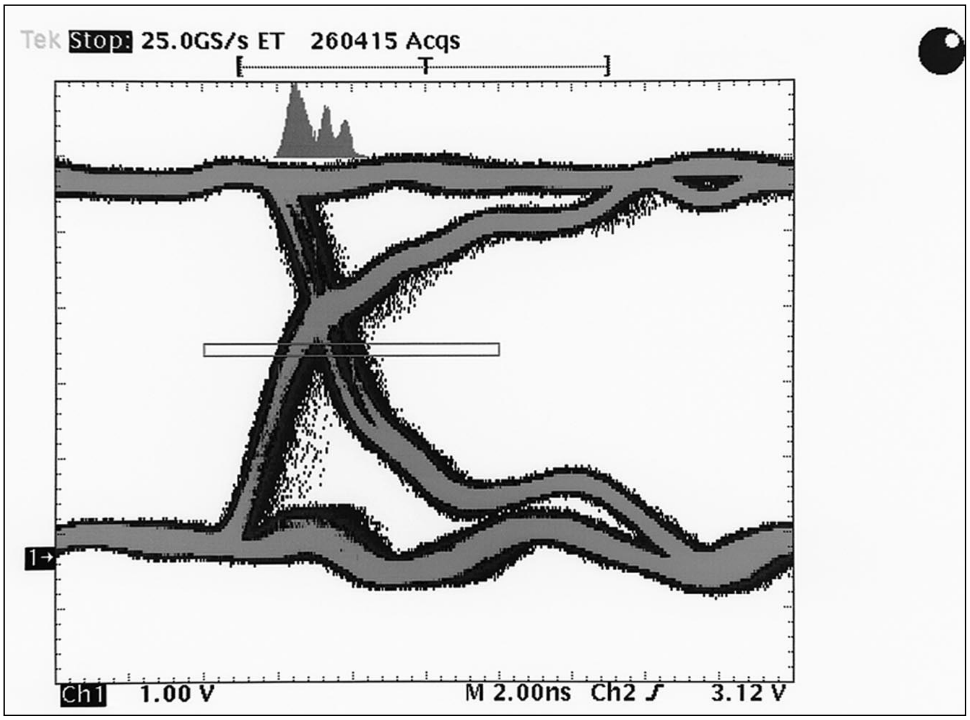
Tektronix

Application Note

Testing Telecommunications Tributary Signals



The SONET/SDH standards for optical telecommunication networks are the most comprehensive means of implementing transport infrastructures. The increased configuration flexibility and bandwidth availability of SONET/SDH provides significant advantages over older telecommunication systems.

However, as the data capacity of SONET/SDH fiber-optic telecommunication networks increases, equipment manufacturers, network operators, and end consumers would experience significant losses if a system were to fail. Therefore, testing the signals that go into the network and analyzing the signals that come out becomes ultimately important. The so-called "tributary rate" signals (e.g., optical OC-12/STM-4 and electrical DS1 and E1) must be tested to ensure that the signals conform to standards before they are distributed on the broadband network.

A key element of tributary signal testing is testing the equipment's physical layer. The physical layer is the lowest layer in the Open Systems Interconnection (OSI) network model. Table 1 lists several of the physical layer specifications for optical tributary rate signals.

Table 1. SONET/SDH Physical Layer Specifications

Line Rate	Signal Type	Media	Bit Rate
OC-1/STM-0	Optical (1310 nm or 1550 nm)	Single Mode Fiber	51.84 Mb/s
OC-3/STM-1	Optical (1310 nm or 1550 nm)	Single Mode Fiber	155.52 Mb/s
OC-12/STM-4	Optical (1310 nm or 1550 nm)	Single Mode Fiber	622.08 Mb/s

Table 2. Common Electrical Physical Layer Specifications

Line Rate	Signal Type	Data Encoding	Media	Bit Rate
ANSI T1.102 DS1	Electrical	AMI	100 Ω Balanced Pair	1.544 Mb/s
ANSI T1.102 DS3	Electrical	AMI/B3ZS	75 Ω Coaxial Cable	44.736 Mb/s
ITU-T E1	Electrical	AMI/HDB3	120 Ω Balanced Pair/ 75 Ω Coaxial Cable	2.048 Mb/s
ITU-T E2	Electrical	AMI/HDB3	75 Ω Coaxial Cable	8.448 Mb/s
ITU-T E3	Electrical	AMI/HDB3	75 Ω Coaxial Cable	34.368 Mb/s
STS-1	Electrical	AMI/B3ZS	75 Ω Coaxial Cable	51.84 Mb/s
STS-3/STM-1E	Electrical	CMI	75 Ω Coaxial Cable	155.52 Mb/s

Table 2 lists characteristics for some of the electrical tributary rate signals.

This application note describes how to use a Digital Phosphor Oscilloscope (DPO) to perform physical layer testing of tributary signals. The measurements discussed highlight some of the oscilloscope's capabilities for design debugging, verification of compliance with industry standards, and signal characterization. All example tests are done with a Tektronix TDS 700D Series or TDS 500D Series DPO with the communication signal analyzer option.

