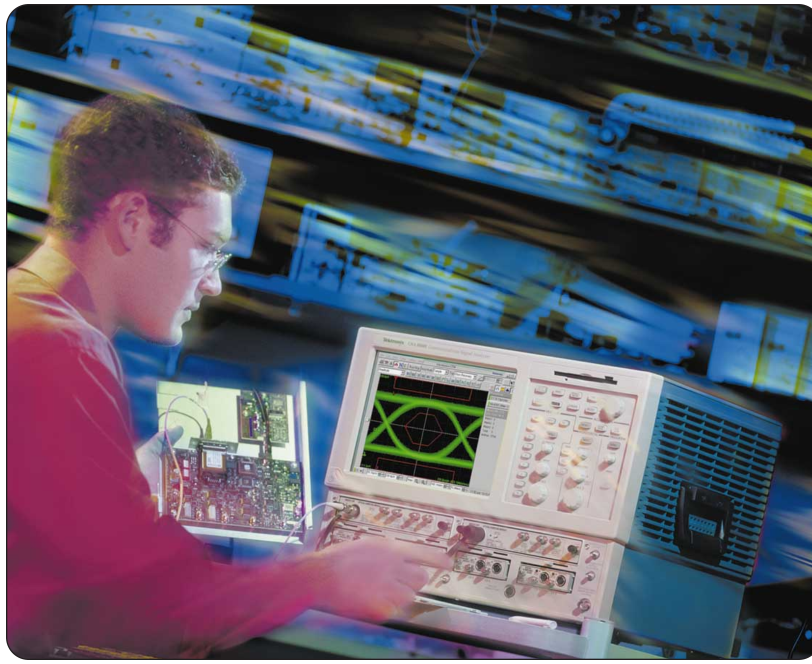
Characterizing and Testing GBICs with the CSA8000 Sampling Oscilloscope and GTS1000 GBIC Test System



Optical Signal Measurements for Gigabit Networks

The CSA8000 sampling oscilloscope, with its family of optical sampling modules, and the GTS1000 GBIC test system provide the measurement features needed to support GBIC (Gigabit Interface Converter) testing and more general-purpose optical signal display.

Connections operating at gigabit speeds are rapidly becoming an important element in datacom networks. These gigabit interconnections are increasingly being implemented with fiber-optic components, emphasizing the need for high-performance optical transceivers. The Gigabit Interface Converter (GBIC) is an industry-standard optical transceiver for datacom applications. Tektronix has recognized the need for high-performance measurement tools for physical-layer testing of GBICs and similar optical interfaces. We have developed the GTS1000 Series test systems to provide a compact platform for GBIC testing in a Fibre Channel or Gigabit Ethernet network.

Gigabit Networking Standards

The dominant gigabit datacom protocols in use today are Fibre Channel and Gigabit Ethernet. Both of these protocols define a serial communication interface at the physical layer with support for both optical and electrical media. Both protocols also define a common physical layer encoding method (8B/10B encoding), although a recent electrical variant of Gigabit Ethernet, 1000BASE-T, uses a very different encoding method to support gigabit communication over unshielded twisted pair (UTP) cable. However, optical interfaces are eventually expected to dominate gigabit interconnections because of optical fiber's higher bandwidth, longer routing distance without repeaters, and better noise immunity due to its inherent electrical isolation.

The Fibre Channel interface was developed in the late 1980s to provide an enhanced transport mechanism for data storage peripherals. It defines a high-speed serial interface to replace existing parallel interface cabling standards, such as SCSI, to connect computers to hard-disk storage. The increasing demand for high-speed data storage in computer networks has led to the development of separate storage area networks (SANs) between network servers and large disk arrays. Fibre Channel has become the dominant interface in these SANs as well as in some specialized point-to-point data applications such as video transport. Although most Fibre Channel systems today are operating at a bit rate of 1.0625 Gbaud (100 Mbytes/s + transport overhead), the standard defines a scaleable progression to higher bit rates.

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The Gigabit Ethernet interface was developed in the mid-1990s as an evolutionary enhancement to the Ethernet datacom standard. Ethernet has been the dominant local area network (LAN) standard for several decades, and has progressed from a shared 10 Mb/s data rate, to a switched 10 Mb/s rate, then to a 100 Mb/s FAST Ethernet rate, and now to a 1000 Mb/s Gigabit Ethernet rate. This scalability of data rates in the Ethernet standard has been promoted as a means to provide a common data frame structure in LANs from desktop to network backbone. The Gigabit Ethernet physical-layer standard work leveraged the existing Fibre Channel standard, using the same 8B/10B encoding method but a different frame encapsulation protocol. The use of the 8B/10B encoding method adds a 25% overhead to the data transfer rate and results in a 1.25 Gbaud encoded data rate. The Gigabit Ethernet standard supports 8B/10B encoded data communication using the following physical media:

- 1000BASE-SX (short wavelength)
- 1000BASE-LX (long wavelength)
- 1000BASE-CX (shielded copper)

Gigabit Optical Transceivers

Both the Fibre Channel and Gigabit Ethernet optical interfaces enable duplex data transmission using separate transmit and receive fibers. This physical media topology requires an electrical-to-optical (E/O) transmit interface and an optical-to-electrical (O/E) receive interface at each network node. These transmit and receive functions are often combined into a common module referred to as an optical transceiver. Because of the specialized optical technology required in their construction, optical module vendors have commonly supplied optical transceivers for gigabit network interface cards.

The first generation of gigabit transceiver modules, used in Fibre Channel applications, was called a Gigabit Link Module (GLM). The GLMs included both the optical transceiver function and a serializer/deserializer function to convert an encoded 10-bit parallel data stream into a high-speed serial data stream. The current generation of gigabit transceiver modules has been simplified to include only the optical transceiver function, and is now available in both fixed and pluggable form factors. The less expensive, fixed location transceivers are designed to be soldered to circuit boards and are supplied in an industry-standard, 1x9 pin leaded package. The more flexible, pluggable transceivers, designed to allow hot-plugging into a network interface card, have been standardized by optical module vendors as a GBIC. The newest generation of transceiver modules, referred to as Small Form Factor devices, has been designed for higher packing density. Both the solderable, 2x5 pin Small Form Factor (SFF) transceiver and the Small Form Factor Pluggable (SFP) transceiver are half the width of a GBIC and fit into an RJ-45 footprint space. Improvements in reduced size, higher bit rate, and enhanced laser quality and reliability have marked the progress of gigabit transceiver modules over time.

The GBIC was developed in 1995 as an improved, industry-standard, optical transceiver for gigabit networks. Its hot-pluggable interface enables increased flexibility in the configuration and replacement of datacom network switching equipment. Because of cost-vs-distance tradeoff issues with gigabit transceivers, the availability of short-wave (SW) GBICs, long-wave (LW) GBICs, and even copper (CU) GBICs, allows both equipment manufacturers and network administrators to more cost-effectively configure network systems. A network can be initially populated with only the interface nodes that are needed at the time, can be reconfigured as necessary, and can also be upgraded as network demands change. In service, the hot-swappable design allows for a simpler exchange of defective modules, possibly without having to shutdown the entire network. The GBIC also supports some advanced status and control functions that allow for improved diagnostic servicing.

Gigabit Interface Converters (GBICs)

A GBIC (Figure 1) has a duplex SC-type optical interface on one end of the module and a 20-pin electrical connector on the other. The SC-type optical connectors are self-aligning, and use a simple push-for-insertion, pull-for-release mechanism. The GBIC module is ordinarily inserted into a shielded, instrument-panel housing slot, and is locked into place with one of several possible mechanical latching mechanisms, depending on the GBIC vendor. The optical signals are propagated in a binary, NRZ format, with the stronger light intensity representing a binary 1 and the weaker light intensity representing a binary 0. The intensity of the light signals is limited by design so that the module can be safety-classified as a Class 1 laser device.

