High-Speed Digital Testing of XFP MSA Modules

by Charlie Schaffer, SyntheSys Research, Inc.

The XFP/XFI Transceiver MSA (multi-source agreement) has developed significant momentum in the telecommunications and datacommunications industry. Many transceiver manufacturers, including Bookham, JDSU, Agilent Technologies, Finisar, MergeOptics, Intel, Infineon, Opnext, Picolight, and Sumitomo Electric, have announced XFP modules and a number of communications IC vendors having announced devices in support of the standard. Perhaps most important, at least one key equipment manufacturer, Cisco, has committing to the new interface. Unlike the other 10 Gb MSAs, the XFP transceivers feature a 10 Gb/s differential I/O interface—XFI "ziffy"— instead of a 16-channel SERDES found in the 300-pin MSA and 4-channel Xaui in Xenpacks, Xpaks, and X2. Though the other MSAs will doubtless continue to be used for some time, many in the industry expect XFP to become the dominant 10 Gb optical interface for applications other than DWDM and long haul transport.

XFP transceivers offer a compelling value proposition. First, they are designed to be multi-protocol, so they are able to support both established telecommunications standards (SDH – STM 64, SONET – OC-192), and emerging applications—10 Gb Ethernet (10 GbE), and 10 Gb Fibre Channel (10 G FC). Second, in part by moving the SERDES needed for muxing and de-muxing signals out of the module, XFP transceivers are extremely compact. This offers network equipment manufacturers the ability to greatly boost the capacity of both existing equipment and new designs with up to sixteen 10 Gb channels per linecard. XFP modules are hot-pluggable, which allows customers to provision network equipment with just the capacity they need today, and add more 10 Gb channels as needed to meet increased bandwidth demand. Finally, XFP modules offer the most economical 10 Gb/s optical interface with prices in quantity quoted as low as $500 each.

Multiple protocol capable XFP modules can achieve higher manufacturing volumes through their ability to interface with SONET/SDH telecommunications equipment, Ethernet in the enterprise and MAN networks, and Fibre Channel Storage Area Networks (SANs). In order to address multiple markets, XFP manufacturers have to be prepared to perform optical compliance tests to each of the related standards—either on each module or by supplying different model numbers for different applications. High-speed digital SONET/SDH optical compliance tests include transmitter mask and extinction ratio as well as receiver BER sensitivity testing and jitter tolerance tests. 10 GbE and 10 Gb FC require transmitter mask test, vertical eye closure penalty and optical modulation amplitude measurements, stressed receiver sensitivity test and transmitter dispersion penalty test.

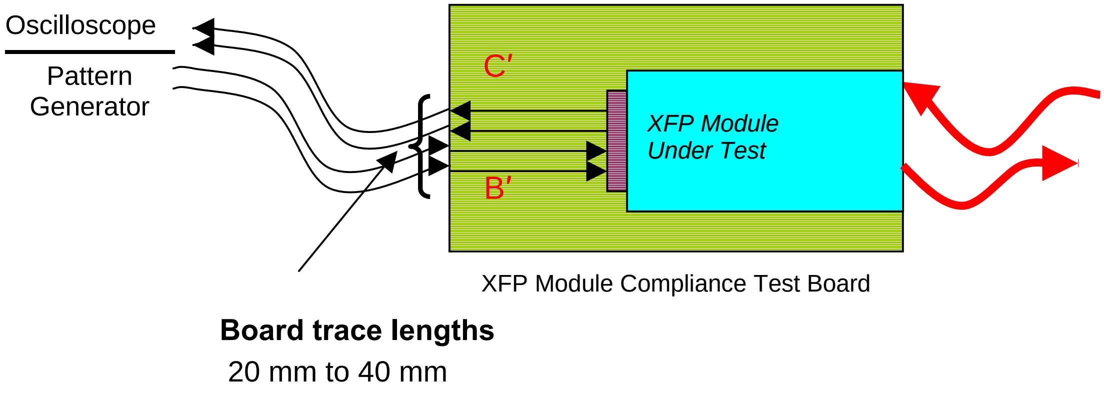


Figure 1: XFP module and compliance test board block diagram with test points B' and C' for the XFI serial 10 Gb/s 100 ohm differential I/O. The applicable digital high-speed measurements are: at B', Input Stress Sensitivity and Jitter Tolerance; at C', Eye Mask and Jitter Output.

