designfeature *By Dima Smolyansky, TDA Systems*

WITH THE ADVENT OF XAUI, INFINIBAND, PCI XPRESS, SERIAL ATA, AND GIGABIT ETHERNET, TESTING PROCEDURES FOR CABLE ASSEMBLIES ARE BECOMING MORE COMPLEX.

Testing and modeling yields a better cable assembly

Cable and connector assemblies are becoming critical pieces of system design at gigabit speeds in XAUI (extended attachment-unit interface), InfiniBand, PCI Xpress, Serial ATA, and Gigabit Ethernet. With increased signal speeds, new specification-compliance testing procedures for cables and cable-connector assemblies have become more complex and now include both time-domain tests, including impedance, skew, and delay, and frequency-domain tests, including insertion and return loss. Eye-diagram testing also has become a key requirement for cable and connector manufacturers.

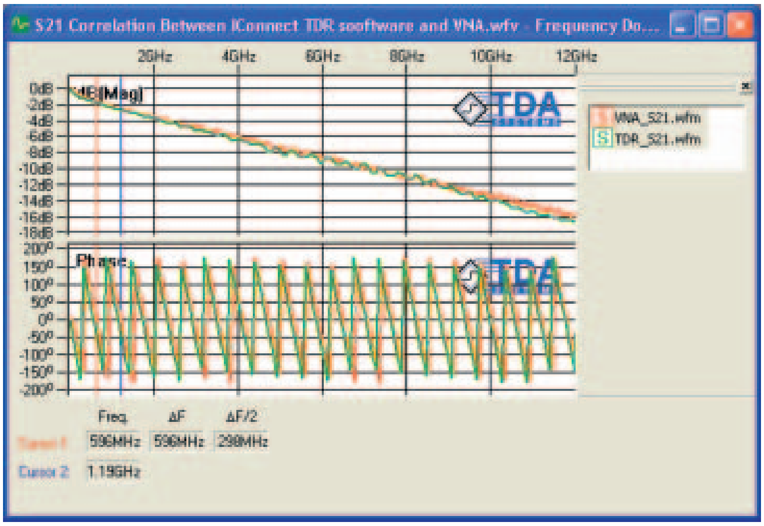
In the current business environment, cost savings are crucial for the cable-assembly houses, placing a heavy focus on cost-effective test-equipment sets to perform tests that high-speed specifications require. Conventional equipment ineffectively addresses these cost-sensitivity issues, but new, currently available technology offers a threefold savings over typical methods. In addition to cost savings during the compliance-testing phase, you can achieve additional functions, such as creating Spice/IBIS (I/O Buffer Information Specification) models for the cables and connectors, including the frequency-dependent loss, with no additional cost with the defined set of equipment.

TIME- AND FREQUENCY-DOMAIN TESTS

A typical set of time-domain tests includes impedance, delay, skew, rise-time degradation, and time-domain crosstalk. Cable-assembly manufacturers normally perform these tests with a TDR (time-domain-reflectometry) oscilloscope. Because the requirement for these tests has existed for some time, most cable-assembly-manufacturing facilities own TDR oscilloscopes to perform these tests, which makes it logical to base the required specification testing on a TDR platform.

Specification developers are increasingly adding frequency-domain tests, such as insertion loss, return loss, and frequency-domain crosstalk, to the recently released specifications. In addition, eye-diagram mask testing has become part of every new specification. Testers traditionally have performed these tests with VNAs (vector-network analyzers). Because all the new signaling standards are differential, manufacturers require differential VNAs to perform these tests.

To measure the eye diagram, test engineers can employ the sampling channels of the same TDR os-



S21 Correlation Between IConnect TDR soaftware and VNA.wfv - Frequency Do...

	Freq.	ΔF	ΔF/2
Cursor 1	596MHz	596MHz	298MHz
Cursor 2	1.19GHz		

Figure 1 In an example of an insertion-loss measurement from a TDR oscilloscope, differential-transmission measurements are converted into the insertion loss using TDA Systems' IConnect software, which employs these techniques.

