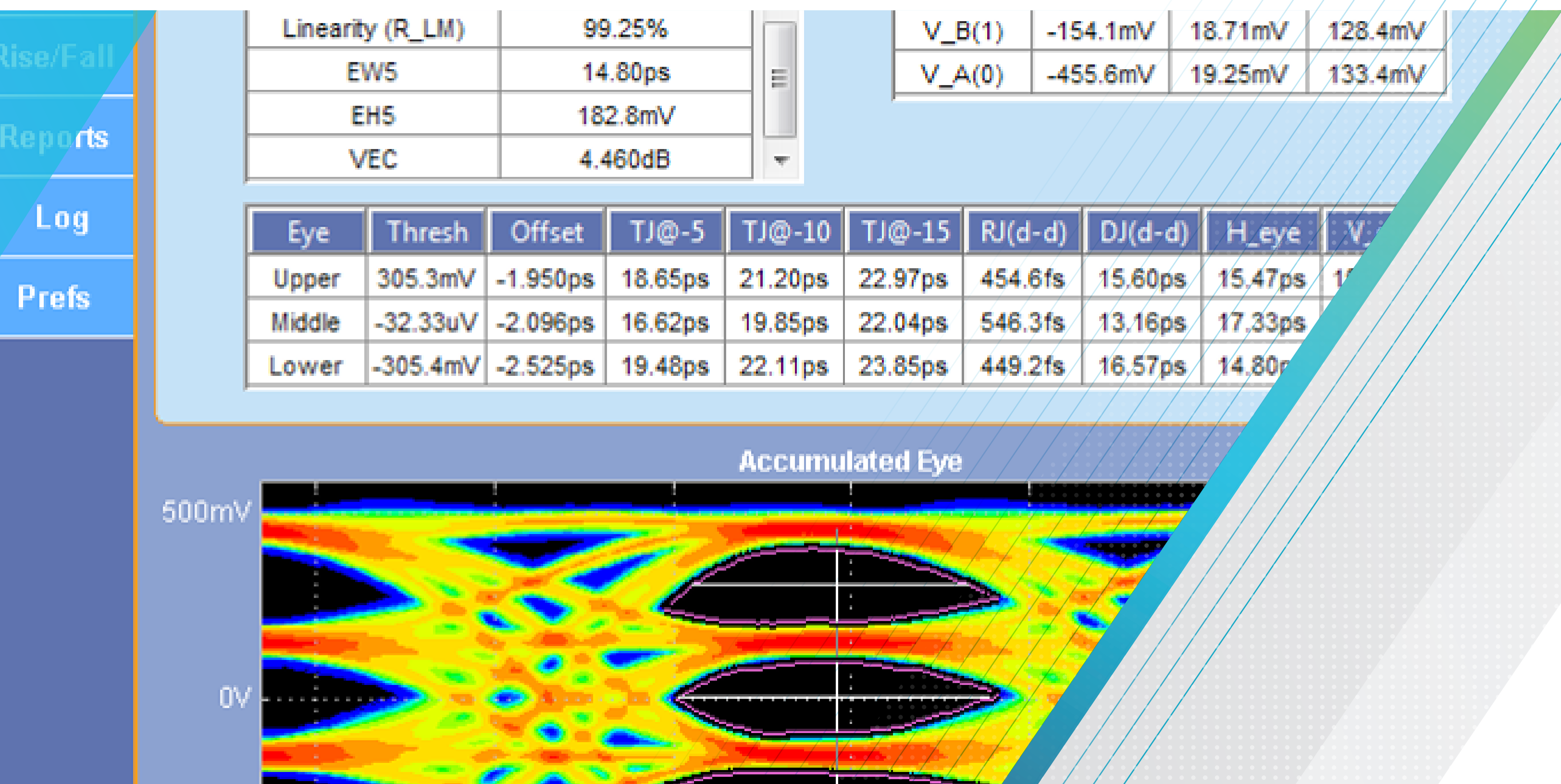
100G and 400G Datacom Transmitter Measurements

Determining Proper Measurement Tools for 100G/400G Datacom Testing

APPLICATION NOTE



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The datacom market is an exciting place to be these days, driven in no small part by relentless consumer demand for higher quality video and other high-bandwidth cloud-based services.

Beginning in 2012 with the deployment of 25 Gb/s, the industry watch word has been innovation as all the major players step up to fulfill consumer demands for more and more bandwidth. Stepping forward a few years, we're now seeing initial deployments of 400G technology using 25 Gbaud PAM4. As you might expect, 56 Gbaud PAM4 is about to happen as well. All of these technologies require a solid, well thought out testing plan as well as more capable and powerful oscilloscopes.