The GBIC module transmit function uses a directly modulated semiconductor laser to control the optical signal output. The laser modulation control signal comes from the TX_DATA input on the electrical connector. The module circuitry includes a laser power control circuit with fault sense and safety shutoff. The detection of a safety-related transmitter fault condition is indicated with the GBIC's TX_FAULT signal. An external transmit disable control input from the electrical connector is also supplied to the laser shutoff circuit. The GBIC module receive function uses a photodiode and transimpedance amplifier to detect the optical signal input. This optical-detector input stage is followed by a post-amplifier and decision comparator to supply a full-swing ECL signal to the RX_DATA output of the electrical connector. The module also contains a loss-of-signal (LOS) detector whose threshold is set to detect when the light intensity is too low to qualify as a valid input signal. This RX_LOS signal is also output to the electrical connector.

The GBIC module is ordinarily surrounded with a metal shield to minimize electrical interference from the gigabit data signals. The electrical data interface uses AC-coupled, 150-ohm differential signaling for both the electrical transmit (TX) and receive (RX) data signals. The electrical signal voltage swing for both the TX_DATA and RX_DATA signals is the standard PECL voltage swing. The power supply voltage specified in the GBIC standard is +5.0 V, with a maximum power dissipation of about 1.5 W in the module. In addition to the optical and electrical conversion circuitry, the GBIC module contains several status and control signals as well as several module definition lines that may be used to support a serial ID function. The optional serial ID lines use the I^2C 2-wire serial protocol and allow read-only access to additional configuration information stored in a serial E^2PROM.

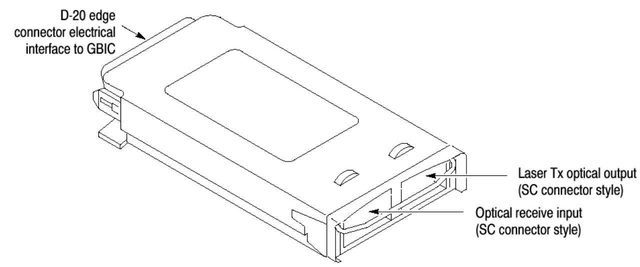

Figure 1. *GBIC module.*

Optical Physical Layer Measurements

The quality of optical network signals is often evaluated using bit-error-rate (BER) testing. Both the Fibre Channel and Gigabit Ethernet standards specify that optical links must support a BER of $<10^{-12}$. BER testing is useful in providing a quantifiable measure of error rate in a transmission channel. However, the long measurement time required to produce a statistically valid BER value and the lack of a visual display of the actual signal shape make the BERT a less than ideal troubleshooting tool. The use of a high bandwidth, low noise, equivalent-time sampling oscilloscope, particularly one with an integrated optical-to-electrical (O/E) converter and statistical measurement capability, enables the evaluation of optical signal parameters that might contribute to BER. The binary, NRZ encoding method commonly applied to optical network signals is a time-domain modulation technique and the majority of the signal parameters are most easily characterized with a time-domain measurement instrument.

The waveform displayed on an oscilloscope depends on both the input signal and the selected trigger source. An equivalent-time sampling oscilloscope ordinarily requires a repetitive signal pattern and a trigger signal synchronized to the pattern to produce a stable pattern display. With data communication signals, however, if the trigger signal applied to the oscilloscope is a clock at the data bit rate, the resulting display is called an eye pattern (Figure 2). The eye pattern display is a composite view of data pulses accumulated over a period of time determined by the oscilloscope display control. The bit-rate clock trigger for the eye pattern display can be supplied directly from the transmit pattern generator or derived indirectly from the data signal with a clock recovery unit. Attempting to use the data signal directly as both display input and trigger source will produce an eye-pattern-like display, but will fail to display some data transitions and will not give an accurate measure of timing jitter. Since an eye pattern displays an accumulation of all data transitions superimposed in a single bit-period time window, a stable display is possible even without a repetitive data pattern. Averaging a clock-triggered eye pattern display is not possible, however, since the bit-rate clock trigger occurs multiple times during each data pattern period. This timing relationship results in a display that is randomized relative to the data pattern period, causing an averaged eye pattern to collapse to a baseline display at the average value between the two binary signal levels. (The CSA8000 FrameScan™ feature does allow eye pattern displays to be averaged, but only when a pattern trigger signal is available.)

An eye pattern resembles a visual display of the variations in a data stream that a receiver threshold detector would see, relative to a recovered clock. An eye pattern display can be used to evaluate both amplitude and timing variations contained in a data stream. Ideally, the receiver detector's decision point would occur in the center of the eye pattern for the largest amplitude and timing margin. In order to reduce the variability possible between different high-performance measurement systems, many eye pattern measurements are bandwidth-limited. A typical measurement filter specified in several datacom standards is a linear-phase, 4th-order Bessel-Thompson filter at three-fourths the bit rate (797 MHz for FC1063 and 937 MHz for GBE). Optical measurement systems that include standard response filters are referred to as reference receivers. Measurements that can be made from bandwidth-limited eye pattern displays include mask testing, extinction ratio, jitter, and average power. Optical pulse parameter measurements such as rise time can also be made from eye pattern displays, but usually without a filter or possibly with a less-limited bandwidth filter. The Fibre Channel and Gigabit Ethernet standards differ on both recommended test methods and data patterns for use in verifying optical transmit and receive signal characteristics. The latest versions of those standards should be referred to for recommended methods (see ***References List***).

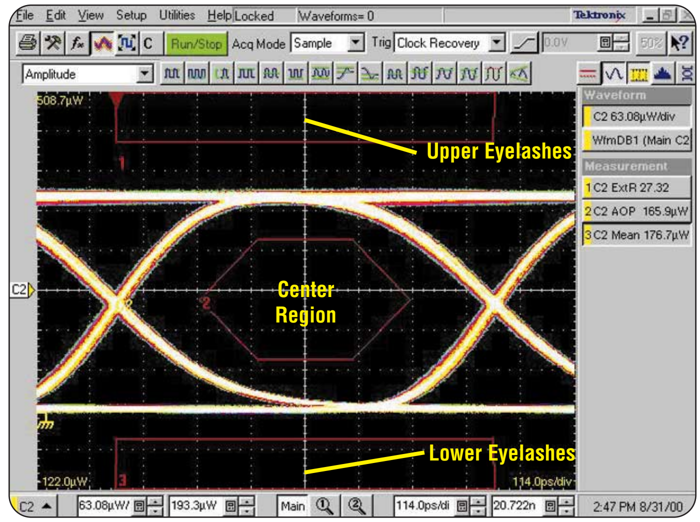

Figure 2. *Eye pattern mask testing.*

Eye pattern mask testing is used to analyze a communication signal for amplitude and timing errors. An eye pattern mask is a template that overlays an eye pattern unit interval. An eye pattern unit interval is defined as the bit-rate period between eye pattern data transition crossing points. The eye pattern mask (Figure 2) defines a keep-out region that, if not violated, has been statistically shown to provide a reliable transmission of signals through a network. An eye pattern mask typically includes three regions. The first is a center region that can be violated by either timing or amplitude variations. Timing violations of this center region are usually the result of excessive timing jitter – either random jitter from a noisy signal, or deterministic jitter from excessive duty cycle distortion or pattern dependent variations. Amplitude violations of this center region are often the result of the closing of the eye due to pulse dispersion effects from transmission over long distances, or increased noise due to signal attenuation. The other two keep-out regions are the upper and lower "eye lashes" that define regions of excessive signal overshoot and undershoot. Amplitude violations of these two regions can lead to saturation of the receiver amplifier, which in turn can lead to detector bit errors.

