The Basics of Optical Physical Layer Testing Using a Communication Signal Analyzer

Communication has been a driving factor to our development as humans since the first cave etchings and sign languages of our distant ancestors. Today we communicate on a worldwide basis without even thinking of the complex systems that allow us to do so. With PC's connected through millions of networks, phone systems that we could not live without, and many other communication devices it is amazing that it all works. It works only because of the care taken during the engineering and testing of these systems that guarantees such consistent results. This paper will explore the basics of how testing is done with an Communication Signal Analyzer on the *physical layer of communication signals. Because of the many types of communication signals this paper will concentrate on optical physical layer testing only.

Optical Standards

In order to build a network that will work with many different manufactures, signal types and transport mechanisms it is necessary first to develop standards that all devices can be developed around. For optical communications there are several standards that were developed to accomplish this.

North America:

Telcordia GR-253-CORE
and ANSI T1.106 (SONET OC-n signals)
ANSI X3.230 (Fibre Channel)
ANSI X3.166 (FDDI signals)

International:

ITU-T G.957 (SDH STM-n signals)
ITU-T G.691 (SDH FEC)
ITU-T G.709 (SDH FEC)
IEEE 802.3ae (Gigabit Ethernet)

- Using the OSI (Open System Interface) model, the Physical Layer specifies the cables, connectors, signal shapes, and levels of these communication signals. Other layers in the OSI model include the Data Link Layer, the Network Layer, the Transport Layer, the Session Layer, the Presentation Layer and the Application Layer.

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The telecom hierarchy allows tributary data at many different rates and from various standards to be combined into a common format. This format is called SONET (Synchronous Optical Network) in North America and SDH (Synchronous Digital Hierarchy) in the rest of the world. These two standards are most typically transmitted over optical fiber because it can handle more data at faster rates and is much more reliable especially over long distances. Within these standards the engineer or designer can find the specifications for each of these rates and specific methodologies used to test these rates for compliance. One of the most common tools used to test these rates is the Communication Signal Analyzer (CSA).

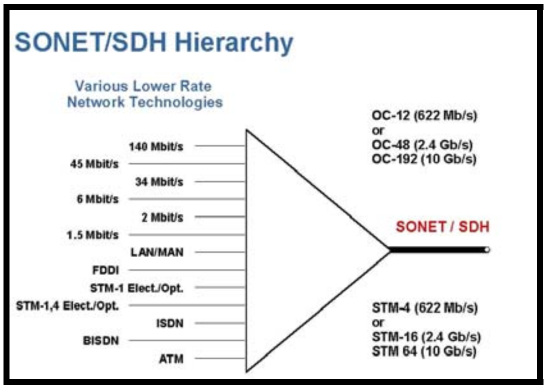

Figure 1 SONET/SDH Hierarchy

Sonet Standard	SDH Equivalent	Electrical Standard	Line Rate MBPS
OC1	N/A	STS-1	51.84
OC3	STM-1	STS-3	155.52
OC12	STM-4	STS-12	622.08
OC48	STM-16	STS-48	2488.32
OC192	STM-64	STS-192	9953.28
OC768	STM-256	STS-768	39813.1

Table 1 Sonet and SDH rates

Communication Signal Analyzers (CSA)

Because of the many data rates used in today's communication devices it is important to have a CSA that can handle the wide variety of data rates. This is why in most cases a Sampling Oscilloscope is used for optical communication signal analyzer. The sampling oscilloscope offers the bandwidth required for the faster data rates and because of the modular nature of most sampling oscilloscopes, new modules can be added as new rates and standards are developed. The sampling oscilloscope has been around for over 20 years and has become the industry standard for high speed very accurate optical communication signal measurements. The architecture of the sampling oscilloscope is somewhat different than the traditional oscilloscope or what is called the Real Time Oscilloscope. With the sampling oscilloscope a sample is taken sequentially with every trigger. So this is where it gets its name. The sampler is also placed inside a small module that can be removed from the main instrument. Also all of the components required for Optical Signal Analysis can be integrated into the module like the Optical-to-Electrical Converter and Optical Reference Receiver. So it is possible to connect an optical fiber directly to the module. Also to properly characterize the optical signal the CSA should not be triggered on the received data. So an external trigger must be used or clock recovery capability built into the modules. Since a sample is taken with each trigger and the waveform is captured from many triggers signals either must be repetitive or synchronous to the trigger signal. How fast these samples can be taken and how much data must be acquired will determine test completion times.

Figure 2 CSA8000 Communication Signal Analyzer

Optical Reference Receiver (ORR)

In order for the optical signal to be measured correctly on the CSA the communication standards specify a filter to be used that will show the data similar to what the receiver will see. This will reduce the effects of the transmitter's high frequency overshoot and noise. See figures 5 and 6. This is called the Optical Reference Receiver (ORR). This ORR is a 4th Order Bessel Thomson Filter and is its –3dB bandwidth varies according to the data rate being measured. For compliance testing the filter H(p) is a combination of the ORR, Optical to Electrical Converter and the oscilloscope sampler. With these all integrated into one module re-calibration is kept to a minimum. See figure 4.