The innovation in the datacom industry hasn't just been limited to datacom players themselves. Test and measurement vendors – whose equipment is required to bring new innovations to market – are stepping up as well. A prime example is the multiple award-winning DPO70000SX oscilloscope that uses a patented Asynchronous Time Interleaving (ATI) architecture to provide the lowest noise and highest fidelity for real time signal acquisition of any oscilloscope available today.

In many sites where high-speed datacom design work is occurring, the tool of choice has traditionally been an equivalent time oscilloscope (ETO) or sampling oscilloscope. However, with the introduction of the DPO70000SX, a real-time oscilloscope (RTO) may not only be a viable choice, but in many cases the preferred choice. This application note walks through a number of common misconceptions and key considerations to help you better select the proper scope technology for your needs.

Market Technologies

The high speed datacom market today is focused on building out 100G and 400G Ethernet capability into the datacenter interconnect and metro networks. Initial deployments will start by running at aggregate speeds such as 25G x 4 or 8 lanes and, eventually, 56G x 4 or 8 lanes.

For transmitter testing, oscilloscopes address individual lanes so single-line signaling is the more useful classification. Here's a list of standards currently supported by Tektronix oscilloscopes:

- "100G" technology: NRZ (PAM2) at 25.78 Gb/s, 100GBASE-KR4 or 100GBASE-LR4. Other names here include 100GBASE-CR4, CAUI-4 and CEI-VSR 28G.
- "400G" technology: 26 GBd PAM4 or CDAUI-8 (aka 400GAUI-8), OIF-CEI 56G VSR or 200GBASE-LR4, 400GBASE-FR8
- "PAM4 next generation" technology: 53 GBd PAM4, OIF-CEI 112G VSR or 100GBASE-DR, 400GBASE-DR4

With 50 GHz and 70 GHz models now available with the low-noise ATI architecture, RTOs are now capable of delivering good effective bits performance and measurement results for these standards.

ETO vs RTO

The wide adoption of ETOs in the datacom industry stems in no small part from the fact that up until recently, RTOs had hit a wall in bandwidth around 30 GHz while ETOs were capable of supporting input bandwidths exceeding 70 GHz and included optical inputs. This is despite the fact that ETOs have a significantly slower digitizer than RTOs.

The challenge for RTOs is that they must acquire samples fast enough to reconstruct all of the signal within their bandwidth and dynamic range. And they have to sample over Nyquist; that is, their sample rate must be minimally more than 2x their bandwidth. ETOs, on the other hand, construct a picture of a repetitive signal by capturing a little bit of information from each repetition. The waveform slowly builds up like a string of lights, illuminating one by one. This approach is what allows the ETO to capture signals whose frequency components are much higher than the oscilloscope's sample rate.

The past several years have seen development efforts focused on RTO performance including notable advances in underlying chip and DSP technologies. Tektronix' recent addition, the DPO70000SX RTO has also proven to be a significant breakthrough, offering a significant improvement in signal fidelity compared to traditional interleaving approaches using a patented time-Interleave technique called ATI. The result is that RTOs like the DPO70000SX can now support electrical datacom Tx testing at 100G and 400G with excellent correlation to ETO systems.

From a practical test and measurement perspective, RTOs have distinct advantages over ETOs. For instance, RTOs support adjacent standards such as enterprise PCIe, SATA/SAS, NVM Express, and others not found on ETOs. RTOs are also very flexible with support for compliance testing, future 400G speeds, link negotiation, trigger and debug, and whatever else your needs might be.

Let's take a deeper look at oscilloscope differences to help with datacom Tx measurement needs.

Noise Levels

A common misperception is that RTO noise is "much worse" than an ETO's. The reason for this misperception can be seen in Figure 1 which shows a comparison of noise level of both oscilloscopes vs. "full scale." While the ETO does have some advantage, smaller signals tend to diminish the noise advantage.