Extinction ratio measurements are used to measure the modulation control performance of an optical transmitter. A directly modulated laser transmitter, like that used in a GBIC, must not be fully shut off or powered below its lasing threshold when in a logic-zero state. If fully shut off, the laser linearity, frequency response, and wavelength stability are severely degraded. The extinction ratio provides a measure of how well the laser bias control circuit gives the necessary modulation depth without increasing the output power to an unacceptable level. Extinction ratio is defined as the ratio of the optical power used to transmit a logic-one level to the power used to transmit a logic-zero level. Extinction ratio can be measured from an eye pattern display by evaluating the optical power levels at the two logic states as observed near the center of the eye pattern unit interval. Since an extinction ratio measurement involves the division of a larger value by a smaller value, offset errors in the measurement path that are significant relative to the smaller value can lead to very significant extinction-ratio errors.

Jitter measurements are used to characterize the timing variations present in a data stream at the data-transition points, which appear in an eye pattern display at the unit interval crossing points. These undesirable timing variations result from system noise effects as well as non-ideal signal generation and propagation effects.

Total system jitter is usually comprised of both random and deterministic components. ***Random jitter*** results from probabilistic phenomena such as thermal or electrical noise effects and is usually measured from a timing histogram as RMS jitter (see Std Dev measurement in Figure 3).

Deterministic jitter is attributable to systematic causes such as duty-cycle distortion or timing variations due to data pattern content and is usually measured as peak-to-peak jitter (see Pk-Pk measurement in Figure 3). Since jitter testing bit sequences have a large impact on stressing a system's jitter characteristics, datacom standards usually define specific data patterns for testing random and deterministic jitter. The Fibre Channel and Gigabit Ethernet standards specify the use of symmetric, square-wave patterns such as the D21.5 or K28.7 transmission codes in testing for random jitter. The mixed frequency content pattern K28.5 is generally specified for use in testing for deterministic jitter. There are also more complex data frame patterns defined in both the Fibre Channel and Gigabit Ethernet standards that can be used to test for jitter with a simulated data payload having a frequency response profile with broad spectral content and minimal peaking.

Optical power measurements are fundamental to the specification of any data transmission system. The loss of optical power from failure or aging of the transmission source, or due to damage to the fiber cable medium, or from problems with fiber optic connections along the transmission path can all lead

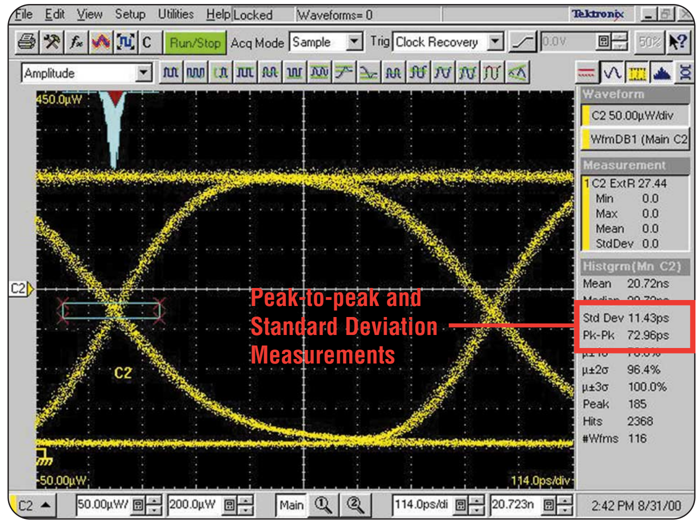

Figure 3. *Eye Timing histogram illustrates jitter measurements.*

to transmission system failure. Although stand-alone optical power meters are often used to make average optical power measurements, optical power measurement capability is now being embedded in some sampling oscilloscopes. In these oscilloscopes, this optical power measurement capability is often not limited to a simple calculation of the mean value of the displayed optical power waveform, but can include independent hardware measurement, derived from monitoring the photodetector bias current. The hardware-based embedded optical power meters generally have improved dynamic range and accuracy compared to calculations made from displayed waveforms. Although the accuracy and dynamic range of the stand-alone optical power meters is superior to that of the embedded power meter in a sampling oscilloscope, the convenience of embedded measurements may make it the method of choice if the specified accuracy is acceptable.

The GTS1063 and GTS1250 GBIC Test Systems

The GTS1063 and GTS1250 provide a simple, yet flexible platform for physical-layer testing of GBICs. The GTS1000 Series GBIC test system front panels (Figure 4) include a slot into which a standard GBIC can be plugged. The GBIC test system provides support features to exercise both the transmit and receive functions of a GBIC transceiver. Moreover, its status and control features should be useful in a GBIC test environment. Although designed specifically for GBIC testing, this test system can also be used as a relatively inexpensive optical signal generator, and as an electrical clock recovery unit.

Both the GTS1063 and GTS1250 contain a low-noise internal pattern generator with push-button selection of standard test patterns to evaluate the transmit performance of a GBIC. The GTS1063 outputs data patterns at the Fibre Channel baud rate of 1062.5 Mb/s and the GTS1250 outputs similar patterns at the Gigabit Ethernet baud rate of 1250 Mb/s. The internal pattern generator not only drives the GBIC test port connector with standard data patterns for optical output, but also provides a set of electrical pattern signals on front-panel SMA connectors. The GBIC test system electrical transmit signals include two complementary DATA pattern outputs, a CLOCK output at the full bit rate, and a SYNC output at the data pattern repetition rate. For added flexibility, the GBIC test system also includes an EXTERNAL DATA input to drive the inserted GBIC with user-selected patterns from an external pattern generator source.

Six standard data patterns can be selected by push buttons on the system's front panel. The D21.5, K28.5, and K28.7 patterns are 8B/10B transmission codes (see sidebar ***8B/10B Transmission Code***) with special bit-pattern characteristics useful for jitter testing. The D21.5 and K28.7 codes are square-wave patterns at one-half and one-tenth the bit rate respectively, which are commonly used for random jitter testing. The K28.5 code (Figure 5) is a pattern with mixed high-frequency and low-frequency components that is usually used for deterministic jitter testing. The PRBS7 pattern is a 127-bit long pseudo-random sequence test pattern. Although not a standard 8B/10B transmission code pattern, the PRBS7 pattern is often used by bit-error rate testers. The LONG and SHORT patterns in the GTS1250 and the CRPAT and CJTPAT patterns in the GTS1063 are complex data patterns referenced in the Gigabit Ethernet and Fibre Channel standards. These complex patterns are fully encapsulated data packets with a data payload that has been designed to produce a broad and flat frequency spectrum. These more complex data patterns are suitable for eye pattern mask testing.

The GBIC test system also provides features that enable the measurement of GBIC receiver performance, such as its complementary unbuffered RX_DATA outputs, suitable for connection to a 50-ohm measurement system. Since the output impedance of the complementary GBIC receiver signals at the GBIC port connector is 75 ohms, the GBIC test system contains an internal 75-to-50 ohm min-loss attenuator to preserve the frequency response of these unbuffered data outputs. The consequence of using this attenuator, however, is a loss of receiver signal amplitude to about 42% of the amplitude output from the GBIC on both of the complementary outputs. The system's optional clock recovery feature provides both a low-jitter RECOV.CLK signal at the system bit rate and a full amplitude, retimed, RECOV.DATA signal. Since the RX_DATA connectors provide attachment to the receiver-side attenuator network, they can also be used, without a GBIC, as inputs to the clock recovery function, thus providing an independent clock recovery feature for electrical data signals. The clock recovery unit's narrow bit-rate capture range provides a low-jitter recovered clock at the specified bit rate.

