Optical transceivers are essential components in mobile-phone base stations, short-link data centers, campus networks, and long-haul telecommunications networks. Transceiver manufacturers produce millions of these components every month, and a competitive marketplace forces vendors to keep their prices low. This price pressure compels manufacturers to find ways to drive down production costs—including the cost of test.

Improving test processes can reduce overall production costs. A single test system for transceivers can cost more than $100,000, and a typical manufacturing site will likely have many test systems. Given the small profit margins of optical transceivers, it may be surprising to find that the contribution of test instrumentation to overall costs may be quite small compared to the manufacturing cost for millions of transceivers. Test time, however, is a significant factor in overall manufacturing expenses, and reducing test time offers the greatest opportunity to cut costs.

**Beyond electrical tests**

From an electrical perspective, the laser in an optical transceiver operates as a diode, but the test process required for transceivers deviates significantly from the process used for purely electrical components. For example, the laser semiconductor chip must be mated with lens structures so its output efficiently couples into a fiber-optic cable.
Even if you have a mature product with a stable manufacturing process, you must individually tune each laser for correct biasing to achieve proper output power and waveform properties. The laser in the transceiver’s transmitter produces an output-power-versus-input-current transfer function that’s somewhat similar to the current-versus-voltage curve of a common diode. At lower current levels, a laser diode emits very little light power. The plot in Figure 1 shows that at some point, the emitted light power increases rapidly with current. Thus, you must bias the laser so it emits very little light when it receives an electrical input of logic 0 and has a high light power at logic 1. The best way to perform the biasing is to use a resistor network optimized for the specific laser.

To gauge if a laser is correctly biased, you need to measure its light power at logic 0 and logic 1. You can use a wide-bandwidth oscilloscope with an integrated optical front end to make the measurement. These types of oscilloscopes, which Agilent Technologies calls DCAs (digital communications analyzers), display eye diagrams of many bits overlaid on each other. The eye diagram lets you see the laser’s extinction ratio, which is the mean value of the logic-1 level of the eye divided by the mean value of the logic-0 level. Extinction ratio is a useful parameter that indicates how efficiently a laser diode converts electrical inputs to modulated light. You can use a histogram to analyze signal levels, which are usually based in the central 20% of the eye (Figure 2).

Extinction-ratio measurements let you set both the AC and DC laser-bias conditions. Laser biasing also influences the shape of the output waveform, which an eye diagram will show. You can monitor
the eye diagram while tuning the laser, and you can use an eye mask to quantify the shape of the eye.

An eye mask consists of polygons placed above, within, and below the eye, which define regions where the eye diagram may not exist, essentially defining the minimum allowed opening of the eye. For the typical eye-mask test, the outliers of the eye-diagram sample population cause mask violations. It’s common practice to proportionally expand the magnitude of the mask polygons to determine not just whether a transceiver passes the mask test, but also to determine a margin of compliance. Mask margin is the largest percentage expansion of the mask dimensions that an optical transmitter’s signal can reach without violating the mask limits.

The laser-tuning process can represent significant cost to a transceiver manufacturer. Tuning takes time and will limit a manufacturing system’s capacity, influencing the number of test stands and manufacturing floor space required to meet production demands. Although usually highly automated, the tuning process typically requires a technician or an engineer to install the transceiver in a test fixture and make the necessary fiber connections. The test equipment required to perform the eye diagram test can represent a significant capital outlay. Any efforts that improve test efficiency are likely to reduce the cost of testing a transceiver.

**Checking test efficiency**

To evaluate the efficiency of your test, begin by examining how you acquire and measure an eye diagram. To create the eye diagram, send an electrical data signal to the transmitter and capture the optical data signal with a DCA-type oscilloscope. The data pattern should represent the data that the transmitter will send when in actual use; engineers commonly use a PRBS (pseudorandom binary sequence) for this test because it represents a wide range of data patterns. The DCA will construct and display the transmitter signal’s eye diagram by acquiring data samples from throughout the transmitted data pattern. You should set the DCA to run in infinite-persistence mode. Data samples will remain on the display indefinitely. The eye diagram will continue to build as the DCA collects more data samples.

Industry standards such as IEEE 802.3ae and 802.3ba and ITU G.957 and G.691 (Refs. 1–4) specify measurements and the test equipment you need to make those measurements, but they don’t specify how much data you should collect. You might think that the more data you collect, the more likely it is that the eye-diagram will show the true performance of the transmitter. Acquiring more data takes more time, however, and it effectively increases the cost of test by reducing a test system’s overall throughput. You could use a faster test system, but a better option is to develop a test method that provides valid results with only small amounts of data.