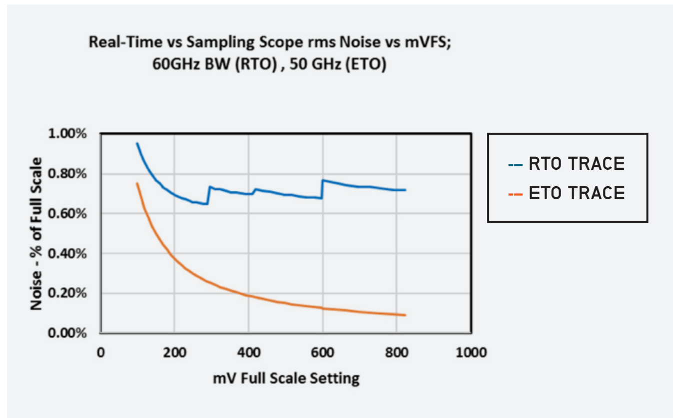
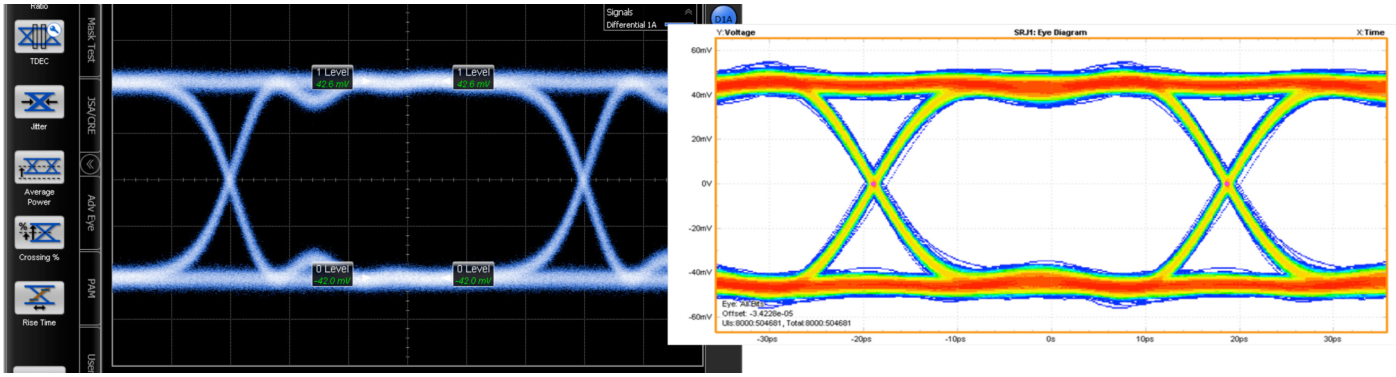


FIGURE 1. Smaller signals diminish the ETO noise advantage (RTO is the blue trace, ETO is the orange).

But the more important point here is that in a real measurement situation, there are other distortions that impact the ETO's measurement results that close this noise gap. For one, the ETO's ENOB (effective number of bits) performance is only a bit or two better than an RTO's. Moreover, the DUT being measured by the scope adds noise to the equation as well.



ETO TRACE

RTO TRACE

FIGURE 2. The eye diagram of an 80 mV_{diff} datacom signal looks similar on both ETO and RTO instruments.

As a result, in real-world measurements, eye diagrams such as the ones in Figure 2 show that the fidelity of an RTO is very good and comparable to an ETO. Both eye diagrams are very open. Note that the population is important as well, meaning you need to run the ETO for multiple minutes to get a large number of samples and thicker traces to effectively evaluate the eye diagram. With the RTO, these results appear in seconds.

The ETO does have a somewhat lower noise level, but the eye diagrams of both RTO and ETO instruments are comparable, and more importantly the measurement results are as well.

SNDR Measurements

Another common misperception is that difficult 100G measurements, such as SNDR (Signal-to-Noise Distortion Ratio) can only be done on ETOs. SNDR is a new methodology for sampling 25 Gb/s on 25 Gbaud NRZ electrical measurements. The imperfections of the signal, noise and distortion are summed up, and their amplitude (RMS) is compared to the size of the signal. SNDR is independent of insertion loss effects, like ISI, but includes all other sources of transmitter noise and distortion.

A result above 27 dB is a pass in today's electrical backplane standards (25 Gb/s NRZ), 26 dB for electrical cables. For PAM4 this result needs to be even higher. For example, 100GBASE-KP4 requires SNDR ≥ 31 dB.

In many ways, this is the ultimate test of a measuring device. To learn more, we used a fast BERT to generate a signal that by conventional wisdom should be too much for an RTO to handle. Can the RTO do the signal justice?

As you can see in Figure 3, measurements of SNDR at 25 Gb/s clearly correlate very well between a Tektronix DPO70000SX RTO and a typical competitor's ETO, laying to rest once and for all the notion that accurate SNDR signal testing is out of bounds for RTOs.

	unit	RTO	ETO
SNDR	[dB]	31.8	32.2

FIGURE 3. Comparison of key SNDR measurements for 25 Gb/s NRZ electrical results.

Clock Recovery

There really is not much room for debate on the topic of higher speed signal clock recovery: RTOs offer superior support for clock recovery. The clock recovery of RTO instruments is built in to the instrument and works on higher-speed datacom standards – even upcoming PAM4 signals as well as on small NRZ signals.

