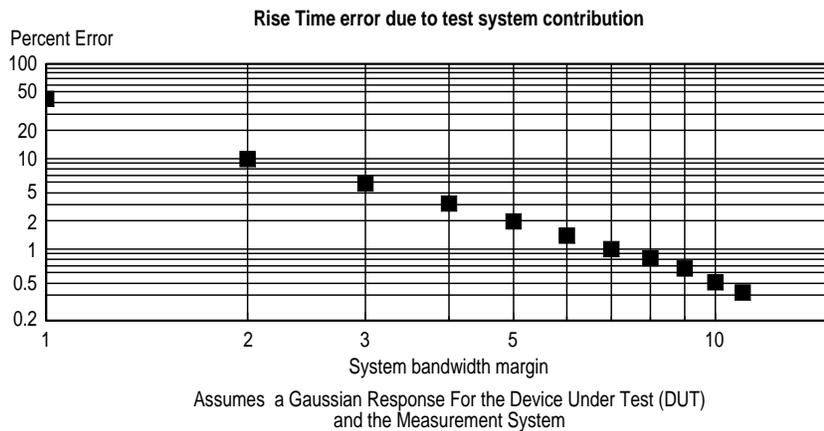


Figure 18. System BW margin versus rise time measurement error. System BW margin = system BW/DUT BW

The HP 83475 provides several automatic measurements to characterize the time-domain response of lightwave and electrical transceivers. Measurements can be performed on either eye diagrams or general, pulsed waveforms. The complete list of measurements available with

General waveform measurements:

Time: Rise/fall time, frequency, period, +width, -width, delay, phase, duty cycle

Voltage/power: Amplitude, max level, min level, peak-to-peak, top level, base level, average, rms, preshoot, overshoot

Transmitter measurements

Typical transmitter measurements that can be performed with the HP 83475 include:

- rise time and fall time
- jitter
- noise
- overshoot
- undershoot
- distortion

With the HP 83475, all of the above measurements, except for undershoot, can be performed on an eye diagram. The measurements are done using histogram-based algorithms. In effect, they are statistical measurements based on the acquisition of a user-defined set of waveform samples.

For pulsed waveforms, the HP 83475 available measurement set is different. Of the above measurements, rise time, fall time, overshoot, undershoot and distortion can all be automatically performed.

If you are trying to characterize the transmitted data after heavy attenuation due to, for example, a long link of fiber, the sensitivity of the HP 83475 optical channel can become a limiting factor. As previously mentioned, the HP 83475 optical channel consists of a very linear receiver composed of a PIN photodetector and a transimpedance amplifier. This combination provides very good waveform fidelity and good sensitivity. Typically, at 1300 nm, signals down to -20 dBm can be viewed and analyzed. If higher

sensitivity is required, there are other options. The combination of an avalanche photodetector and a linear amplifier can typically provide a greater than 10 dB increase in sensitivity. Such receivers, however, may contribute an increase in non-linear effects. These effects may be acceptable depending on the application and test objectives.

When more sensitivity is required, APD-based receivers are recommended. A good example is the BCP 310 from Broadband Communications Products, Inc. of Melbourne, Florida. Such receivers may be connected to one of the electrical channels of the HP 83475.

Receiver measurements

Typical receiver characterization measurements made by the HP 83475 include:

- jitter (rms and pk-to-pk)
- distortion
- eye height

Other measurements, when appropriate, can be performed. All of the above measurements can be performed on eye diagrams. The jitter is measured by taking a histogram, with a user-defined number of samples, at the crossing point. Distortion can be characterized through a measurement of the eye-diagram crossing level percent relative to the mean high to low level amplitude.

For general, pulse waveforms, the waveform distortion can be characterized. This can be done through measurements of the duty cycle of a 1010 pattern and/or measurements of the pulse + and – widths. Ideally, the duty cycle should be at 50% and the + and – widths should be identical.

It is important to keep in mind that sensitivity is a very important consideration for receiver measurements. Especially for optical receiver testing, typical received average power levels, after a long link of fiber, can be quite low. It is important that the receiver have sufficient sensitivity such that the receiver's electrical output signal can have enough S/N margin with respect to the measurement system noise. This minimizes the measurement uncertainty attributed to the influence of system noise.

The minimum S/N ratio required to conduct an accurate measurement depends on the measurement algorithm and type (General or Eye). For eye-diagram measurements, one way to improve measurement repeatability is to increase the statistical sample size. Unfortunately, waveform averaging cannot be conducted on a two-level eye diagram. The

result is the average of the high and low eye-diagram levels. If a pulsed waveform is being analyzed, waveform averaging can be activated. For the HP 83475, a S/N ratio greater than 12:1 is recommended for most eye-diagram measurements. For general waveform measurements, given that averaging can be conducted, lower signal-to-noise ratios may be tolerated.

Making eye-diagram measurements

To make the measurements on an eye-diagram, follow the steps outlined below.

1) First, make sure you obtain a stable eye-diagram display. To get the best results, the eye diagram should be obtained using a reference clock as the external trigger signal. Make sure that the eye diagram is around 3 to 6 vertical divisions in amplitude. Horizontally, you must have at least two crossing points displayed and, for best results, display only two crossing points.

2) To access the automatic time and amplitude measurements, press either the front panel **Power/Voltage** key or the **Time** key. Make sure you have the measurement type set for Eye:NRZ, the correct measurement source selected (E2, Op or E1), and select an appropriate number of time and amplitude samples. Typically, 300 time samples and 1000 amplitude samples is sufficient for repeatable measurements on signals of greater than -17 dBm average signal power.