Communications Design Debugging

Following is a summary of the equipment choices available for physical layer testing.

Sampling Oscilloscopes. When designing a communications transmitter, engineers need to capture intermittent failures that can occur. They also need to observe the device's output and determine if its parameters are within acceptable limits. In the past, observation of high data rate signals such as OC-12/STM-4 was limited to higher bandwidth sampling oscilloscopes. In addition, the limited availability of oscilloscopes with built-in communications measurements also required the use of a sampling oscilloscope. Sampling oscilloscopes acquire data using one point per trigger. The sampling oscilloscope uses hundreds of triggers in order to build a waveform. This low duty cycle acquisition works well for high data rate signals whose characteristics are repetitive. However, the time required to acquire enough waveform data using a sampling oscilloscope rules out any possibility of capturing infrequent events.

Bit Error Rate Testers. Bit error rate testers (BERT) are another tool often used in communications design. A BERT transmitter outputs a known data pattern to stimulate the device-under-test. The BERT receiver accepts the device's output data and looks for bit errors to occur.

BERTs can be very effective in finding errors that occur very infrequently, but only if the communication device under test is working well enough to accept inputs and/or transmit data. If the design is not working, a BERT cannot help a designer determine the source of the problem. When a transmitter is not working or "partially" working, an oscilloscope is invaluable for debugging the design. The DPO's graphical display of the digital data makes finding the problem easier. By contrast, the BERT receiver typically only has a numeric display that shows bit error rate.

Digital Phosphor Oscilloscopes (DPO). For communications hardware debugging, a real-time oscilloscope is often the best test instrument. A DPO with its real-time acquisition has the ability to see problems that happen so infrequently that a sampling scope will miss them. Additionally, although it's not a substitute for a BERT, the DPO is a valuable companion to the BERT because of its intensity-graded display that enables the user to observe a transmitter's output and immediately see if there are intermittent problems.

In many cases, the advanced triggering available in a DPO allows quick location of signal errors. The TDS Series DPOs offer five different categories of advanced triggers including communications, logic, and pulse width triggering. Many of these advanced triggers can be used to quickly debug a communications problem. For example, Figure 1 shows an Alternate Mark Inversion (AMI) encoded signal that has a polarity violation on the eighth pulse in the pulse sequence. This polarity violation was found using the TDS oscilloscope's timeout trigger function. In timeout trigger operation, the TDS triggers if it has not seen a high-to-low transition in the specified period of time. In this case, the DPO was set up to take advantage of the fact that the AMI signal can only have a limited number of zeros. The timeout trigger was used to find a data pattern in the sig-

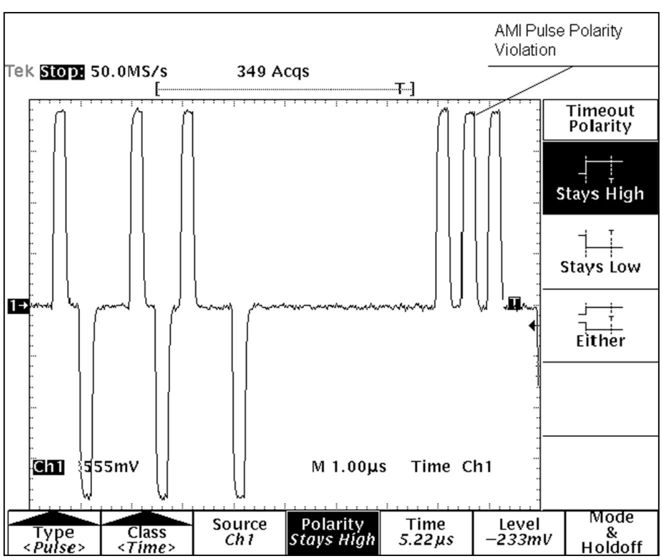


Figure 1. AMI pulse violation captured with timeout triggering.

nal where a logic one with negative polarity was expected but did not occur.

Standards Verification

Before a communication system can move from the development lab to a network installation, it must be tested for compliance with industry standards such as ANSI T1.105 or ITU-T G.708. These standards list physical layer signal parameters such as data rate, pulse width, maximum amplitude, extinction ratio, and pulse shape.

Mask Testing Requirements. Many of the required measurements such as pulse width and amplitude can be made manually with an oscilloscope or automatically using the DSO's automatic measurements. A mask that defines the region where the signal must reside on the oscilloscope's display specifies the pulse shape test. These masks vary by the type of signal being tested. For many of the lower data rate electrical tributary signals, a mask for a single positive or negative pulse is defined. For the high-speed electrical and optical signals, an eye diagram mask is defined. Figure 2 shows an example of each type of mask.