In comparison, an ETO needs an external hardware function and, making matters worse, many of the hardware devices are limited in bandwidth to less than 30Gb/sec.

Built-in DSP-based clock recovery is essential to recovering complex timing and performing analysis of low signal-to-noise ratio PAM4 and smaller NRZ signals.

Advanced Trigger System

There's no getting around the fact that ETOs need a lot of samples to reconstruct a signal, which make it difficult for them to capture or even see rare events. Unlike an ETO, an RTO can capture drop-outs of the signal, precisely measure time spans between triggers, and provide other asynchronous information not available from a clock-synchronous tool like an ETO.

Troubleshooting is a decisive advantage for the RTO. Oscilloscopes should be capable of handling the unexpected and RTOs with advanced trigger systems such as that provided by the DPO70000SX are up to the task. The DPO70000SX provides the highest trigger system performance available in a real time scope.

Figure 4 shows triggering on <50 ps bit-wide runt pulses (fails to cross both thresholds within specified time) on 25.78 Gbaud signaling. The RTO's high system bandwidth and extreme trigger timer precision enable reliable capture of signal aberrations and efficient isolation of fault conditions.

FIGURE 4. Triggering on <50 ps bit-wide runt pulses.

Link Negotiation, Visualization and Troubleshooting

Unlike ETOs and other RTOs, Tektronix RTOs are uniquely capable of capturing the link initiation or negotiation protocol on 50G and slower links and analyzing it. Continuous waveforms captured by the RTO allows segments of interest to be fully captured, while the FastFrame feature allows you to skip over the idle parts of the negotiation.

Using multiple trigger events, the Tektronix DPO70000SX FastFrameTM captures and stores targeted short bursts of signals and saves them as frames for later viewing and analysis. Capturing thousands of frames is possible, so long-term trends and changes in a bursting signal can be analyzed.

Measuring the 100GbE link is only a part of the answer. The link boot-up is also important and helpful to understanding overall system behavior and performance. Figure 5 shows how a link training sequence can be parsed into an interactive protocol negotiation table.

FIGURE 5. The capture of a 100GbE link training sequence is parsed into an interactive protocol negotiation table on a DPO70000SX RTO.

Deskew

Achieving good time alignment between differential channels is critical in many datacom NRZ or PAM4 measurements. Using the deskew function to get time-alignment on an ETO is typically limited, often requiring the use of expensive phase adjusters to gain any deskew and requires manual attention every time a deskew needs to be performed. In comparison, all DPO70000SX models include differential fast-edge outputs matched to <1.6 ps on the front panel that provide a convenient source for aligning channel timing in a coaxial environment.

Summary

If you are working in the datacom Tx measurement application area, there are good reasons now to consider the key advantages and disadvantages of an RTO vs. an ETO, particularly in light of the most recent advancements in RTO technology. Tektronix offers industry leading RTOs and ETOs as detailed on the following page.

DPO70000SX Series Real-Time Oscilloscopes (RTO)

The DPO70000SX series of oscilloscopes offer a number of advantages for high-performance compliance and debug applications compared to previous generation oscilloscopes, including:

- High bandwidth, low noise ATI channels for the best signal fidelity and widest measurement margins for today's and tomorrow's fastest signals.
- A flexible architecture allowing units to be configured at the customer site to go from 23 GHz to 70 GHz with little downtime.
  - 70GHz bandwidth @ 200GS/sec sample rate
- Industry-best triggering with 25 GHz edge trigger bandwidth to easily capture the fastest signals along with unique link training capability that shortens debugging time.
- The industry's highest-precision time base delivering the best, most accurate timing and jitter measurements on today's fastest standards.
  - Time base jitter: <125fs RMS
- An integrated counter/timer that enables high precision timing measurements to characterize designs and debug problems.

DSA8300 Series Equivalent Time Oscilloscopes (ETO)

The DSA8300 is a state-of-the-art Equivalent Time Sampling Oscilloscope that provides industry leading fidelity measurement and analysis capabilities. Key features include:

- Low time base jitter:
  - 425 fs typical on up to 8 simultaneously acquired channels
  - <100 fs on up to 6 channels with 82A04B phase reference module
- Industry's highest vertical resolution – 16 bit A/D
- Electrical resolution: <20 μV LSB (for 1 v full range)
- Optical resolution from <20 nW for the 80C07B (1 mW full range) to <0.6 μW for the 80C10C (30 mW full range)
- Optical bandwidths to >80 GHz
- Electrical bandwidths to >70 GHz
- Over 120 automated measurements for NRZ, RZ, and pulse signal types
- Automated mask testing with over 80 industry-standard masks

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