3) To activate measurement tracking, press **Time** or **Power/Voltage**, [More 1/4], [Show Meas Off On] **On**. When the measurement is performed, markers appear showing the measurement location on the eye.

4) To set the upper and lower thresholds for the rise time and fall time measurements you must go to the **Time** measurements menu and press [More 1/4], [More 2/4], [More 3/4], [Define Thresh]. Once in this sub menu, you have three options to set up the thresholds. The first two options set the lower and upper thresholds at 10%/90% or at 20%/80% of the mean 1 to 0 level amplitude. The third option is to set the thresholds at user-defined levels. To do this, press [Variable], [Lower], and then use the general-purpose knob below the **Measure** front panel section to set the lower threshold to the desired level. You can then do the same to set the upper threshold. When done, press [Previous Menu].

4) You can define the location, on the eye-diagram high level, on which the noise measurement will be made. To define the measurement window, press the front panel **Power/Voltage** key and then [More 1/4], [More 2/4], [More 3/4], [Define Eye Window].

Highlight the [Min] and [Max] limits by pressing the appropriate keys. Use the general-purpose knob to adjust the minimum and maximum limits to the desired locations within the eye crossings. 0% defines the left most crossing and 100% the next crossing point to the right. For best results, it is recommended to set the minimum limit to 40% and the maximum to 60%. When done, press [Previous Menu].

5) If you are using the optical input of the HP 83475 and are using the calibrated watts vertical scale, you can select the units for amplitude measurements as either dBm or μ W. To do this press [Select Units] and then select either [μ W] or [dBm].

5) To begin performing amplitude measurements, press the appropriate softkey to activate the desired measurement. To access different measurements, scroll through the **Time** and **Power/Voltage** menus by pressing the [More x/x] softkeys. The following figure shows the display with some of the measurements activated.

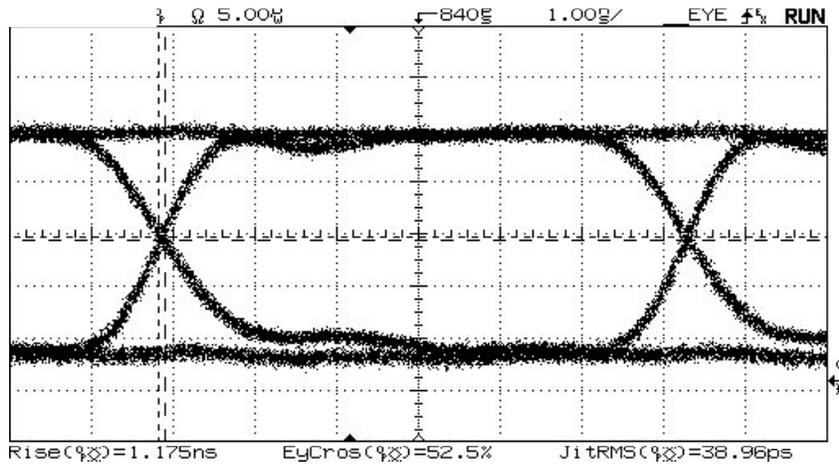


Figure 19. Eye-diagram waveform characterization

General waveform measurements

If you wish to perform general waveform measurements, for example on an NRZ square wave waveform, press either **Time** or **Power/Voltage** and select [Meas Type Genl Wvfm Eye:NRZ] **Genl Wvfm**. The procedure for making measurements is essentially the same as the previous one for eye diagrams. It is important to have a stable waveform display and to show a sufficient number of transitions for measure-

ments such as period, bit rate, and \pm width. As previously mentioned, to increase measurement repeatability, waveform averaging can be used with pulsed waveforms. Figure 20 shows the display with some of the key measurements activated.

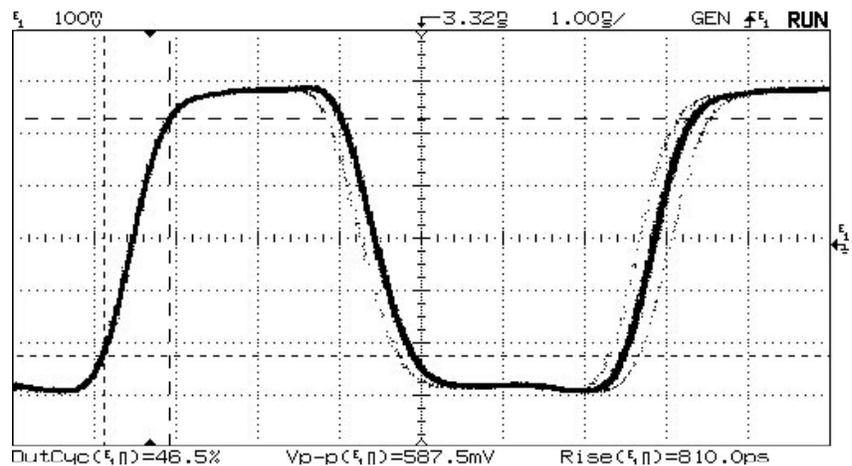


Figure 20. Pulse waveform parametric analysis

Summary

The HP 83475 performs many of the measurements for the analysis and testing of digital communications equipment and components. Built-in algorithms perform standard-required conformance measurements such as mask and extinction-ratio testing. In addition, the HP 83475 automatically measures waveform parameters such as rise time and jitter. A low distortion, integrated O/E converter provides accurate parametric measurements and allows for peak and average optical power measurements. Beyond lightwave communications test capabilities, the HP 83475 functions as a general-purpose 500 MHz oscilloscope. Two available electrical channels can measure electrical signal characteristics and can be used to analyze electrical tributary signals on communications equipment.



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5962-7934E**