Pass/Fail Testing. The TDS 700D/500D Series DPOs are capable of displaying industry standard telecommunications masks. When a mask is displayed on the TDS screen, the AUTOSET button allows the user to quickly center the test signal within the mask boundaries. In addition, by using advanced DSP processing built into the TDS, the DPO can compare the currently acquired waveform to the mask boundaries to see if any mask violations (also called "hits") occur. Readouts on the TDS display show the user where the mask hits occur and how many occur. Finally, an automatic pass/fail mask test can be set up to determine whether a device exceeds the mask boundaries when a user-defined number of waveforms is acquired. Figure 3 shows a 2 Mb/s pulse waveform that is being tested for pass or fail.

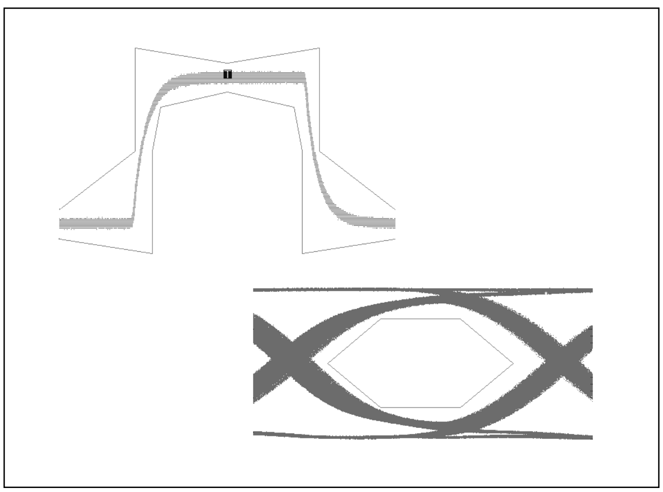


Figure 2. Example pulse and eye diagram masks.

The DPO readouts in Figure 3 show how many waveforms are desired and how many have been acquired. In addition, the "passing" readout shows the current status of the test. If the number of mask violations exceed a user-specified threshold, the readout will change to "failed." This type of testing allows unattended mask testing in a lab as well as automatic testing in manufacturing.

Communication Pattern Triggering. A standard mask test requires that the oscilloscope have a unique data identification capability that many DSOs lack; a trigger capability that can find and trigger on data patterns such as positive pulses with leading and trailing zeros. Many of the standard masks defined for testing tributary signals have regions where the signal must be zero long enough to enter and exit the mask without causing a violation. Figure 4 shows a DS1 mask where the leading and trailing bits surrounding the logic one pulse must be zero for at least one bit time. The signal shown is known as an isolated one.

The ANSI T1.102 specification for the DS1 signal requires a pulse with four leading zeros and one trailing zero for the signal that is tested by the DS1 mask. TDS 700D/500D DPOs have communications triggers that allow them to find and trigger on any isolated ones that

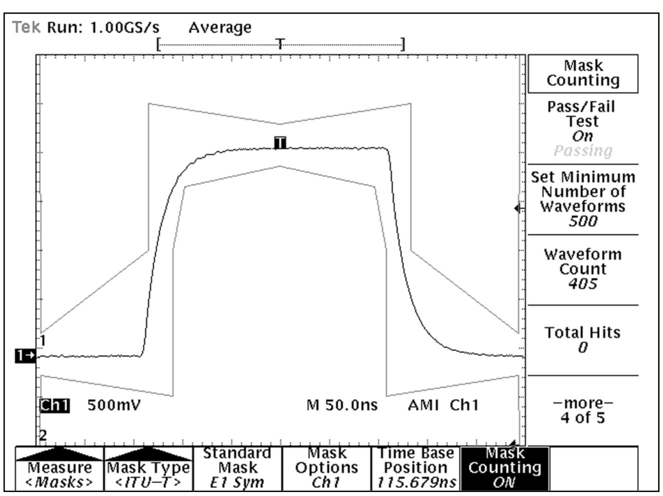


Figure 3. Pass/fail mask test on a 2 Mb/s pulse.

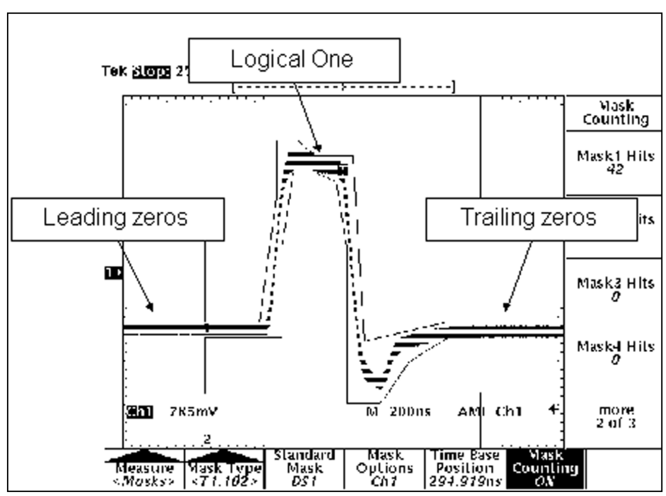


Figure 4. DS1 isolated one pulse.

exist in a random data stream. Masks for other tributary signals are designed to test specific waveshapes such as the code mark inversion (CMI) positive one, negative one, or zero waveshapes.