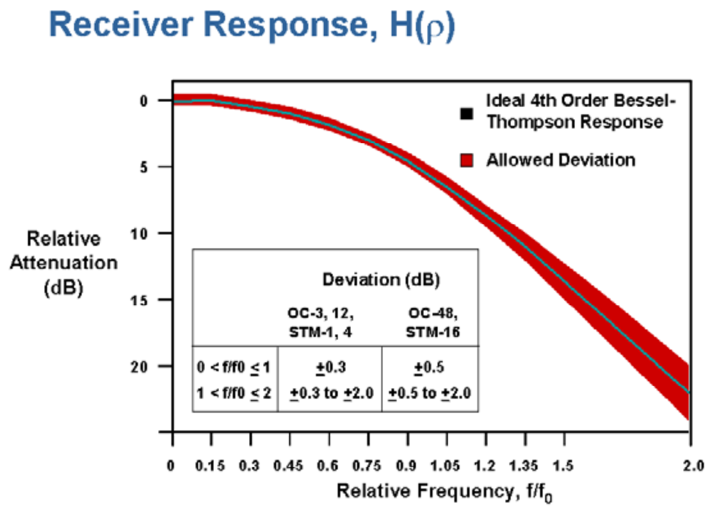

Figure 3 Receiver Response Curve

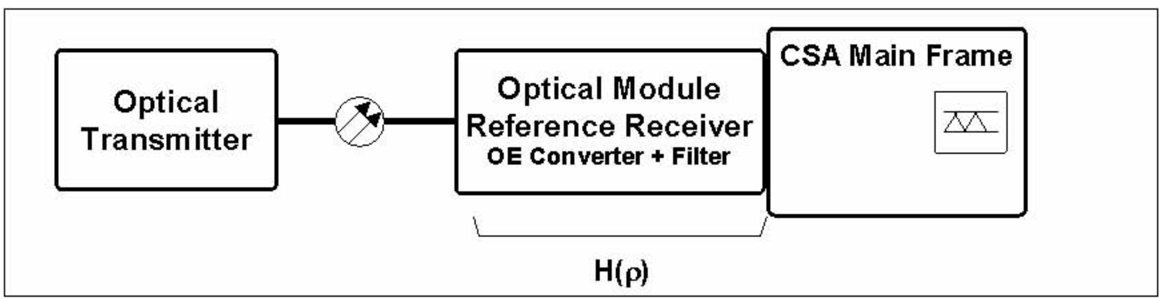

Figure 4 ORR Block Diagram

Figure 5 OC12 without ORR enabled

Figure 6 OC12 with ORR enabled

Figure 5 shows the effects (overshoot and noise) of what an OC12 signal looks like when not using the specified ORR. Figure 6 shows the effects of using the correct ORR.

Eye Pattern

Today's CSAs also have standard features like mask testing and automatic parametric measurements. Other digital features like waveform data bases, save, recall of waveforms and setups, mathematical results, signal conditioning and many others give the engineer/ technician all the tools required to simplify the testing process. When doing communications testing the most common technique is using what is called an eye pattern. The eye pattern is data bits acquired on the CSA overlaid one on top of each other. See figure 7.

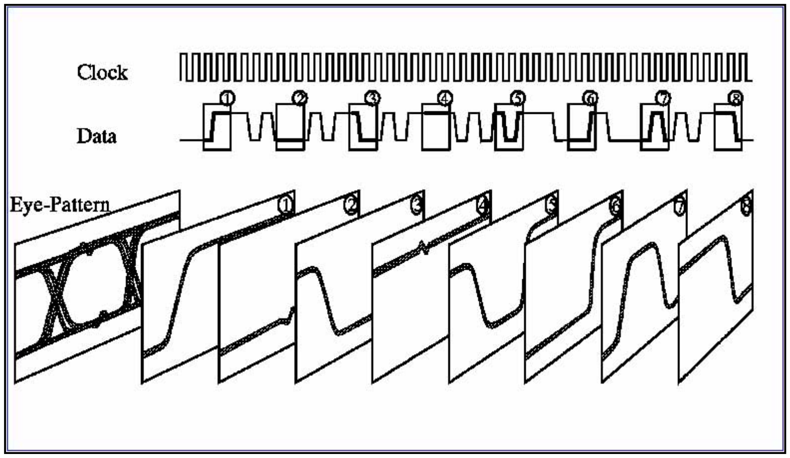

Figure 7 Building an eye pattern with a sampling scope

Using this technique allows for a quick study of most of the data characteristics. When a pseudorandom data stream is displayed as an eye pattern, the overall quality and stability of the communications system can be observed. Data-stream problems such as excessive noise or timing jitter, tend to close the eye. In addition, the rise time and fall times of the data signal and pulse parameters, such as duty cycle, overshoot, and undershoot, can be observed. So in one display, you see how well the system is operating. Using an eye pattern in conjunction with a specified mask, parametric measurements and the correct conditioning hardware gives the user the capability of doing compliance testing to that standard.