The XFI 10 Gb/s 100 ohm differential I/O used by XFP modules and compatible board interfaces posse significant signal integrity challenges and create new measurement requirements. The XFP MSA carefully specifies a board with short traces for module compliance testing (refer to Figure 1). Test point B′ is called the host system output. This is the XFI differential input to the optical transmitter of the XFP module under test. The XFP standard calls for verifying that the module’s electrical receiver operates with a maximum BER of 10 E-12 when tested with the specified stressed eye in combination with a jitter tolerance test. Test point C′ is the XFP module output. The output is an XFI differential signal from the module’s optical receiver. The high-speed digital tests called for at C′ are eye mask (see Figure 3) and jitter output (see Figure 4). All tests require that both output and input signal paths be active during measurements at B′ and C′ and that measurements be made differentially. Coax measurement interconnect cables must be carefully managed to keep channel-to-channel skew below 5 ps. It is also important that all lines be correctly terminated. All eye diagram measurements are made using clock recovery with a corner frequency of 4 MHz to trigger the oscilloscope.

High-speed digital measurements at B′

The stressed eye is defined as an eye diagram that complies with the specified eye template (figure 2). The stressed eye calls for .61 UI of total jitter (TJ) and .41 UI of non-data dependent jitter. The specified stressed eye jitter is a combination of jitter present on the compliant data signal, intentionally added ISI, and sinusoidal jitter added per the specified telecom or datacom template. Total jitter (TJ) includes duty cycle distortion (DCD), intersymbol interference (ISI), random jitter (RJ), and periodic jitter (PJ) (includes intentionally added sinusoidal jitter). Total non-data dependent jitter (DDJ), in the XFP MSA, is defined as the TJ minus the ISI. This definition is used to represent the portion of jitter that will not be affected by the equalization filter that is called for in the eye diagram stressed mask measurements. This equalization filter for the eye diagram measurements is intended to approximate the inverse response of the XFI channel.

The jitter present in the stressed eye signal is carefully defined in terms of total jitter, data dependent jitter, and bounded uncorrelated jitter (this is the sinusoidal jitter which is added). ISI and sinusoidal jitter are added to reach the required .61 UI of total jitter in the stressed eye. The XFP refers to the 10 Gb Ethernet standard, 802.3ae, for setting up the required stressed eye test. The specified datacom and telecom jitter test templates call for a minimum applied sinusoidal jitter of 0.05 UI from 4 MHz to 80 MHz (at least 4.8 ps for 10.3125 Gb/s; 5 ps for 9.953 Gb/s) (p-p).

Once the stressed eye is constructed, BER performance to a (maximum) failure ratio of 10 E-12 is verified while stepping the sinusoidal jitter across the levels specified by the datacom or telecom jitter template. Maximum applied sinusoidal jitter, at the lowest template frequencies (below 130 kHz for datacom, below 2 kHz for telecom) is 1.5 UI (p-p) for datacom applications and 15.2 UI (p-p) for telecom. This obviously means the stressed eye has even larger amounts of jitter at the lower frequencies, but the clock recovery in the XFP should track out this jitter, which is the point of the jitter tolerance test.

