Measure Return Loss in Multimode Fiber-Optic Systems

Richard Buerli - October 01, 2000

Many LANs now use multimode fiber-optic systems to handle data at gigabit-per-second rates. Multimode systems incorporate a variety of components that help keep costs low. They use light-emitting diodes (LEDs) as well as short-wavelength laser diodes, or vertical-cavity surface-emitting lasers (VCSELs), in the transmitter. Receivers rely on silicon detectors. Even the optical fibers used in multimode systems (Fig. 1) are less expensive than those used in other fiber-optic systems. But lower cost doesn’t mean cutting back on testing.

All of these components are susceptible to back reflections, or return loss. Laser-diode transmitters offer higher performance than LEDs, but they’re also more sensitive than LEDs to light reflected back into them from the fiber-optic communication system. The reflected light can change the wavelength of the transmitting laser and add noise to the transmitted signal. Reflections that enter a VCSEL affect lasing action in the cavity and add noise to the optical signal. The added noise will degrade an entire fiber-optic communication link, thus leading to data loss and reduced information throughput. Lasers operating at a narrow spectral width, say 5 nm, are particularly sensitive to back reflections.

Manufacturers of lasers and designers of fiber-optic systems must carefully measure return loss to ensure it’s small enough to not disturb a transmitter’s laser or lasers. (The actual value that will upset communications varies from product to product.) Return loss, known formally as optical return loss (ORL), describes the ratio of the incident light launched into a fiber and the power of the light reflected or returned down the fiber. The ratio is expressed in positive decibel units (dB or dB$_{RL}$), and the greater the number, the better:

\[
\text{Return Loss} = 10 \log \left( \frac{\text{Incident Power}}{\text{Returned Power}} \right)
\]

Back-reflections, also known as Fresnel reflections, occur in an optical fiber when light traveling down the core encounters a medium with a different refractive index. For instance, if a space exists between two physical contact connectors along an optical path, the air space causes a reflection. Other small reflections, called backscatter or Rayleigh scattering, occur due to the reflection of light from atoms, small particles, and density gradients in the optical materials in a fiber.

Several groups have established minimum performance standards for return loss in fiber-optic communication systems. The TIA/EIA-568A¹ series of standards, established jointly by the Telecommunications Industry Association and the Electronic Industry Association, specifies a system return-loss value greater than 26 dB for fiber-optic premises networks. Future revisions or new standards will likely increase this value. Engineers developing products for European customers should refer to the CENELEC EN 50173² standard that establishes performance guidelines for
measuring the return loss of multimode fiber-optic networks.

![Multimode Fiber Diagram](image)

**Figure 1.** A multimode fiber lets light pass through its transparent core material over many different paths. Because light travels on different path lengths, a sharp pulse gets spread somewhat during transmission. But for local communication systems, multimode fibers work well.

You can choose from among three methods to measure the return loss of multimode fiber-optic systems: optical continuous-wave reflectometry, optical time-domain reflectometry, and optical-reflection discrimination. Each of these methods has its own advantages and disadvantages, as summarized in **Table 1**.

<table>
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<th>Measurement Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<td>Optical Continuous-Wave Reflectometry</td>
<td>Tests can use inexpensive equipment and setup is easy. Calibration of equipment is easy.</td>
<td>Power meters respond to all reflections and the characteristics of directional couplers depend on the wavelength and mode of light transmissions. Tests require a mandrel wrap, or similar termination, at the far end of a cable.</td>
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<tr>
<td>Optical Time-Domain Reflectometry</td>
<td>An OTDR accurately measures losses and lengths for long runs of fiber-optic cable.</td>
<td>An OTDR cannot make measurements on short cable runs. An OTDR can take up to 30 s to make a series of measurements and calculate a result.</td>
</tr>
<tr>
<td>Optical-Reflection Discrimination</td>
<td>The ORD technique provides better measurement accuracy compared to the OTDR method, specifically for shorter cables.</td>
<td>Mandrel-free operation can be limited to a few meters.</td>
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**Optical Continuous-Wave Reflectometry**

The most widely used method for measuring return loss is optical continuous-wave reflectometry (OCWR). Using this method, you launch a single wavelength of light at a known power level into the fiber-optic system and to the device under test. You should choose a wavelength close to the wavelength the communication system will use in its intended application. A directional coupler routes back reflections to a detector in an optical power meter (**Fig. 2**).
Although you can use a calibrated light source, you don’t have to. You can calibrate the measurement system using the Fresnel reflection from the fiber-to-air interface at a standard polished connector. Such a connector used in place of the device undergoing testing provides a reflection of \(-14.7\) dB at 1550 nm. Then, you substitute the DUT for the connector and determine the difference in returned power—the return loss. OCWR return loss test procedures are described in detail in Fiber Optic Test Procedure (FOTP) 107.\(^3\)

Although the OCWR method is simple, it has a few drawbacks. The power meter will measure power from all reflections that occur in a fiber, not just those reflections from a DUT. The reflections that don’t come from the DUT can amount to more than the reflections from the DUT, thus limiting the sensitivity of the power meter. (The difference between a large signal and a large signal plus a small signal proves difficult to detect.) You also need a “mandrel wrap” or a termination plug at the end of the fiber to eliminate reflections from components other than the DUT. A mandrel wrap is achieved by wrapping a length of fiber around a hexagonal. The wrapped fiber reduces reflections.