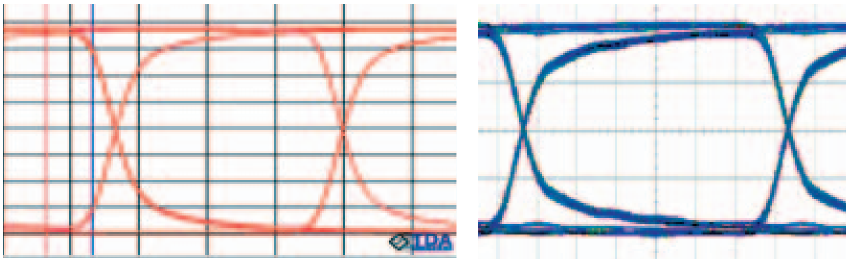


Figure 2 This correlation between measured and simulated eye-diagram degradation uses IConnect TDR software and TDT measurements (left) and the eye diagrams using a pattern generator (right) at a 1.5-Gbps data rate (courtesy Molex Inc).

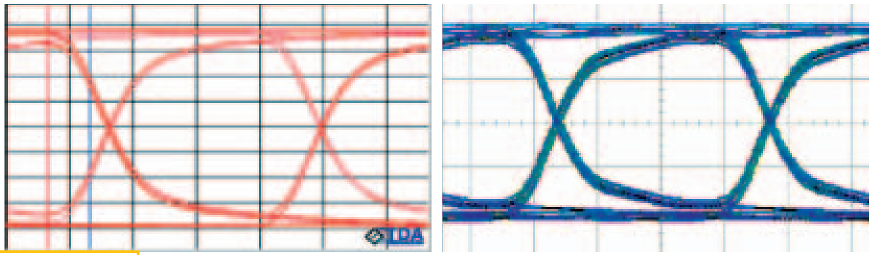


Figure 3 This correlation between measured and simulated eye-diagram degradation uses IConnect TDR software and TDT measurements (left) and the eye diagrams using a pattern generator (right) at a 3-Gbps data rate (courtesy Molex Inc).

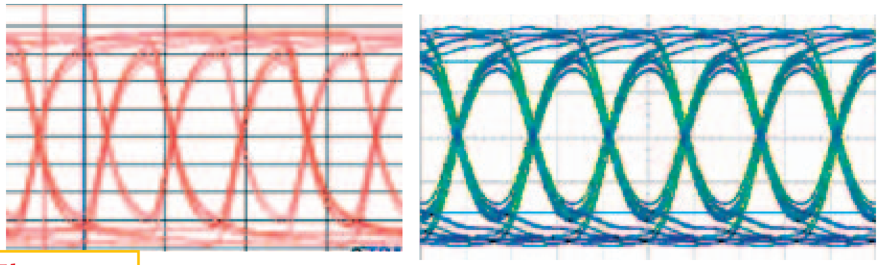


Figure 4 This correlation between measured and simulated eye-diagram degradation uses IConnect TDR software and TDT measurements (left) and the eye diagrams using a pattern generator (right) at a 6-Gbps data rate (courtesy Molex Inc).

cilloscope they use for the suite of time-domain-compliance tests. However, a cable, unlike an active component, cannot by itself generate the required test pattern. Therefore, testing requires a pattern generator operating at gigabit speeds. A differential VNA and a gigabit pattern generator can be expensive additions to instrument sets for compliance testing of a cable assembly. However, ways exist to avoid the additional expense and still meet the required specifications.

Insertion loss is one specification that requires frequency-domain measurement. Specifications sometimes also require return-loss and frequency-domain-crosstalk measurements. Because all of the new signaling standards are differential, testers must perform these measurements in differential mode. Researchers have extensively reported on the techniques for measuring S-parameters from TDR and TDT (time-domain-transition) measurements or TDNA (time-domain-network analysis). With the use of these techniques, cable-manufacturing facilities can leverage the TDR equipment they own and perform the required insertion loss, return loss, and frequency-domain crosstalk tests. **Figure 1** shows an example of an insertion-loss measurement from a TDR-oscilloscope; differential-transmission measurements you convert into the insertion loss using TDA Systems' IConnect software, which employs these techniques.

The dynamic range you can obtain with the TDR oscilloscope is less than the dynamic range of a VNA. It is also worth noting that you can improve the dynamic range of a TDR oscilloscope by using digital averaging, which plays the same role as narrowband filtering in the frequency domain. With TDR, if you use this technique enough, you can obtain perhaps 50 dB of dynamic range, whereas a properly used VNA can produce 100 dB or more of dynamic range. However, consider that a typical insertion-loss specification for any of the digital standards is approximately −10 to −15 dB, whereas insertion loss for a typical frequency-domain crosstalk test is about −30 dB. Therefore, as important as it is to have high dynamic range for testing microwave components, such as narrowband filters, a TDR oscilloscope with the appropriate TDNA software well serves testing of cable assemblies for a high-speed digital application. Within the dynamic range specified, the data from a TDR oscilloscope well matches the data from a VNA. If you use a standard TDR plug-in from Agilent or Tektronix, for example, you can obtain useful S-parameter data to approximately 12 GHz, which covers most mainstream signaling standards.