Compliance Mask Testing

Take for example, the OC12/STM-4 signal, a popular 622 Mb/s standard used in many telecommunication transmission systems. To view this signal you will need to connect the signal to the CSA using the appropriate optical module that has an optical-to-electrical converter and optical reference receiver. Next, you could select clock recovery if available in the module or connect an appropriate trigger for the signal. Next use a waveform database to hold and display all the acquired values, as shown in figure 8.

The OC12/STM4 mask shown in figure 8 consists of three regions. A compliant eye pattern surrounds the hexagonal center-mask region and remains between the top and bottom regions. The display will indicate if any failures have occurred.

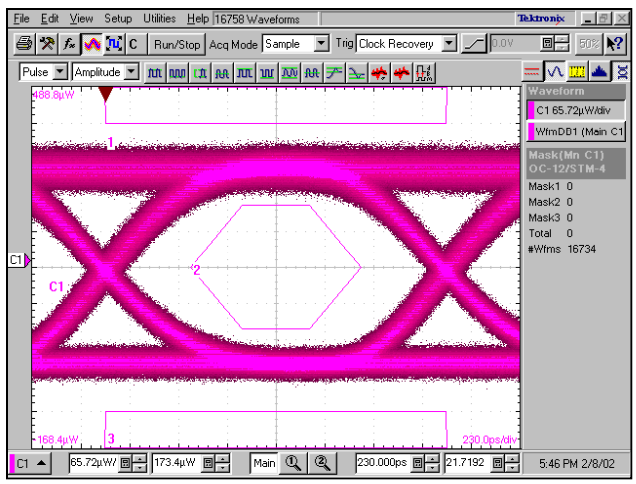

Figure 8 OC12 signal with mask enabled

Although automatic mask testing is convenient, particularly in the manufacturing environment, there are times when a user will want to perform manual mask testing. This is especially true during the design and debug phase of the product. In the manual mask testing mode, the CSA displays all the acquired waveforms, perhaps over millions of data cycles, with respect to the mask. Consequently, you can see any anomalies that might creep in across thousands of acquisitions. The resulting display gives a wealth of information that can be a real asset when characterizing or debugging a design.

Parametric Measurements

Along with the straightforward measurements made with the eye mask, you should consider several important complex measurements. These include jitter, extinction ratio, and average optical power.

Jitter is an important measurement, especially for high-speed data rates. Cycle-to-cycle jitter can cause the eye opening to close and affect a receiver's capability to decode a data stream. As the jitter increases, the data-transition points move closer and closer to the decision point of the receiver and eventually the bit error rate of the system increases.

Cycle-to-cycle jitter can be broken into two types: deterministic and random. Deterministic jitter is caused by the data bits preceding the current bit in the data stream. Random jitter is due to random noise. If the deterministic or pattern-dependent jitter is negligible, random jitter can be characterized and measured by statistically analyzing the data using a CSA's histogram capability. The CSA should display the rising edge, falling edge, or eye crossing where the jitter will be measured, and then create a histogram of the region where jitter is occurring.

If the histogram of the placement of the signal edge is a normally distributed curve, the standard deviation is equal to the RMS jitter of the waveform. The observed peak-to-peak jitter or ether histogram measurements also can be turned on to characterize the jitter as in figure 9.

There are two unique measurements specified in the Bellcore and International Telecommunications Union—Telecommunications sector (ITU-T) standards for optical systems. These measurements are extinction ratio and average optical power.

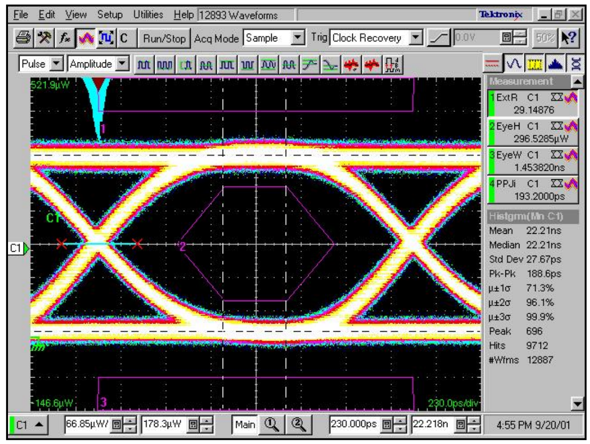

Figure 9 Use of histogram to measure jitter

Extinction Ratio:

The extinction ratio measurement is the ratio of average power for a logical one to the average power of a logical zero. The higher the ratio, the more margin the system has to resist added noise.