Without communications triggering, properly performing a mask test requires that the transmitter output a specified bit pattern such as all ones. To test a device with realistic traffic signals such as pseudo-random data, the oscilloscope must be able to find and trigger on the specific bit pattern before performing the mask test.

Inverted Masks. Many standards with bipolar signals such as AMI require mask tests on the positive and negative polarity pulses. For example, the ITU-T G.703 standard requires testing of both pulse polarities. The TDS pulse masks allow the mask to be inverted in order to perform these tests. In addition, the communication trigger function allows triggering on an isolated –1 as well as a +1. An inverted pulse mask test is shown in Figure 5.

Optical Reference Receiver. Performing tests of optical tributary signals such as OC-12/STM-4 with an oscilloscope requires conversion of the optical signal from optical power to electrical voltage. Devices called optical-to-electrical (OE) converters are available to allow measurement of optical data communications signals with a DPO. The Tektronix P6703B OE converter is an example of an OE converter that converts optical signals between 1100 and 1650 nm to a proportional electrical signal. The P6703B works best with Tektronix TDS oscilloscopes.

Another requirement for optical communications testing, especially mask testing, is an optical reference receiver. The optical reference receiver is not necessarily a single device; rather it's a system specification for the measurement devices being used in the optical mask test. A system used for optical mask testing must have a frequency response such as the curve shown in Figure 6.

In the TDS 700D/500D Digital Phosphor Oscilloscopes, an optional system calibration of the DPO and the OE converter allows the pair of devices to exactly match the SONET/SDH standard requirements for an optical reference receiver. The TDS optical reference receiver frequency response is achieved using advanced digital filtering in the TDS oscilloscope. By using a digital filter for the optical reference receiver, the TDS oscilloscopes are capable of supporting multiple standard data rates. Also, the digital filter response is closer to the ideal frequency response. This improved filter response results in more margin relative to the industry standard limits. The TDS 700D/500D DPOs, along with the P6703B OE converter, can match the optical reference receiver frequency response required for measurement of the OC-1, OC-3/STM-1, and OC-12/STM-4 optical signals. In addition, the user can quickly and easily switch between the various data rates using the TDS digital filtering.

Extinction Ratio. Another optical compliance measurement specified by the SONET/SDH standards is extinction ratio. The extinction ratio measurement is the ratio of the average power level for a logical one (E1) to the average power level of a logical zero (E0):

$$\text{Extinction Ratio} = 10\log\frac{E_1}{E_0}$$

Extinction ratio is a measure of the digital signal's modulation depth. The higher this ratio, the more margin the transmission system has to resist distortions before the BER increases. A desired range for a system's extinction ratio is set by the standard requirements and by the data rate requirements. The TDS 700D/500D DPOs can make the extinction ratio measurement automatically. As a result, the measurement is not difficult, but there are recom-

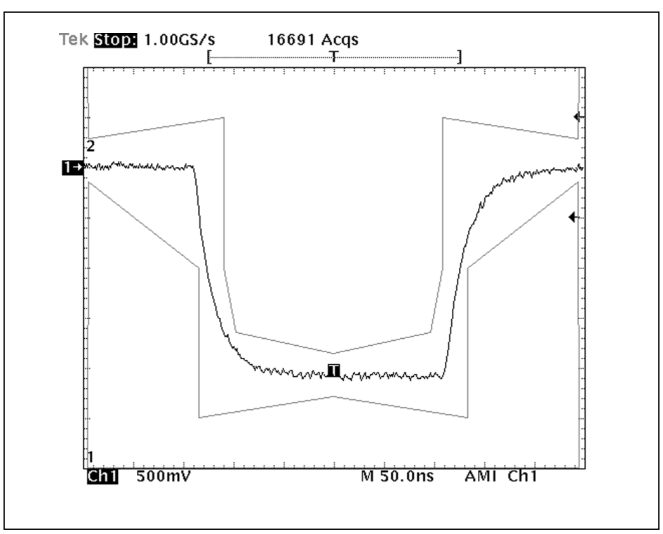


Figure 5. Inverted mask test on a 2 Mb/s pulse.

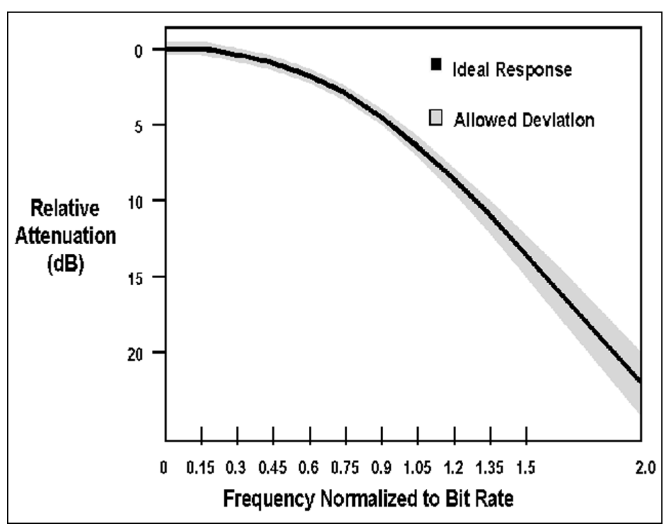


Figure 6. System frequency response for an optical reference receiver.

mendations that should be followed for accurate extinction ratio measurements.