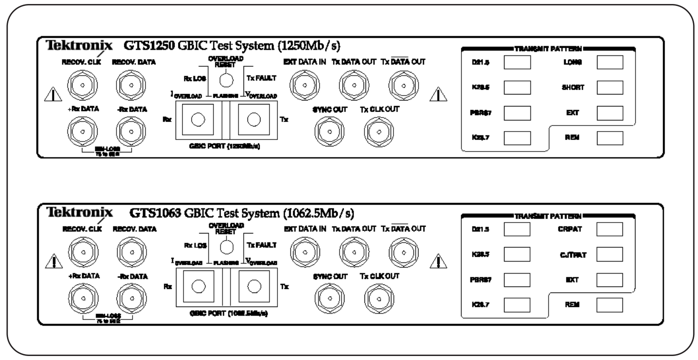

Figure 4. *GTS1000 Series GBIC test system front panels.*

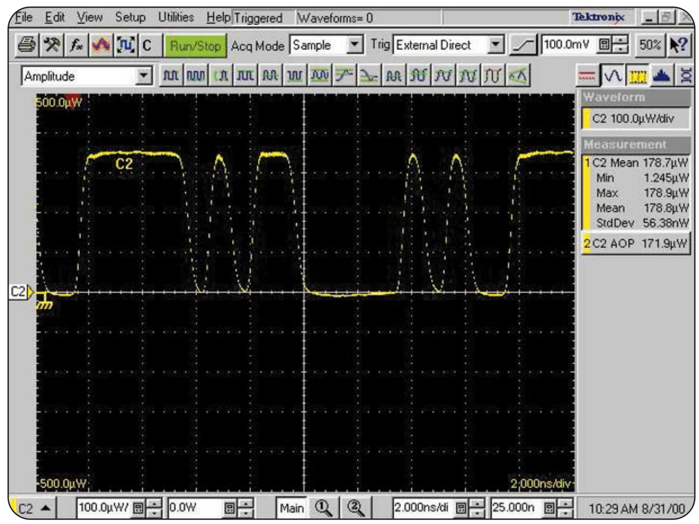

Figure 5. *The K28.5 pattern is an 8B/10B transmission code with special bit-pattern characteristics useful for jitter testing.*

The GBIC test system also includes some status and control features that support GBIC testing. The front panel includes two status LEDs that normally indicate the state of the TX_FLT and RX_LOS signals output by the GBIC. These same LEDs are also used in a flashing mode to indicate an overload condition in the GBIC power supply. A rear-panel connector on the GBIC test system also provides a remote port with TTL control signals for remote data pattern selection, GBIC power monitoring and control signals, access to the MOD_DEF serial communication lines from the GBIC, and a few other miscellaneous signals.

The CSA8000 and 80C03 Measurement System

The CSA8000 communications signal analyzer is a high-speed, precision, digital sampling oscilloscope with built-in measurement features for datacom testing. Built on an open Microsoft Windows® platform, the CSA8000 provides users with a variety of ways to operate their instruments – traditional control panel, touch-sensitive displays, and pull-down menus. The 80C03 is an optical sampling module for the CSA8000 mainframe that provides a fully calibrated optical interface for optical datacom signals. The CSA8000 configured with an 80C03 optical sampler delivers an excellent measurement platform for GBIC testing.

The CSA8000 is the mainframe for a sequential equivalent-time sampling oscilloscope. It contains compartments to install a variety of electrical and optical sampling modules. The sampling modules of the CSA8000 acquire one sample per trigger event. The CSA8000 ***acquisition system*** builds up a waveform record by incrementally skewing the sampling time relative to the repeated trigger events. This equivalent-time sampling process requires both a periodic input signal and a synchronized, low-jitter, trigger signal. It provides, in return, higher effective bandwidth, increased timing precision, increased amplitude precision, and lower noise than is available from real-time sampling oscilloscopes.

The CSA8000 ***trigger system*** accepts an edge trigger, which is selectable from several different sources. Trigger signals at a bit rate less than 3 GHz can be applied to the Trigger Direct connector on the CSA8000 front panel (Trigger signals at higher bit rates, but less than 12 GHz, can also be applied to the Prescale Trigger Input). For optical modules configured with the optional clock recovery feature, an internal clock recovery trigger can be derived from the optical signal input for some standard data rate signals. For stable triggering, the trigger level control must be adjusted to a valid level. For complex trigger signals, the trigger hold-off may need to be adjusted as well. In the case of trigger signals that are load-sensitive, a probe power connector allows the attachment of an SMA-compatible active probe, such as the P6209 TEKPROBE™ SMA active probe, to the Trigger Direct input.

The CSA8000 ***horizontal timing system*** controls the displayed time window relative to the trigger event. The trigger event is considered to be time zero for the displayed waveform and the front-panel horizontal scale, position, and resolution controls adjust the displayed time window. For eye pattern testing, these horizontal controls should generally be adjusted for minimum time delay, since that condition gives the best jitter performance. The timebase mode of operation should also be set to Short Term Jitter mode for normal eye pattern testing. The CSA8000 timebase is extremely stable and provides <1 ps_{RMS} typical timing jitter performance on the External Direct trigger input for short time delays. The CSA8000 timebase can also be locked to a highly stable internal clock, which greatly extends the timebase's useable delay range. In general, for viewing delay times greater than about 500 ns after the trigger, the timebase mode should be set to Lock to Int 10 MHz. Although horizontal jitter continues to increase with increased delay time, the Lock to Int 10 MHz timebase mode provides about 5 ps_{RMS} jitter performance even for a time delay of 100 µs.

The CSA8000 ***vertical signal acquisition system*** provides scaling, offset, and positioning controls for signal input to the sampling modules. The diode samplers used in the CSA8000 electrical sampling modules have a limited dynamic range of 1 $V_{p\text{-}p}$. Signals outside the sampler dynamic range will begin to exhibit non-linear effects such as compression and saturation, leading to distortion of the acquired signal. The offset control can be used to effectively increase the dynamic range of the vertical system by summing the DC offset signal (over its ±1.6 V range) with the input signal to bring the input signal within the sampler's dynamic range. An electrical sampler's dynamic range can also be extended by using an SMA-compatible active probe, such as the P6209 TEKPROBE™ SMA active probe, although generally with reduced bandwidth.

The CSA8000 measurement system includes many features that are very useful in GBIC testing. The processing power of the CSA8000 measurement system allows for the accumulation of waveform data into waveform databases. The availability of waveform databases enables the display of color-graded waveform data, the display of amplitude and timing histograms, the use of waveform database measurements in eye pattern mask testing, and the display of measurement result statistics. The sophisticated internal vertical and horizontal compensation capability of the CSA8000 acquisition system also helps to enhance the accuracy of the CSA8000 measurement system.

The 80C03 sampling module also has many features that simplify the testing of GBIC modules. The 80C03 module contains a flexible optical input, a broadband optical-to-electrical converter, built-in hardware reference receiver filters, a low-noise sampler, and an optional multi-rate clock recovery unit. The optical input connector can be easily modified with removable adapters to support a variety of standard optical connectors. The input connector and broadband O/E converter use 62.5 µm optical fiber, which is compatible with optical signal capture of either multi-mode or single-mode signals. The O/E converter has an effective wavelength range of 700 nm to 1650 nm with internally calibrated wavelengths of 780 nm, 850 nm, 1310 nm, and 1550 nm. Since the conversion gain of the O/E converter photodetector diode varies with wavelength, the use of internally calibrated wavelengths at several standard settings allows the CSA8000 to display optical signals on a calibrated optical power scale. In addition to the internally calibrated wavelengths, a user wavelength gain setting is available to match the internal average optical power to a user-supplied value measured with an external power meter.