The extinction ratio measurement can be automatically performed by most CSAs making this measurement easy to do. Follow these recommendations for an accurate ER measurement:

1. An optical Reference Receiver filter must be used for the ER measurement. Since the data rate will be high and only the average power levels are desired, the filter's integrating effect will give an accurate representation of the average power levels even at high data rates.
2. Be sure that a Dark Level or zero-light level of the system is correctly measured and accounted for before any optical power readings are performed. Once the dark-level correction has been done, ensure that the signal being tested is a stable eye diagram. Then the automatic measurement can be run.

Average Optical Power:

Average optical power is another measurement specified by the SONET/SDH standards. The measurement can be performed with a CSA with an optical module or an optical power meter.

The accuracy and dynamic range of the CSA must support this measurement. Primarily, this measurement must determine the strength of the communications signal. The more power the signal has, the further it can travel in the fiber-optic-cable. This obviously is an important measurement when characterizing or debugging a communication system.

As communication capabilities continue to be incorporated into mainstream electronic systems, you will need to verify communication signals. Fortunately, today's advanced CSAs can dramatically shorten the learning curve and simplify the task of compliance testing and debugging communications signals.

What is new

The new trends are developing towards data rates at 40Gb/s and requirements for lower cost , low powered optical data transmitters are growing rapidly. Testing these capabilities faster and less expensively have also been a major focus in CSA products

40 Gb/s

The standards up to OC192/STM64 (10Gb/s) are well handled by today's CSAs. "All in One" solutions are available, with O/E, ORR filtering and CR integrated into one module and also capable of several rates. In contrast, the OC768/STM256 (40Gb/s) solutions are just emerging, and even the standard itself is still not firm. (Jan 2002) At this point, 4^{th} order B-T approximate solutions exist, but the tolerances for the Reference Receiver is not specified yet. Other changes are related to what type of modulation format is used. For rates up to OC192/STM64 Non Return to Zero (NRZ) modulation schemes are most common. For 40Gb/s signals both NRZ and Return to Zero (RZ) modulation formats are gaining popularity. The difference between an NRZ and RZ signal is somewhat self-explanatory. The RZ signal transmission of a logic '1' will always begin at zero and end at zero. The lower of the two diagrams shown is of the RZ format. Note how all '1' pulses, whether they are preceded by and followed by a 1 or a 0, start and end at the low power state. In contrast, the NRZ diagram (top display) shows how a '1' will stay at the high level if the preceding bit is a 1. Measuring RZ signals require more bandwidth than NRZ signals. Intuitively this is clear when considering that the RZ signal is switching twice as often as the NRZ signal. NRZ is not likely to remain the only standard; most experts predict that the RZ coding will become prevalent – at least for 40Gb/s and longer haul

10Gb/s applications. That increases the requirements on BW. A CSA with at least 50GHz (Optical) BW is required.

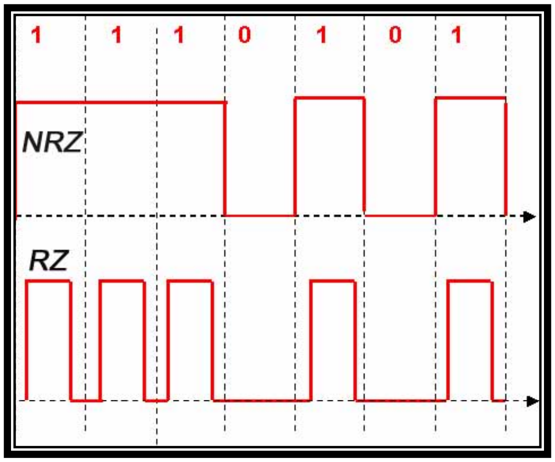

Figure 10 NRZ and RZ formats

10 Gigabit Ethernet Signals

With data communication signals becoming some of the most common signals being used today, being able to design and test these signals as quickly as possible is a requirement for today's CSA. Data Com signals tend to be transmitted with lower power devices such as LEDs rather than lasers. This requires high signal to noise performance in the optical to electrical converter being used. It is important to consider using an amplified O to E for these applications.

Automation

With the integration of the PC and oscilloscope together many tasks have become trivial on the new platform of sampling oscilloscopes. Now with the Window's™ based instruments, the sky is the limit on the new features and benefits of this combination. Being able to write simple test procedures and run them directly on the oscilloscope is just one of the new capabilities of the Tektronix CSA8000 Communication Signal Analyzer. This greatly improves the test time required not only for training but actual conformance testing of today's communication signals.

About Tektronix

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