First, it's recommended that an optical reference receiver be used for the extinction ratio measurement. The extinction ratio needs to be done on a full data rate signal where the logic one and logic zero average power levels are measured over one full period of the signal. Since the data rate will be high and the average power levels are desired, the reference receiver's integrating effect will give a good approximation of the logic one and logic zero power levels, even at high data rates.

Next, the following recommendations will help reduce error in the measurement. One possible source of error is DC voltage offsets in the oscilloscope or the OE converter. To ensure an accurate extinction ratio measurement, it's important to null out any offsets. This procedure is called a dark level or zero light level calibration. The zero light level corresponds to the voltage level measured by the DPO when no light is input to the OE converter. The TDS 700D/-500D Digital Phosphor Oscilloscopes have an automatic zero light level calibration function.

The extinction ratio value can change significantly if the zero light level changes. Figure 7 shows two examples of how a different zero light level reference can affect the extinction ratio value. On the left of the figure, the logic zero level is measured as 2.5 µW above the reference. The logic one level is measured as 13 µW above the reference. The extinction ratio calculated from these values is 7.2 dB. On the right side of the figure, a different zero light level is shown after the calibration has been run. With this new reference, the resulting logic zero and logic one levels are 1.5 and 12 µW respectively. Using these values to calculate extinction ratio yields 9.0 dB, a significant increase.

A second potential source of error is the oscilloscope and OE converter measurement uncertainty. Depending upon the extinction ratio value, the accuracy specification of the OE and oscilloscope can cause significant error in the extinction ratio measurement. For example, consider a signal with an extinction ratio of 8 dB. If the logic one level of this signal as measured by the oscilloscope is 100 mV, the logic zero level is measured as 16 mV. If the uncertainty in the measurement is ±1 mV, the extinction ratio will vary from 7.7 dB to 8.2 dB. The 0.3 dB change in the measurement is probably acceptable. However, if the signal's extinction ratio is 14 dB and the logic one level of the signal is 100 mV at the oscilloscope, the logic zero level will be 4 mV. Now the ±1 mV measurement variance has a more significant affect. The extinction ratio will vary from 13 dB to 15.2 dB, a 1 dB to 1.2 dB variance.

A couple of recommendations will help avoid or minimize this type of measurement error. First, set the DPO's voltage range such that the optical signal uses as much of the scope's dynamic range as possible. Secondly, it's best to make multiple measurements when measuring extinction ratio and use an average value. The figure below shows a TDS 700D/500D extinction ratio measurement with the mean (µ) and standard deviation (σ) of the extinction ratio displayed.

Verifying compliance with a telecommunications standard requires several tests such as data rate, pulse width, amplitude, extinction ratio, and signal shape. Using a DPO, many of these tests can be performed in the development lab, in manufacturing, or onsite at a network installation.

Signal Characterization

For many designers, complying with an industry standard is not enough. They want to fully characterize their system to find its operating limits. If necessary, the device can be designed with a tolerance to prevent failures in manufacturing test or in the