The O/E converter in the 80C03 module includes an ***amplified photodetector*** for greater sensitivity and lower noise performance. The use of an amplified photodetector, however, also results in lower signal bandwidth and a smaller dynamic range. The lower bandwidth is not really a disadvantage, since the 80C03 system bandwidth is tuned to match a datacom standard. However, the smaller dynamic range must be taken into account so that amplifier compression and saturation effects do not result in unacceptable signal distortion for large signals. The 80C03 module is specified to exhibit very linear performance, including operation within reference receiver frequency response curves, for signal levels less than 200 μW_{p-p} at any wavelength. Since most datacom signals are designed for DC-balanced, 50% duty cycle operation, the resulting average optical power limit for specified reference receiver performance is 100 µW, assuming a high extinction ratio signal. This optical power limit for specified reference receiver performance requires that a calibrated optical attenuator be used to reduce the GBIC transmitter optical power level to a value within this limit. However, the 80C03 module exhibits acceptable linearity performance for most applications, even with signals larger than that specified for reference receiver performance. For example, the 80C03 module can typically display signals with good linearity up to a limit of 1 mW_{p-p} for 850 nm signals and to a limit of 500 μW_{p-p} for 1310 nm signals. The difference in this linearity limit for long and short wavelength optical signals results from increasing conversion gain with wavelength.

The 80C03 module has built-in ***reference receiver performance*** to support the 1.0625 Gbaud Fibre Channel, the 1.25 Gbaud Gigabit Ethernet, and the 2.488 Gbaud SONET OC-48 communication standards. Its clock recovery option includes bit-rate, complementary clock outputs and retimed complementary data outputs to support these same communication standards. In addition, the 80C03 module includes an embedded average optical power meter, which monitors the current flow through the O/E converter photodiode's reverse-biased power supply. This embedded optical power meter provides a much wider dynamic range (typically +4 dBm to –30 dBm) and greater accuracy than the mean power value calculated from displayed optical power waveforms. The 80C03 module also includes an automated compensation capability, which should be exercised regularly for best performance. The compensation features include both general module Compensation (accessible from the Utilities menu) as well as Dark Level Cal (accessible from the Vertical-Optical settings menu). Dark Level Cal should always be performed before making extinction ratio measurements due to the sensitivity of that measurement to small optical power offsets.

The CSA8000 measurement system provides support for mask testing of 80C03 sampled optical signals. In addition to the display of standard datacom masks, its autoset feature can be used to automatically scale an eye pattern display onto the mask template. The CSA8000 measurement system can also monitor the eye pattern acquisition for mask violations, can accumulate data on violation activity, and if desired, can stop the acquisition on a mask violation. Because many eye pattern measurements, like random jitter, are statistical in nature, they are affected by measurement time. Since the CSA8000 acquisition system can be set to stop on various conditions, measurements like timing jitter can be made more repeatable by setting an acquisition stop condition – for example, 100 to 1000 mask waveforms. Mask testing on this measurement system is also made more flexible by the addition of mask margin controls.

Common GBIC Failure Mode Testing

Optoelectronic test equipment is essential to the testing of new GBIC modules in a production environment. Because of the high bandwidth of the GBIC module signals, similar equipment is also required in a service environment to identify the cause of GBIC failures. The remainder of this note will focus on the most common GBIC failure modes and test methods for identifying these failures. The most common GBIC failure modes include the following:

- Low Optical Launch Power (Figure 7)
  (A typical requirement is > –9.5 dBm, avg. optical power)
- No AC Modulation (Figure 8)
- No DC TX Output (Figure 9)
- Low Extinction Ratio (Figure 10)
  (A typical requirement is >9 dB)
- Excessive Jitter (Figure 11)
- RX Detection Failure (Figure 12)

The procedure that follows uses the equipment listed below to test a GBIC for the failure modes listed above.

Equipment List:

- GTS1250 or GTS1063 GBIC Test System
- A GBIC–LW (1310 nm) or SW (850 nm)
- CSA8000 Communications Signal Analyzer
- 80C03 Optical Sampling Module
- 80E02 Dual Channel Electrical Sampling Module
- FC/SC and SC/SC optical cables (single-mode for LW GBICs and multimode for SW GBICs)
- Coaxial cables with SMA connectors

Test Procedure:

1. **Initial Equipment Setup.** With the CSA8000 oscilloscope unpowered, install the 80C03 optical sampling module in the wide slot for CH1. Install the 80E02 electrical sampling module in the narrow slot for CH3/4. Apply power to both the CSA8000 oscilloscope and the GTS1000 GBIC tester and allow a 20-minute warm-up time. Install a GBIC in the GTS1000 tester. (Note: GBICs can be hot-plugged.)
2. **Compensation.** After warm-up, check the compensation status of the CSA8000 and its sampling modules with the Utilities —> Compensation Window. If necessary, execute the compensation process on the CSA8000 mainframe and save the resulting CAL constants. (Note: This may take several minutes to complete.) Execute the compensation process on the 80C03 optical sampling module and save the CAL constants.
3. **Signal Connection.** Connect the GTS1000 tester Tx Clk Out signal to the CSA8000 Trigger Direct input with an SMA cable (see Figure 6). Connect the GBIC optical transmit output to the 80C03 optical input with the appropriate mode of FC/SC optical cable to match the type of GBIC used.
4. **Pattern Selection.** Set the GTS1000 tester's transmit pattern selection to PRBS7. (Note: Other GTS1000 tester patterns could be selected instead for an eye pattern display.)
5. **Configure Trigger.** Set the CSA8000 Trigger Source to External Direct. (Note: If the 80C03 module has the optional Clock Recovery feature, the Trigger Source may be set instead to Internal Clock Recovery and the SMA cable to the Trigger Direct input should be removed.) The Trigger Level should be set to 0.0 V and the