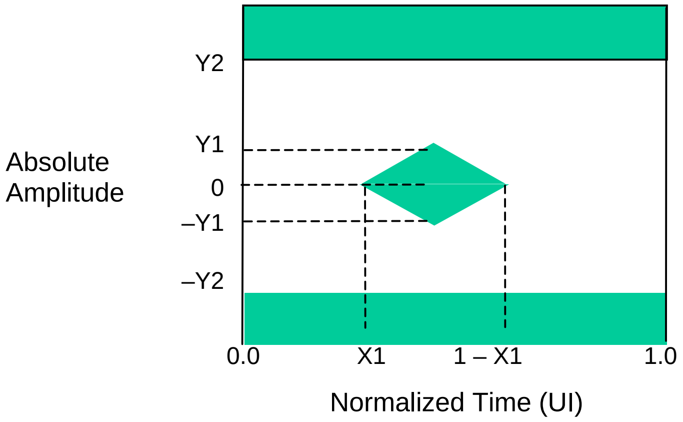
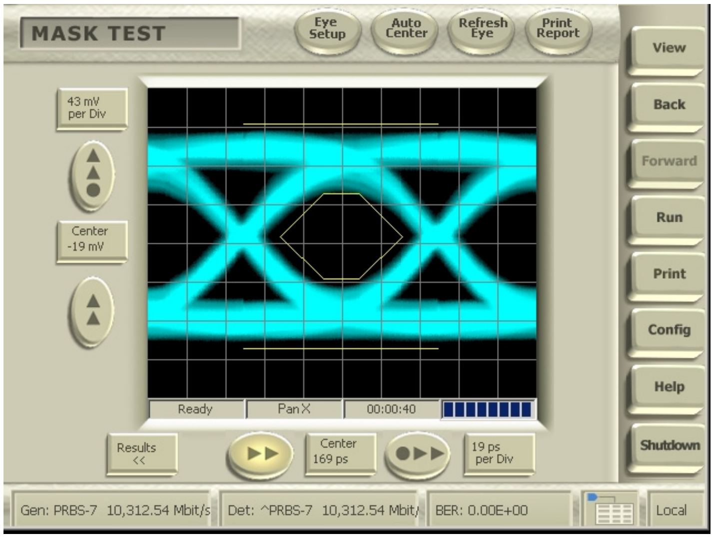


Figure 2: Stressed Eye Input Mask at test point B'. X1 is .305 UI for total jitter condition and .205 UI if total non-DDJ jitter is measured.



43 mV per Div

Center -19 mV

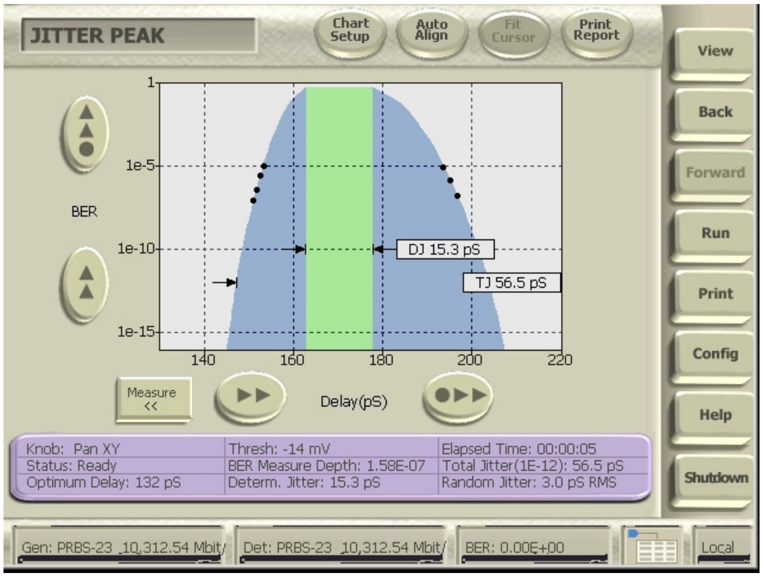
Ready | Pan X | 00:00:40

Center 169 ps

19 ps per Div

Gen: PRBS-7 10,312.54 Mbit/s | Det: ^PRBS-7 10,312.54 Mbit/ | BER: 0.00E+00 | Local

Figure 3: XFP differential XFI output mask test at C′ measured on SyntheSys Research BERTScope.



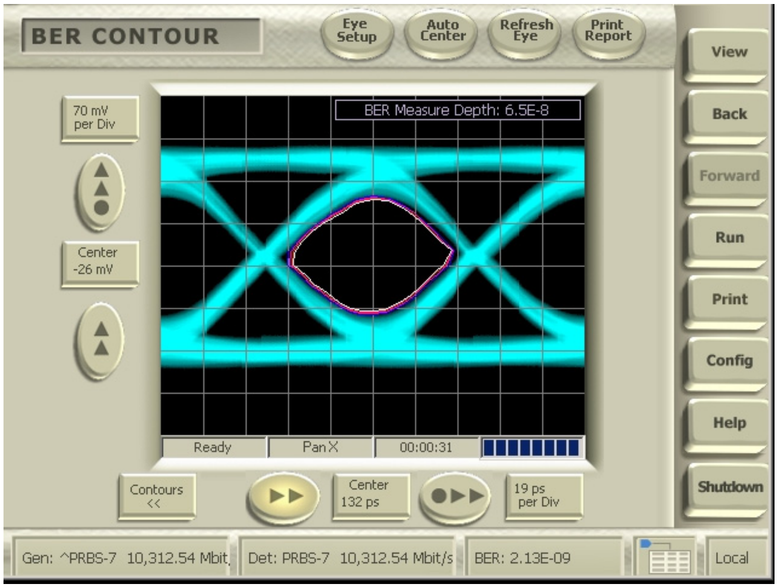
Knob: Pan XY
Status: Ready
Optimum Delay: 132 pS
Thresh: -14 mV
BER Measure Depth: 1.58E-07
Determ. Jitter: 15.3 pS
Elapsed Time: 00:00:05
Total Jitter(1E-12): 56.5 pS
Random Jitter: 3.0 pS RMS