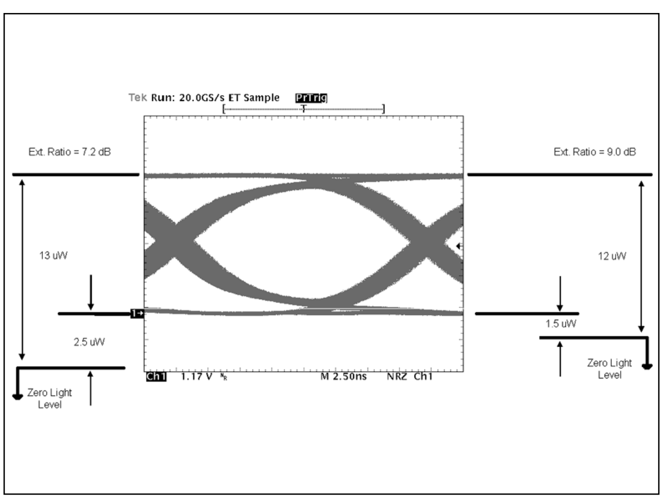


Figure 7. Dark level calibration

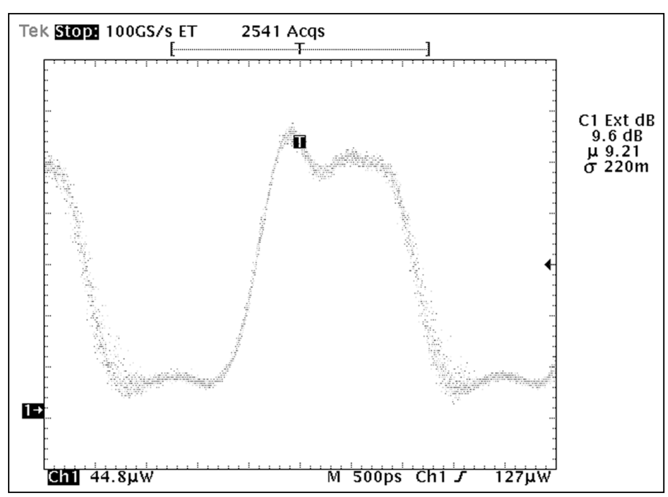


Figure 8. Extinction ratio measurement with mean and standard deviation statistics.

field after years of operation. This section discusses some of the possible signal characterization measurements that are possible with a DPO.

Mask Margin Testing. The section on standard compliance discussed the use of industry standard masks. In addition to ensuring standards compliance, masks can be used to determine the amount of margin in a signal relative to the standard requirements. Testing a design's margin level ensures that a system still complies with a standard under worst case conditions. It could also ensure a mass produced system would comply with industry standards as well as the original design that was tested in the lab. To check a device for margin using a mask, percent margin can be added to the mask. Then a mask test can be run and checked for failures. Mask margin testing can be performed with the TDS 700D/500D DPOs by using the mask margin feature. Figure 9 shows a set of eye diagram masks with the original boundaries (center mask) and two larger, less tolerant masks being used for margin testing.

When this mask test was run, over a hundred mask hits occurred. However, all the hits occurred in mask number 5. No hits happened in mask 4 or mask 2. Mask 5 is 20% larger than the standard mask, while mask 4 is 10% larger. From this test, it can be concluded that the design has between 10% and 20% margin relative to the standard requirements.

Jitter Measurements. As the speed of digital designs and communications systems increase, characterizing jitter becomes more important to ensure proper operation of a system. Jitter can reduce a system's margin for error. Jitter can be defined as a phase variation or a timing deviation from an ideal. In digital communications systems, excessive jitter leads to unacceptable bit error rates (BER). The sources of jitter can be data dependent as well as random. Data-dependent jitter is a timing error in one bit caused by the state of one or more of the preceding bits in the transmission sequence. Random jitter is defined as timing errors that are not correlated to the data being transmitted. A simple measurement of jitter could measure both jitter types and result in a total jitter value. However, when trying to eliminate jitter, it's best to measure the random and data-dependent components separately. Then if one type of jitter is dominant, a systematic approach can be used to reduce the random or data-dependent jitter first.

Note: A complete discussion of jitter measurements appears in another Tektronix application note ***Performing Jitter Measurements with the TDS 700D/500D Digital Phosphor Oscilloscopes*** *(55W-12048-0).*

Random Jitter. Measuring random jitter is possible using the histogram measurements available in the TDS 700D/500D DPOs. The steps for measuring the random jitter component are:

1. Stimulate the transmitter with a simple low-frequency repeating pattern. An example low-frequency pattern would be five high bits, then five low bits. This low-frequency pattern avoids inducing data-dependent jitter into the output.
2. Acquire the signal using the fast statistical database in a DPO.
3. Use a horizontal histogram to measure the distribution of the random jitter. For jitter that's truly random, one standard deviation of the histogram data is equal to the random or RMS jitter.

Figure 10 shows a random jitter measurement using a horizontal histogram. The measurement of the histogram data is shown to the right of the waveform. One standard

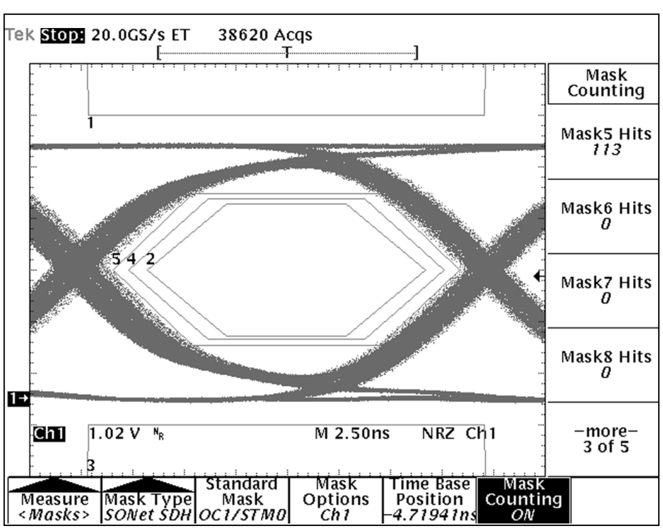


Figure 9. Eye diagram masks with 10% and 20% margin added to the standard mask.