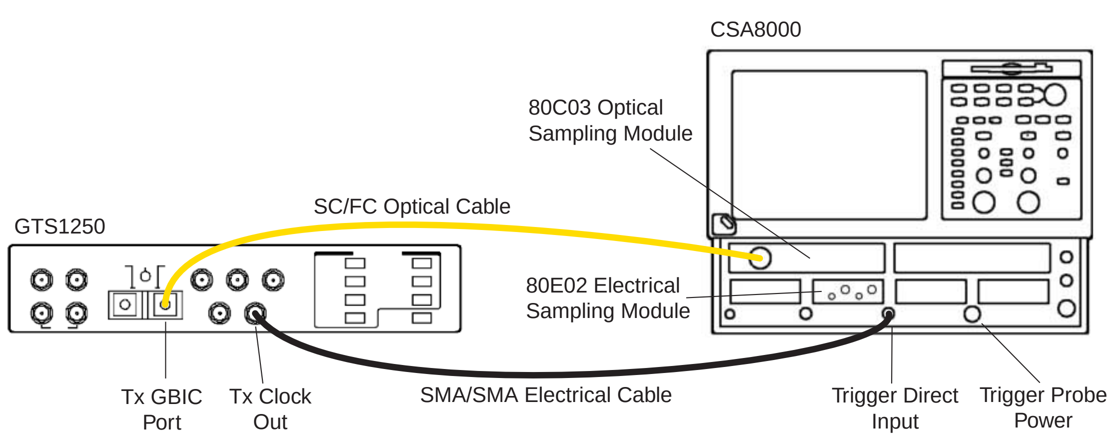

Figure 6. *Signal connections for common GBIC failure mode testing.*

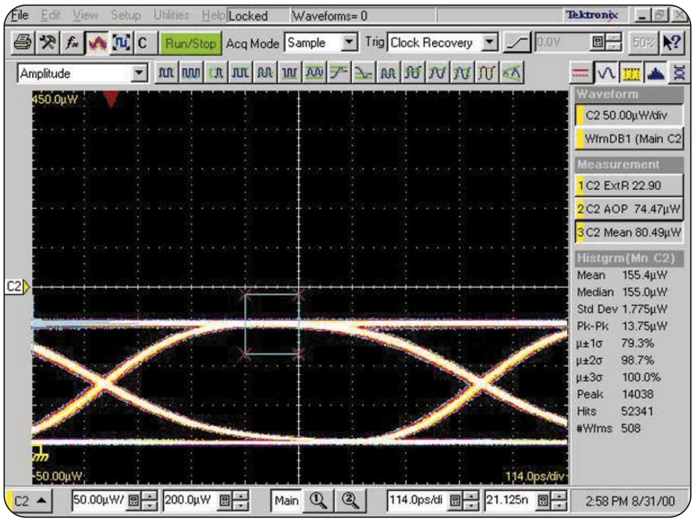

Figure 7. *Faulty GBIC with low launched optical power of 74.5 µW (–11.3 dBm).*

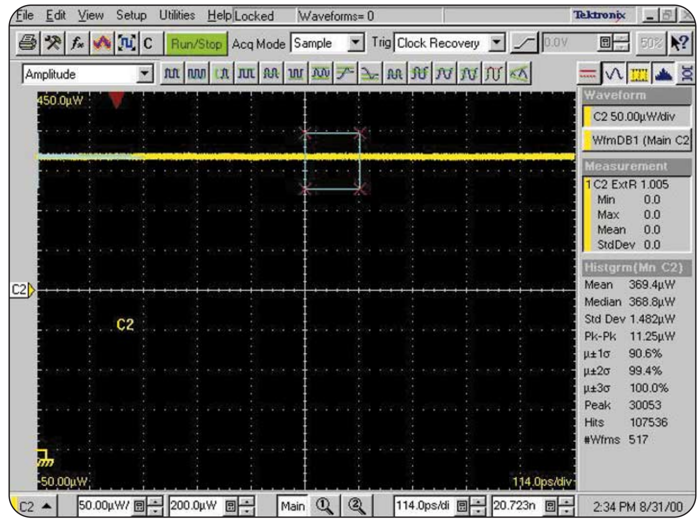

Figure 8. *Faulty GBIC with no AC modulation.*

Trigger Mode should be set to Normal. Since the GTS1000 tester CLK OUT signal is an AC-coupled, 50% duty cycle signal, the Trigger Level setting of 0.0 V places the trigger threshold at the center of the CLK OUT signal swing of about ±200 mV. If the GTS1000 tester SYNC signal were used as the trigger signal, the CSA8000 Trigger Level would have to be changed to +100 mV or so, because the low duty cycle of the SYNC signal shifts the signal swing in a positive direction. The SYNC signal can be used as the trigger signal for the CSA8000 if the bit-pattern sequence in the TX DATA OUT signal is to be examined rather than an eye pattern display.

6. **Configure Vertical.** From the CSA8000 Vertical Settings Window, select CH1 in order to display the 80C03 optical signal. Set the Wavelength setting to 850 nm for a SW GBIC or 1310 nm for a LW GBIC (or possibly 1550 nm for an extended range LW GBIC). If a calibrated optical attenuator is used to reduce the power from the GBIC source, it is possible to compensate for this change by adjusting the Vertical Menu Ext Atten setting to the known attenuation factor. It is also possible to compensate for optical attenuation by measuring the Average Optical Power with an external optical power meter and entering the measured power value with the User Wavelength Gain compensation procedure. Set the Vertical Signal Conditioning Filter setting to the GBE setting for a GTS1250 GBIC tester or to the FC1063 setting for the GTS1063 GBIC tester. The Dark Level Compensation process may be executed at this time if the displayed offset from ground appears to be excessive with no light signal applied to the 80C03 input.
7. **Configure Horizontal and Display.** From the CSA8000 Horizontal Settings Window, set the Timebase Mode to the Short Term Jitter setting. From the Acquisition Settings Window, set the Mode to Sampling and the Stop After control to the Run/Stop Button setting. From the Display Settings Window, set the Style to Normal or possibly Variable Persistence. The waveform display can also be set to Color Grading by clicking the right mouse button on the channel icon or the waveform itself and selecting the Color Grading display mode.
8. **Configure Eye Pattern Mask.** From the CSA8000 Mask Settings Window, select the Source as CH1 and the COMM Std to the GBE setting for a GTS1250 GBIC tester or to the FC1063 setting for a GTS1063 GBIC tester. Press the AUTOSET button to autoscale the vertical and horizontal scale settings for the displayed eye pattern.
9. **Configure Measurements.** From the CSA8000 Measurement Settings Window, select Measurement 1 from the Eye Pattern/Optical Menu and choose Average Optical Power. Select CH1 as the Source for the measurement and turn the measurement ON. In a similar manner, select additional measurements from the Amplitude Menu to display the Min and Max waveform amplitudes.
10. **Check Average Optical Power.** At this point in the procedure, an eye pattern display similar to that in Figure 2 should be displayed on the CSA8000 screen for a properly functioning GBIC. Due to the autoscaling process, however, more than just the correct eye pattern shape is required to qualify a good GBIC. The Average Optical Power measurement must also be checked to see if it falls within the valid range for launched optical power specified for the GBIC.
11. **Launched Optical Power Testing.** Several of the common GBIC failure modes can be identified from an eye pattern display and the Average Optical Power measurement. For example, Figure 2 shows the eye pattern display for a properly functioning GBIC with Average Optical Power of 165.9 µW (–7.8 dBm). Figure 7 shows an eye pattern which, if autoscaled to an eye pattern mask, would appear to have a proper waveshape, but is really an example of a faulty GBIC, with low launched optical power of 74.5 µW (–11.3 dBm). Low optical launched power may be symptomatic of a GBIC laser beginning to burn out or a possible failure in the laser bias control circuitry. Figure 8 shows an example of a faulty GBIC with no AC modulation. In this case the GBIC laser is biased on correctly, but the mod-