LISTING 1—FOR THE MATED CONNECTIONS

```
* Time Domain Analysis Systems: IConnect
.subckt Connector_Model port1 port2 port3 port4 gnd_
****** Partition #1
 t1 port1 gnd_ 1 gnd_ Z0=92 TD=53.4p
 t2 port3 gnd_ 2 gnd_ Z0=92 TD=53.4p
 t3 port1 port3 1 2 Z0=318 TD=53.4p
****** Partition #2
 t4 1 gnd_ 3 gnd_ Z0=98.8 TD=50p
 t5 2 gnd_ 4 gnd_ Z0=98.8 TD=50p
 t6 1 2 3 4 Z0=160 TD=50p
***** Subsegment #1 *****
 t7 3 gnd_ port2 gnd_ Z0=62.3 TD=111p
 t8 4 gnd_ port4 gnd_ Z0=62.3 TD=111p
 t9 3 4 port2 port4 Z0=396 TD=111p
.ends
```

For applications such as 10- and 40-Gbit Ethernet, which may require a wider frequency range of S-parameter data, you can employ a differential module from Picosecond Pulse Labs, which provides a substantially shorter rise time and extends the usability of TDR-based S-parameters to 12 GHz. Alternatively, you can use a differential VNA with the appropriate frequency range to cover those speeds.

Because the TDNA S-parameter measurement procedure can involve much less calibration than a VNA-based one, a test engineer can more easily de-embed the fixture with TDNA measurement. The reference-open waveform is the minimum reference measurement you need to obtain S-parameters from TDR/TDT measurements. If you acquire this waveform at the end of the test fixture, rather than at the end of the SMA cable that connects to the fixture, you effectively de-embed the fixture from the measurement. To achieve the same results with a VNA approach, you would have to follow a multistep de-embedding procedure and have precision calibration standards at the end of the fixture itself.

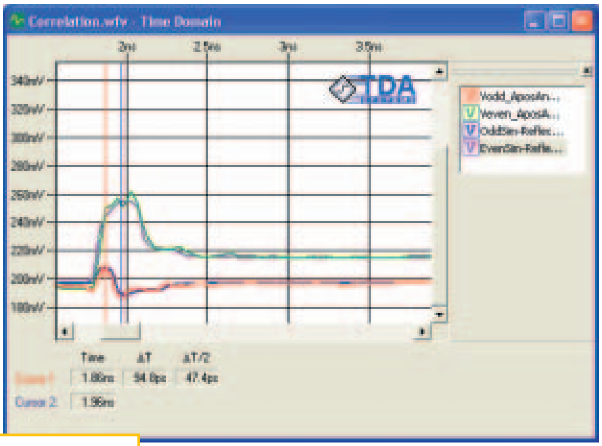


Figure 5 The model correlation for the even- and odd-mode measurements ensures accurate simulation of any signal propagating through the connector.

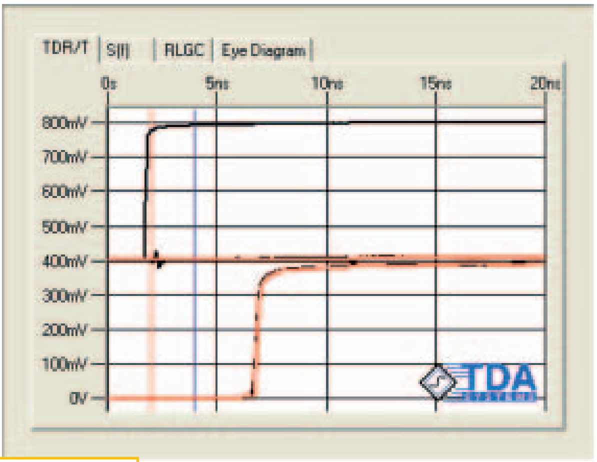


Figure 6 Cable-assembly manufacturers can gain a valuable competitive edge by providing a customer with a model correlation of the model simulation to the measurement.