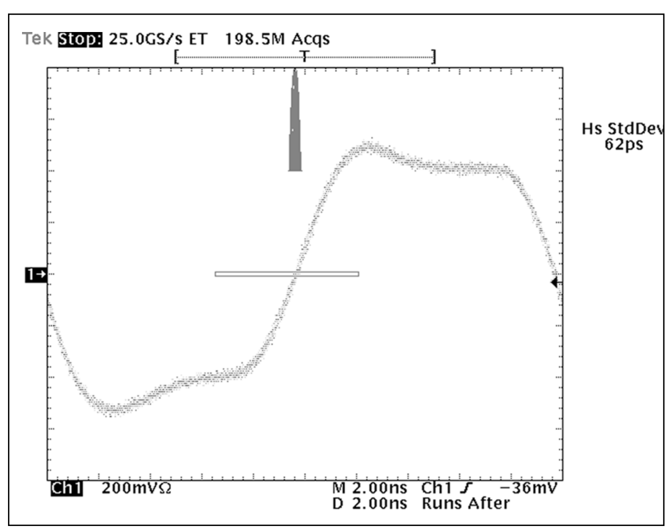


Figure 10. Random jitter measurement.

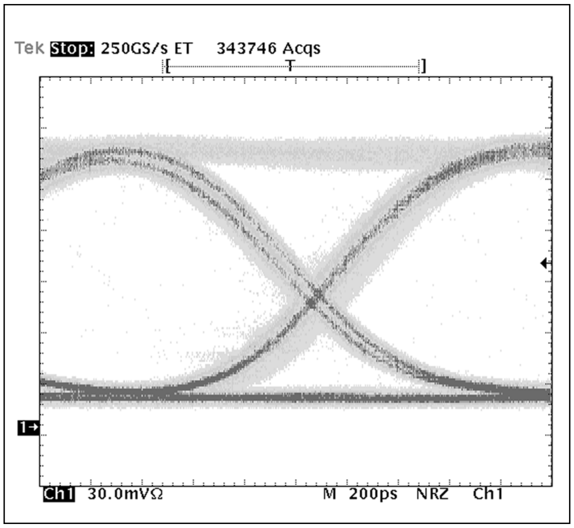


Figure 11. Intensity-graded eye crossing display.

deviation of the histogram data is 62 picoseconds.

For random jitter measurements, it's necessary to collect sufficient amounts of data to have a statistically valid jitter distribution. The histogram data should include many thousands or millions of acquisitions to yield valid statistics. When characterizing lower data rate tributary signals, the acquisition time can significantly slow down the jitter measurement. The Tektronix TDS 700D/500D Digital Phosphor Oscilloscopes allow a histogram to be accumulated and measured much faster than DSOs. Tektronix DPOs acquire and measure histograms 1000 times faster than traditional DSOs. See the sidebar, ***The DPO Acquisition Advantage*** for more details.

Data Dependent Jitter. Spotting a data dependency is easy with the DPO's intensity-graded persistence display. As data is acquired during multiple triggers, the intensity-graded display highlights areas in the waveform that are being hit more often. The intensity grading's highlighting often shows distinct edges in the waveform that are jittered. These distinct edges or modes indicate data pattern dependencies in the transmitter. Once these data dependencies are shown, the DPO can be used to quantify the effects of the various patterns.

Observing the intensity-graded display or a histogram of the eye crossing can show data dependencies that cause different transitions through the eye crossing point. In Figure 11, notice the bi-modal distribution of the edges at the eye crossing point. These distinct modes correspond to timing errors caused by different data patterns being transmitted by a laser. The timing errors induced by these different patterns are examples of data-dependent jitter.

NRZ Serial Triggers

If a data dependency is present in the transmitter, the TDS 700D/500D communications triggers can be used to capture one of several unique data patterns in NRZ serial data. The communications trigger feature offers several 3, 4, and 5 serial bit patterns that can be used to trigger the scope. By observing the behavior of the transmitter when outputting an individual data pattern, it's possible to characterize data-pattern effects.

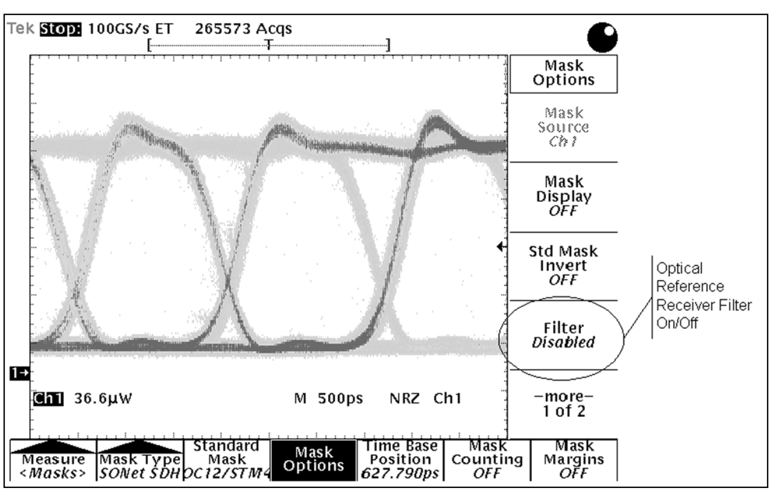


Figure 12. Turning the ORR filter on and off.