The OCWR technique requires you to use a directional coupler that won’t be affected by different modes of light in a multimode fiber-optic system. Unfortunately, multimode signals do affect the performance of common fused-construction couplers. The coupling ratio in these devices changes depending on the distribution of the modes. The mode distribution in turn depends on the characteristics of the laser and any connections between it and the coupler. In addition, modal distribution depends on temperature, so during testing, you would have to carefully control ambient temperature. You could use optical couplers based on conventional beam splitters, but they’re expensive and bulky and require manual alignment of each light path.

Using an LED as a light source for OCWR measurements may cause problems because the LED has a broad spectrum—broader than that of a laser. And the LED’s spectrum does not match that of the laser that will produce the signal actually used for communications. The LED also produces less power. Thus, using an LED as the light source will affect measurement accuracy.
Figure 3. The display on an OTDR shows power loss as it relates to distance from the OTDR. You can use the display to identify the loss from a connector or other component. The OTDR performs the necessary calculations to compute return losses.

Optical Time Domain Reflectometer

You can also use optical time-domain reflectometry to measure optical return loss. An optical time-domain reflectometer (OTDR) launches light pulses into the device under test and then collects backscatter information and superimposed Fresnel reflections. The OTDR computes and displays loss (decibels) vs. unit distance (meters) based on the backscatter signals received by the instrument. The display (Fig. 3) plots points on a graph; the vertical axis represents relative energy in a reflection and the horizontal axis represents the location of the reflecting component. In fact, the horizontal axis represents time, but users preset the speed of light in the fiber undergoing testing so the OTDR can convert time to distance and display distance on the horizontal axis. The TIA/EIA-455-8 series of documents contain procedures for measuring splice or connector loss and reflectance using an OTDR.

To yield accurate results when measuring return loss using an OTDR, you must connect a DUT beyond the instrument’s “dead zone.” The actual dead-zone length varies by OTDR make and model, but it’s usually a few meters. The dead zone length represents the distance over which the OTDR cannot make measurements because reflections in this length “blind” or saturate the OTDR. Thus, reflections that occur in the dead zone cannot be detected or appear on an OTDR trace as a vague anomaly instead of as discrete pulses.

The OTDR’s internal amplifier may limit the use of the instrument for return-loss measurements. Intense backscatter reflections may “swamp” the less-intense reflections from a DUT, so the OTDR’s amplifier clips the DUT’s signal, resulting in false or noisy readings. To prevent this effect, you may have to insert an external attenuator in the optical path to bring the reflection within the linear range of the OTDR amplifier.

During a test of a DUT, the OTDR acquires many measurements that it then averages to reduce random noise. (The actual number acquired depends on the OTDR in use.) Then, the OTDR analyzes the recorded data, computes the losses, and displays the results—potentially a time-consuming process.

Optical Reflection Discrimination
The third measurement technique uses optical reflection discrimination (ORD) to separate backscatter from actual reflections. ORD works in much the same way as optical time-domain reflectometry. A stable laser source injects light pulses into the fiber and thus into the DUT. But the ORD technique uses pulse widths chosen to minimize backscatter. In general, a pulse width of 10 ns or less results in a sufficiently strong signal that won’t cause significant backscatter. An ORD instrument exists as a single piece of equipment, although an ambitious test engineer could configure a ORD test setup using a laser pulser, a coupler, and a sensitive optoelectric converter.

![Figure 4](image.png)

**Figure 4.** A simplified schematic diagram shows the key instruments and components used to make measurements for optical-reflection discrimination.

![Figure 5](image.png)

**Figure 5.** The power vs. time graph obtained during an ORD measurement shows the amplitude pulses of the reflections. The optical receiver discriminates against the backscatter light and measures only strong reflections.

Like an OTDR, an ORD instrument guides reflected light through a directional coupler to a separate receiver. But unlike an OTDR, an ORD instrument uses a time-discrimination process implemented in hardware and software to capture only certain signals. The discriminator captures signals that rise above a minimum level and signals with a “fast” slope. In this way, the discriminator filters out the backscatter and captures only reflections. The receiver converts the light to an electrical signal, amplifies the signal, and measures it (Fig. 4). The ORD instrument records a time base and can plot the amplitude of the reflections and the time of their arrival, (Fig. 5). The built-in software analyzes the reflection signal and reports the return loss of the DUT to the user. An ORD instrument incorporates a highly linear optical receiver; thus, the amplitude of measured reflections is directly proportional to the return loss.

When you make any measurements, you must consider repeatability. Return-loss measurements are no exception. When using any of the above methods, my colleagues and I have found that a deviation of ±2 dB in measurements from one technique to another is not uncommon. (For our measurements, we used exactly the same setup or fiber-optic components to ensure we would take readings of the same DUT in the same fiber-optic configuration.)

Of course, many factors influence repeatability: the types of connectors in use, the measurement method being used, and the signal-to-noise ratio present in the system during the test. But all in all, these three techniques make good measurements. T&MW
FOOTNOTES


FOR FURTHER READING

Brown, Michael A., Reaping the Rewards of Technology Advances in Test & Measurement, Rifocs, Camarillo, CA.


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