You can derive both the extinction-ratio and eye-mask results from the eye diagram, but the amount of data required for accurate results is very different for these two tests. Recall that the extinction-ratio results are obtained from the mean values of eye-diagram histograms; the eye-mask results depend on the statistical extremes of the eye-diagram data.

Finding the ideal biasing conditions is generally an iterative process. You need to set the bias, measure the eye, and adjust the bias levels until you get the greatest extinction ratio. You must repeat the process until the optical transmitter achieves the required waveform performance.

Collecting a large sample size for each bias setting with the DCA-type oscilloscope in infinite-persistence mode could be extremely time consuming, and you can dramatically improve efficiency if you run the DCA in finite-persistence mode. The DCA will report the extinction-ratio results almost
instantaneously because a small data set is sufficient to provide an accurate result. Thus, a test system can continuously tune a laser’s bias while monitoring the extinction ratio. You can then achieve ideal bias in just a few seconds compared to the tens of seconds required using infinite persistence.

**Eye-mask verification offers savings opportunities**

Once you find the optimum laser bias, you can verify the eye-mask performance. The need to observe the statistical extremes of the waveform shape, however, requires that you operate the DCA in infinite-persistence mode so every waveform sample remains on the instrument display. Given that the waveform will contain random signal components such as noise and jitter, there’s no guarantee that any practical sample population will include the extremes of the waveform. As the oscilloscope captures more samples, the likelihood increases that the transmitter will violate the eye mask. Thus, results can only get worse as the data set grows, which will lead to a smaller mask margin. Furthermore this testing is prone to inconsistency. For a given number of waveform samples, the mask margin will likely fluctuate from test to test because one collection of samples might have an extreme outlier, but another set of samples might not.

The IEEE and ITU communications standards resolve this measurement problem by allowing a small percentage of waveform samples to violate the mask. Typically, the standards allow one sample in every 20,000 to intersect the eye mask. With this approach, once the sample population is significantly above 20,000, results are very consistent regardless of the number of samples. This leads to an important question: How little data can you collect while providing a high level of confidence that the mask margin is accurately known? If you can obtain accurate results with less data, you can reduce test time and production costs.

You can trade off three different factors when setting up the mask test: the size of the sample population, the margin of the eye mask, and the measurement uncertainty of the reported eye-mask margin. For example, you can configure an eye-mask test so that the oscilloscope acquires data until the mask-margin expansion percentage is known to within ±1%. In another approach, you can find the largest mask-margin percentage with at most a ±2% error for a small sample size.

These two approaches may seem similar, but the former provides a method to efficiently find the true eye-mask margin, while the latter forces a smaller sample size (thus cutting test time) at the expense of how precisely you know the true mask margin. If you know a transceiver inherently has good mask margins, then you can reduce sample sizes to very small values. Assuming similar test-equipment costs, you must recognize that the most cost-effective test system isn’t the one that collects data the fastest, but rather the one that provides accurate and usable results in the shortest time.
FIGURE 3. a) The eye-mask margin for a high-confidence factor requires 408 waveforms, yet the results are similar to those of b) a mask margin that collects only 82 waveforms in less than 3 s of test time.

**Figures 3a** and **3b** highlight the tradeoff in eye-mask uncertainty and samples. In Figure 3a, the uncertainty of the eye-mask margin is $\pm0.48\%$. In Figure 3b, it is $\pm2.56\%$. The lower uncertainty in Figure 3a, however, comes at the expense of more samples, 502.46 ksamples versus 100.98 ksamples in Figure 3b. Remember that more samples take more time to acquire.

You can also drive down test costs by testing devices in parallel. Some DCA-type sampling oscilloscopes can simultaneously acquire data from several channels without degrading the system throughput. A test operator can thus connect four transceivers to the test system and automatically tune all four devices and obtain eye-diagram results.

The time needed to attach a transceiver to the test equipment becomes the limiting factor to continued cost reduction. Historically, the setup time was considered negligible. This may no longer be true. Handling and setup could become the next areas of the test process that offer opportunities for improvement.

Someday, optical transceiver tests may become as streamlined and efficient as those for purely electrical components. As long as lasers require tuning, waveform analysis using a high-speed
A sampling oscilloscope will be required. Ongoing steady improvements in test algorithms and processes have dramatically reduced the effective cost of test, which lets transceiver manufacturers meet rising production demands while simultaneously improving the cost of test. T&MW

REFERENCES


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