Optical Reference Receiver On/Off

While comparing a SONET/SDH signal to a mask, the limited frequency response of an optical reference receiver is required. For device characterization, a bandwidth several times wider than the bit rate is recommended. To see a signal at full scope bandwidth, it's often desirable to disable the optical reference receiver filtering. On TDS 700D/500D Digital Phosphor Oscilloscopes, turning off the optical reference receiver filter is as easy as a single button push. Figure 12 shows the menu choice for turning the optical reference receiver filter on and off.

Without an optical reference receiver filter, the signal in Figure 12 shows faster edges as well as more ringing and overshoot. Many of the modern receiver components, such as photodetectors, have bandwidths significantly wider than the signal's bit rate. Characterizing the signal at full bandwidth allows observation of the signal aberrations, as the wider bandwidth receiver actually sees them. Using the standard compliance test without characterizing a design could lead to tributary signal transmitters that have intermittent problems in manufacturing and in the field.

Conclusion

The SONET and SDH standards have become the international standards for broadband telecommunication networks. To ensure interconnectivity between systems, SONET/SDH standards require strict testing of all tributary rate signals input to the network. Several tests are specified for the signal's physical layer. The Digital Phosphor Oscilloscope allows engineers to debug, verify, and characterize these signals.

The DPO Acquisition Advantage: 1000X Improvement vs. DSOs

Using DPO technology, TDS 700D and TDS 500D Series oscilloscopes acquire 1000 times more signal data than a traditional DSO can. Tektronix has developed a unique software and hardware technology to provide display sample densities that are orders of magnitude superior. For physical layer testing, this improvement in display sample density translates into more data acquired in less time. Eye diagrams that took minutes to accumulate, now take seconds. Histograms can be done in seconds as well. Finally since more data is acquired in less time, the accuracy of many statistical measurements is improved.

Figures A and B illustrate the speed of DPO acquisition. Notice that the acquisition counter at the top of the DPO display is significantly larger than the normal DSO display's acquisition counter.

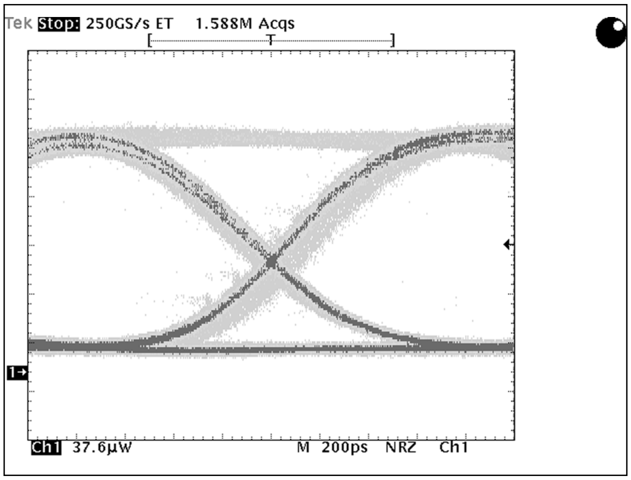


Figure A. Eye crossing with DPO, 10-second accumulation.

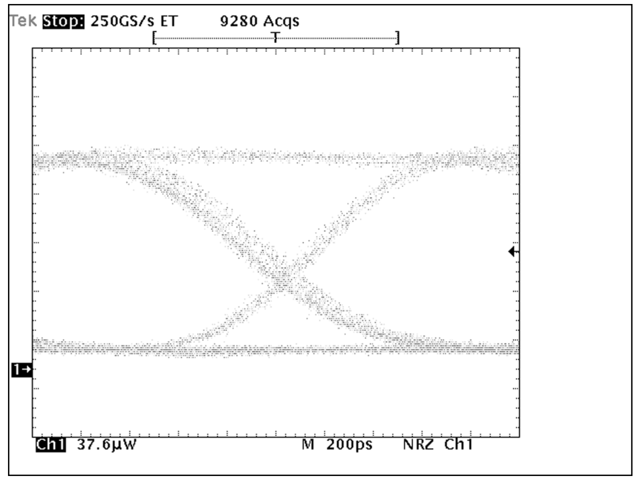


Figure B. Eye Crossing from a normal DSO, 10-second accumulation.

Other Related Products. Tektronix offers several other products suitable for broadband telecommunications system testing (see Table 3).

Table 3. Additional Broadband Test Products From Tektronix

Model Number	Description
CSA 803C	Communications Signal Analyzer
11801C	Digital Sampling Oscilloscope
CTS 710, CTS 750	SONET/DS3/DS1 and SDH/PDH Test Sets
GB700, GB1400	Bit Error Rate Testers
ST2400	2.4 Gb/sec SONET/SDH Analyzer
SJ300E	SONET/SDH Jitter Analyzer
ATM150	ATM Test Set
VX4610	Modular SONET/SDH Analyzer
MTS200	MPEG Test System

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