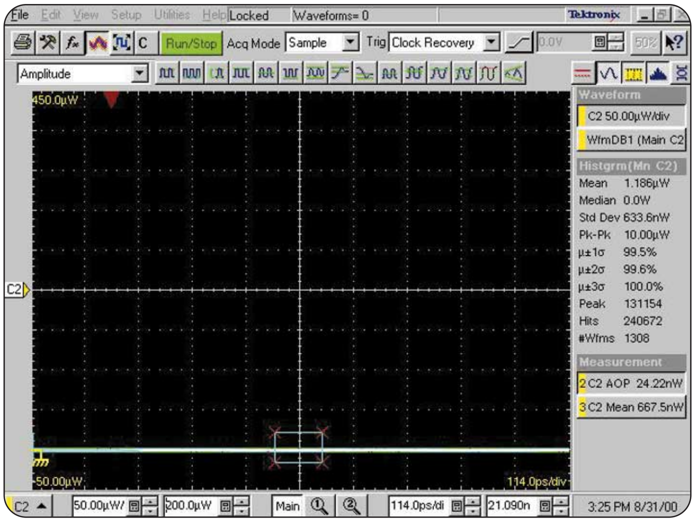

Figure 9. *Faulty GBIC with no transmitted optical power.*

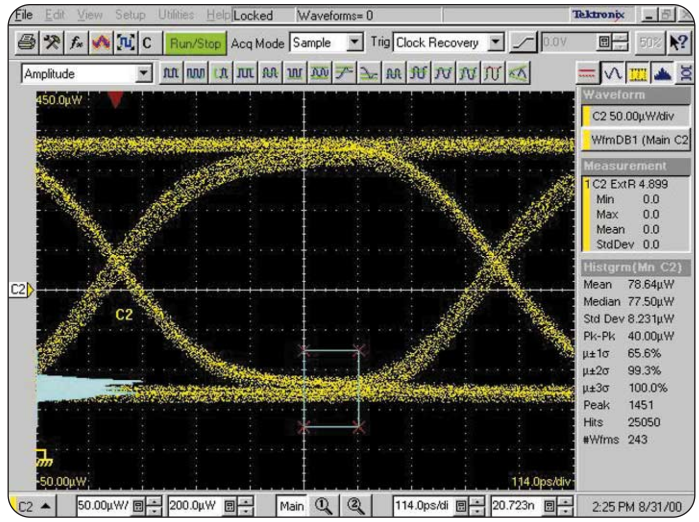

Figure 10. *Faulty GBIC due to a low extinction ratio of 4.9.*

ulation control circuit has apparently failed. Figure 9 shows an example of a faulty GBIC with no transmitted optical power. This probably indicates that a laser has completely burned out. The GBIC current monitor output pin on the rear panel connector of the GTS1000 GBIC tester can also give some indication of whether the laser is active or not. The GBIC status indicator LED, TX_FLT, on the front panel of the GTS1000 GBIC tester also will indicate if the GBIC bias control monitor has entered a fault state.

12. **Extinction Ratio Testing.** From the CSA8000 Measurement Settings Window, add the extinction ratio measurement from the Eye Pattern/Optical menu. Before making extinction ratio measurements with the CSA8000 oscilloscope, a Dark Level compensation should be executed on the 80C03 module from the Vertical Settings Window. A low extinction ratio would likely indicate a problem with the GBIC laser bias control circuitry (see Figure 10).
13. **Jitter Testing.** From the CSA8000 Histogram Settings Window, select and enable a horizontal histogram. The histogram display should also be enabled and the resulting histogram limits box should be adjusted to surround the eye pattern crossing region (see Figure 3). The horizontal histogram measurement display shows the results of statistical measurements made on the histogram database. High jitter is indicative of either a noisy source or a serious distortion of the transmitted signal due to a non-linear response or coupling problems (see Figure 11).

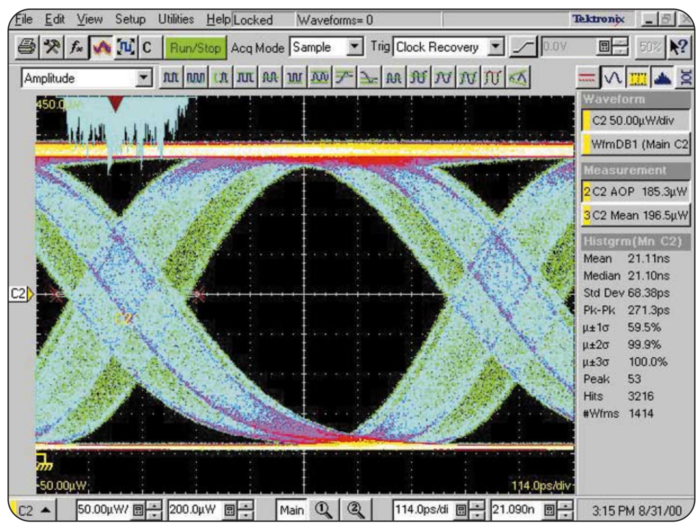

Figure 11. *Faulty GBIC due to excessively high jitter.*

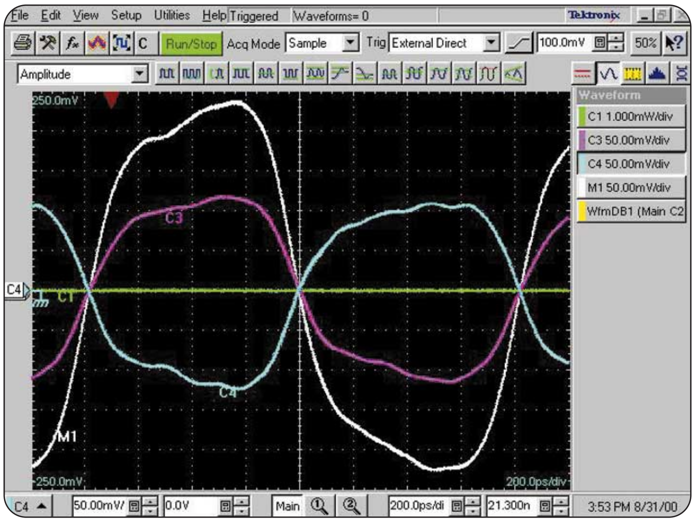

***Figure 12.** Valid RX_DATA+ and RX_DATA– signals displayed on the two electrical channels of an 80E02 sampling module.*

14. **GBIC Receiver Testing.** Detection of GBIC receiver problems may require the display of electrical rather than optical signals on the CSA8000. The GTS1000 Series tester uses the O/E converter built into the GBIC to output an electrical signal representing the received GBIC optical signal. The GTS1000 Series tester also displays the GBIC's RX_LOS signal on its front panel, which goes active when the threshold monitor in the GBIC receiver measures too small a level for valid signal detection. An example of a faulty GBIC with receiver problems is one that indicates a loss of signal by activating the RX_LOS status signal, but which has a valid received signal available. The inverse situation is also possible, where no receiver signal is output, but the RX_LOS signal is held inactive. The amplitude of each of the two complementary signals shown in Figure 12 is 42% of a normal ECL signal swing due to the attenuation of the min-loss pad in the GTS1000 Series tester. The M1 waveform displayed in Figure 12 also shows the voltage difference between channels 3 and 4, which is what a differential receiver would detect.

CSA8000/80C03: An Ideal Platform for Optical Datacom Testing

The Tektronix CSA8000 sampling oscilloscope, when used with an 80C03 optical sampling module, provides an excellent measurement tool to test gigabit optical data signals. The following list of CSA8000/80C03 features shows the ease of use and accuracy available to a design or test engineer involved with gigabit networking:

- Familiar Microsoft Windows user interface
- Automatic communication measurements
- Automatic mask testing capability
- Calibrated optical power display
- Low jitter (excellent signal fidelity)
- Integrated reference receiver performance
- Statistical waveform database
- Embedded power meter
- Optional clock recovery with multiple rates
- Sophisticated compensation controls

The enhanced feature set of the CSA8000/80C03 can be used to improve measurement processes and provide a more integrated, consistent tool to enhance measurement effectiveness for the datacom engineer.

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3. ***SFF Committee Proposed Specification for GBIC (Gigabit Interface Converter)***, SFF-8053, Rev 5.4, Aug 16, 1999

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4. ***Fibre Channel-Methodologies for Jitter Specification (FC-MJS)***, Jitter Working Group Technical Report, T11.2/Project 1230/Revision 10, June 9, 1999.
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8B/10B Transmission Code

Digital fiber-optic serial links operating at gigabit data rates generally use binary NRZ coding. Although this coding scheme is simple and provides a high signal-to-noise ratio margin, it does place some constraints on the data stream pattern for reliable operation. The data stream must have a high transition density to ensure that clock recovery is possible at the receiver circuit. In addition, the high-gain receiver circuit requires an AC-coupling stage at its input, which requires a DC-balanced data stream to reduce problems due to baseline wander. The 8B/10B transmission code used in the Fibre Channel and Gigabit Ethernet standards can be applied to a byte-oriented data stream to provide an encoded serial data stream with high transition density and virtually no DC spectral component.