Gen: PRBS-23 10,312.54 Mbit/ | Det: PRBS-23 10,312.54 Mbit/ | BER: 0.00E+00 | Local

Figure 4: BERTScope Jitter Peak Measurement, at test point C′, of TJ and DJ at 10.3125 Gb/s. XFP/XFI differential output jitter is specified to have a maximum DJ of 0.18 UI or 17.45 ps; and a maximum TJ of 0.34 UI or 32.97 ps. This unit is failing TJ due to poor termination on one side of the differential output.

High-speed digital measurements at C′

Mask testing is a straightforward test to perform on high-bandwidth oscilloscopes or the new SyntheSys Research BERTScope (Figure 3). The XFI output mask template is specified so that an output with the maximum allowed total jitter would pass the mask test at the eye crossing. However, the mask test is also called upon to assure that a BER failure rate of 10 E -12 will not be exceeded using margins or extrapolations, etc. Given the extremely low sample rates of high bandwidth oscilloscopes, the practicality of assuring a BER of 10 E -12 is problematical. One alternative measurements is to perform a jitter peak measurement (Figure 4), which extrapolates BER performance based on samples taken at the full 10 Gb/s data rate which is thousands of times more samples per second than high bandwidth oscilloscopes. Jitter peak (also known as jitter bathtub) measurements also can verify that DJ meets the required specification of .18 UI maximum. The measurement in Figure 4 required 5 seconds. A second alternative measurement to the standard mask template test is to use BER contour measurements (Figure 5). Again, the measurement is executed with sampling rates far higher than a high bandwidth oscilloscope. This greatly reduces the risk that an undetected BER floor, which an oscilloscope will never see, will allow units to pass but fail to provide BER performance of at least 10 E-12. Both accurate jitter peak (jitter bathtub) and BER contour measurements depend on extremely accurate delay adjustments. Accurate, high-resolution, monotonic, delay adjustments were not available with earlier generation 12 GBERTs.



BER Measure Depth: 6.5E-8

70 mV per Div

Center -26 mV

00:00:31

Center 132 ps

19 ps per Div

Gen: ^PRBS-7 10,312.54 Mbit | Det: PRBS-7 10,312.54 Mbit/s | BER: 2.13E-09 | Local

Figure 5: BER contour measurement at test point C'. This BER contour measurement of an XFP module's 10.3 Gb/s XFI output took 31 seconds. The BER measurement depth to 6.5 E-8 gives far higher performance assurance than traditional high-bandwidth oscilloscope mask testing.

Summary

The new XFP MSA promises to bring economical 10 Gb/s optical interfaces to the telecom and datacom industry. XFP's 10 Gb/s serial differential I/O, XFI, brings new signal integrity and test demands to device, transceiver, linecard, and backplane designers and manufacturers. New measurement instruments bring accurate and high speed measurements combined with advanced signal integrity analysis to 10 Gb/s testing. Stressed eye construction requires careful measurements and adjustments of ISI and sinusoidal jitter magnitude. Assuring maximum failure ratios to be less than 10 E-12 requires sample populations far greater than conventional high-bandwidth oscilloscopes can provide. Careful design and manufacture and new IC designs with integrated emphasis and equalization as well as powerful new measurement and analysis tools will enable rapid adoption of XFP.

Charlie Schaffer is Vice President of Marketing at SyntheSys Research, Inc. of Menlo Park, California (www.synthesysresearch.com). Charlie has over 26 years of experience in the test and measurement industry in a variety of roles spanning manufacturing, marketing, and R&D. Charlie graduated with a Master's degree in Engineering from the University of South Florida in 1977.