EYE-DIAGRAM TESTS

An eye-diagram test is another key measurement that most new communications- and computer-signaling standards require. The measurement of the eye diagram for an interconnect captures the deterministic jitter in the interconnect, which results from losses and ISI (intersymbol interference) in the interconnect. Because of this fact, the TDR measurements of a cable assembly contain all the information you need to reconstruct this deterministic jitter. You compute the eye diagram from TDT measurements using a TDR oscilloscope. This eye diagram is as valid and accurate as an eye diagram that you obtain using a pattern generator and a sampling oscilloscope.

Figures 2 through **4** show examples of Serial ATA eye-diagram cable tests using IConnect TDR software and TDT measurements (left) and the eye diagrams using a pattern generator (right). To generate the eye diagrams, the examples use data rates of 1.5, 3, and 6 Gbps. The eye openings are clearly identical, because only deterministic loss and ISI-related jitter exist in the cable interconnections.

Like with the S-parameter measurement, you can acquire the reference waveform for the TDR-based measurement at the end of the fixture, and you can remove the effects of the fixture itself from the eye diagram, thus allowing a more accurate eye-diagram measurement. This easy de-embedding of the fixture is more difficult with a pattern generator, and the additional jitter in the fixture may account for some apparently larger jitter in the pattern-generator-based eye diagram of the cable assembly. Thus, a pattern-generator-based eye diagram for a passive component, such as a cable assembly, may produce an eye diagram that the fixture has degraded, and, as such, this degradation is worse than the degradation that the cable assembly itself causes.

LISTING 2—CABLE-COUPLED MODEL

```
.MODEL LossyLine_Model W MODELTYPE=RLGC N=2
+ Lo=2.5e-007 3.6-008 1.27e-006
+ Co=9.97667e-011 -8.21e-012 9.97667e-011
+ Ro=1.48 0.1826 1.48
+ Go=0 0 0
+ Rs=0.00015 0.0000957 0.00015
+ Gd=1.06667e-011 0 1.06667e-011
.ends
```

CABLE-ASSEMBLY MODELING

Even though most specifications require no model for a cable assembly, providing such a model could provide a competitive edge for a cable-assembly company. These companies may not perform such modeling on a production floor, but they can efficiently do so in an R&D environment or in an application-support group. Again, the modeling system based on a TDR oscilloscope with IConnect software provides the efficient approach to modeling both the connectors and the losses in the cable itself.

You should model each connector differential pair with the Z-line impedance-profile approach. This approach provides a coupled model for the connector. Furthermore, you can model the cable using the lossy-line model, which allows you to include the frequency-dependent losses of the cable in the model. As a result, you can obtain a complete and accurate model for the complete cable assembly, enabling you to accurately simulate the cable-assembly performance as a part of the overall system-level simulation.

Listing 1 shows the model for the mated connector without the cable. You could also generate an alternative lumped model. However, keep in mind that for such a model to be valid, each LC subsegment must be shorter than the rise time of the signals with which you want to use this model. The **listing** gives the validation for the connector model for the even and odd mode of propagation, which ensures model correlation for these two modes and ensures accurate simulation of any signal propagating through the connector (**Figure 5**).

You can also use TDR/TDT measurement to extract a lossy-line model for the cable assembly. You can use such a model to predict the eye diagram and the insertion loss. **Listing 2** shows the cable-coupled lossy-line model. **Figure 6** shows the overall correlation of the model simulation to the measurement. Cable-assembly manufacturers can gain a valuable competitive edge by providing a customer with a model with this level of correlation.

This article demonstrates the economical approach to cable-assembly testing. In this approach, one piece of test hardware—a Tektronix or Agilent TDR oscilloscope—couples with IConnect to complete a suite of tests—from cable impedance to insertion loss and eye diagrams—for cable assembly on the production floor. You can achieve substantial cost savings using this approach, decreasing the cost of required equipment by threefold to fivefold at the SATA or PCI Xpress speeds and by tenfold at 10-Gbit speeds.□

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Dima Smolyansky has spent his professional career in the instrumentation and measurement industry working with high-speed time-domain-reflectometry oscilloscopes and frequency-domain network analyzers. At TDA Systems (www.tdasystems.com), he works on business development for IConnect TDR and VNA software products, which help with signal-integrity and high-speed digital design work. During his professional career, Smolyansky has accumulated significant experience in high-speed digital-interconnect measurements and modeling. He has published a number of papers and taught short courses on interconnect measurements and modeling. He holds a master's degree in electrical engineering from Oregon State University (Corvallis, OR) and an engineer diploma (master's) degree from Kiev Polytechnic Institute (Kiev, Russia). Reach him at dima@tdasystems.com.

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