The cost for improved transmission characteristics of a serial data stream with 8B/10B encoding is a 25% bit-rate increase, caused by the extra two bits transmitted for every data byte encoded. These extra two bits also allow for the creation of special character codes that are used to identify data-frame delimiters, signal a transmission idle state, or provide other special control information. Some of these special character codes also contain a unique 7-bit sequence called a "comma," which is used to establish byte synchronization. An 8B/10B encoded data stream is also run-length limited, with a maximum run length of 5. The run length refers to the number of identical, contiguous 1s or 0s in the encoded data stream and must be small for high-transition density. A run-length limited code also reduces data pattern-dependent jitter caused by variable data path propagation delay as a function of past data stream history.

The 8B/10B transmission code used by Fibre Channel and Gigabit Ethernet is implemented by partitioning each byte into two sub-blocks, effectively combining a 5B/6B and 3B/4B transmission code. This implementation is exemplified in the standard notation convention: Dx.y for encoded data code-groups and Kx.y for encoded special code-groups, where x is in the range 0...31 and y is in the range 0...7. Although all the possible data code-groups are considered valid, only a limited number of special code-groups are supported by this transmission code. The table below shows the mapping between the 8B unencoded bit patterns and the 10B encoded bit patterns for several code-group values. The unencoded input byte is broken into two sub-blocks, 'H'..'F' and 'E'..'A', where 'H' is the most significant bit and 'A' is the least significant bit. The encoded bit pattern is described by the two encoded sub-blocks, 'a'..'i' and 'f'..'j', where 'a' is the first bit transmitted from the serializer.

Running disparity, which monitors the difference between the number of 1s and 0s in each sub-block, is an important consideration in the 8B/10B transmission code. Running disparity is positive if a sub-block contains more 1s than 0s; running disparity is negative if a sub-block contains more 0s than 1s. Otherwise, running disparity at the end of a sub-block is the same as at the beginning of the sub-block. Depending on the current running disparity, the encoded bit pattern will equate to one of two possible different values. (See table.)

Partial Listing of 8B/10B Transmission Code-group Values

Code Group	Octet Value	Octet Bits HGF	EDCBA	Current RD– abcdei	fghj	Current RD+ abcdei	fghj
D0.0	00	000	00000	100111	0100	011000	1011
D1.0	01	000	00001	011101	0100	100010	1011
...	...	...		...		...	
D31.0	1F	000	11111	101011	0100	010100	1011
D0.1	20	001	00000	100111	1001	011000	1001
D1.1	21	001	00001	011101	1001	100010	1001
...	...	...		...		...	
D21.5	B5	101	10101	101010	1010	101010	1010
...	...	...		...		...	
D28.5	BC	101	11100	001110	1010	001110	1010
...	...	...		...		...	
K28.5	BC	101	11100	001111	1010	110000	0101
K28.7	FC	111	11100	001111	1000	110000	0111

Advanced GTS1250/GTS1063 Features

The GTS1000 Series GBIC test system was primarily designed to support a single, specific datacom standard at a fixed bit rate.

Not all the GTS1000 Series tester features, however, are limited to operating solely over a narrow frequency range. The GBICs themselves will generally operate at a reduced bit rate down to several octaves of range below the specified maximum bit rate. The GBIC operating frequency range is limited primarily by the electrical modulation path coupling capacitors. By driving the GBIC from the External Data input rather than the internal pattern generator, the GTS1000 Series testers can transmit optical signals over a broad frequency range both above and below the specified baud rate. Although not specified to operate beyond 1.4 Gbaud, the External Data input has been shown to be functional, up to the full bit rate of a 2.5 Gbaud GBIC. Similarly, the GTS1000 Series receiver RX_DATA outputs have been shown to be functional up to the full bit rate of a 2.5 Gbaud GBIC. Since the GBIC transmit and receive signal paths controlled by the GTS1000 Series testers appear functional well beyond the specified baud rate, it is possible that these testers may find some use in supporting the next generation Fibre Channel transceivers at 2.125 Gbaud.

Another advanced feature of the GTS1000 Series GBIC testers is error injection. The jitter control input on the rear panel of the GTS1000 Series testers effectively controls the duty cycle of the internal pattern generator data stream and has a frequency response range from DC to >10 MHz. Since jitter injected by modulating this jitter control input is really duty cycle distortion, it will likely have limited use in testing jitter transfer. Although it appears as jitter on an oscilloscope display, it will not generally stress a clock recovery circuit because the cycle-to-cycle period is relatively constant. However, it is possible to inject frequency-modulated jitter into the internal pattern generator by driving the External Clock signal input with an external signal generator. When the External Clock input is enabled, the External Clock replaces the internal clock as the timing source for the pattern generator. If the external signal generator has modulation-control capability, modulation applied to the External Clock input should be transferred to the pattern generator output.

It is also possible to use the GTS1000 Series testers to inject error signals into an optical network. A GTS1000 Series tester can be inserted into an optical network by first opening the optical network link and connecting the optical network signal to the GBIC receiver port. The resulting network signal on the GTS1000 Series tester's buffered or retimed RECOV.DATA output is then routed to the GTS1000 Series tester's External Data input. With the GTS1000 Series tester in External Data transmit mode, the signal received from the optical network is then retransmitted by the GBIC optical transmit port, which effectively reconnects the optical network link with the GTS1000 Series tester inserted into the optical signal path.

The unbuffered receiver data port on the GTS1000 Series tester makes it possible to insert the tester into an optical network path while still making the RX_DATA connectors available to monitor activity on the optical network. Because the RX_DATA connections are part of a min-loss attenuator network, errors can be injected into the optical network by applying an electrical error signal to the RX_DATA connectors. The amplitude of the injected error signal and its timing relative to the signal received from the optical network must be carefully specified. The injected error signal is effectively summed with the signal received from the GBIC receiver port as shown schematically in the GTS1000 Series Instruction Manual. The injected error signal should be capacitively coupled into the min-loss attenuator so as not to disturb the DC bias of the digital comparator that follows. By appropriately scaling the amplitude of the injected error signal, the optical network data stream received can be modified. An example of control of the data stream content and timing is the use of a repetitive test pattern generator with a pattern sync signal output. By using the pattern sync to trigger a pulse generator with controlled time delay and pulse width, errors can be injected into the test pattern at controlled times.

CSA8000 Communications Signal Analyzer

Specifically designed for high-performance communications applications, the CSA8000 Communications Signal Analyzer is the ideal tool for design evaluation and manufacturing test of datacom and telecom components, transceiver subassemblies, and transmissions systems.

Optical Sampling Modules

The 8000 Series sampling oscilloscope, configured with one or more optical sampling modules, provides complete optical test solutions for telecom (622 Mb/s to 9.953 Gb/s) or datacom (Fibre Channel and Gigabit Ethernet) applications, as well as general-purpose optical component testing. The CSA8000 sampling oscilloscope, when used with an 80C03 optical sampling module, delivers an excellent measurement platform for GBIC testing.

Electrical Sampling Modules

The 8000 Series sampling oscilloscope, configured with one or more electrical sampling modules, provides complete electrical test solutions from 12.5 GHz to 50 GHz bandwidth, including a module for time-domain reflectometry (TDR) characterization.

GTS1063 and GTS1250 GBIC Test Systems

The GTS1063 and GTS1250 test systems provide a simple, yet flexible platform for physical-layer testing of GBICs. Front-panel controls, low-noise internal pattern generators, and features that enable the measurement of GBIC receiver performance make these test systems ideal for GBIC testing.

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