Bidirectional OTDR Testing: Multimode vs. Singlemode Fibers

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As competition heats up among Europe's new and established telecommunications companies, network reliability is emerging as the vital factor in the battle to secure a long-term customer base. Quite simply, with the era of zero-downtime networks fast approaching, carriers can no longer tolerate service outages on cables, or even single fibers, designed to transport numerous gigabit-per-second optical channels.

Once an optical cable has been installed, network managers need to be certain that each separate fiber span matches or exceeds the carrier's specifications. The optical time domain reflectometer (OTDR) remains the only instrument available to characterize fibers at the required level of detail, generating distance versus attenuation data, as well as insertion loss measurements for all splices, defects, kinks, or breaks.

Singlemode OTDR users are reminded that, sometimes, as light crosses from one fiber to the next, backscatter may increase. That way, combined with the actual loss at that location, the slope of backscatter may remain unchanged.

At this point, because of the difference in backscatter, the OTDR trace will therefore show neither loss nor gain. No OTDR will detect the *0 dB* event. An acquisition from the opposite end of the fiber will show an event with an overestimated loss measurement. Averaging the two unidirectional results will provide the true loss for that particular event.

Also, on singlemode fibers, OTDR acquisitions taken from opposite directions can be compared and the loss for each event averaged to alleviate the dreaded *gainer*, or positive event—this is often an issue of concern for the untrained eye. In fact, this averaging procedure removes the error due to different fiber backscatter ratios and provides better loss accuracy for each event.

One of the OTDR's principal attractions is that it can provide detailed analysis with a single-ended test, requiring just one technician and one test set. However, this approach is really only sensible in multimode premises networks. In the singlemode world, where operators require extremely tight control of overall loss budgets, bidirectional OTDR analysis is very much the order of the day.

Optical Probes

Careful data acquisition is the single most important factor for reliable OTDR characterization of singlemode links. Unfortunately, many field technicians expect miracles from their test instrument. Since the OTDR can see the end of the fiber, it is often assumed that everything along the fiber span will be characterized and measured correctly.

In many cases, though, this is an ill-founded assumption, mainly because the quality of event detection depends heavily upon the signal-to-noise ratio (SNR). This means that when an acquisition becomes noisy—because of insufficient averaging time or inappropriate test settings, for example—the OTDR will struggle to measure losses and, eventually, to locate events with an acceptable level of accuracy.

An OTDR injects short light pulses (not unlike probes really) into an optical fiber and then generates *snapshots* of the low levels of reflected light (against time) that come back out of the same end of the link. As the probe pulse travels down the fiber, it undergoes Rayleigh scattering: some of the light is scattered forward and continues along the fiber, some is scattered sideways into the cladding, and the rest is scattered backwards along the fiber to the OTDR photodetector. By monitoring the rate at which the backscattered energy decreases (the slope), the OTDR is able to establish the attenuation in every portion of the fiber under test.

Sudden drops in the backscattered energy levels (typically the width of a pulse) indicate the presence of a non-reflective event—a fusion splice between two fibers, for example. However, the probe pulse may also undergo a process called Fresnel reflection. This occurs when light travels from one medium to another—say from glass to air in an optical connector or at a fiber break—and experiences an abrupt change in the index of refraction. For both reflective and non-reflective phenomena, the OTDR estimates losses by calculating the difference in backscatter energy levels before and after the event location.

To complicate matters further, the power levels measured by the OTDR are affected by the fiber's backscattering ratio (which in turn is governed by the mode-field diameter). This becomes a real headache when the OTDR must estimate the loss for an event, such as a fusion splice, which involves two fibers of slightly different mode-field diameters.

Bidirectional Benefits

Network installers overcome this problem by using bidirectional OTDR analysis. Since the effect of the backscattering ratio difference is reversed when measurements are performed from opposite ends of a link, the average of the two measurements will eliminate any effects related to fiber mismatch. Obviously, it is vital that the two original OTDR acquisitions are of high quality, otherwise the averaging will only further reduce the loss measurement accuracy.

There are several other benefits of the bidirectional strategy. For starters, OTDR traces from opposite directions will eliminate the dreaded *gainer*.
These *positive* events can occur when three sections of fiber are spliced together, with the central section having a slightly larger core than the other two. The positive step in the OTDR trace is caused by a higher level of scattered signal coming from the central fiber section.

Bidirectional analysis also reveals events that are hidden by dead zones in one direction but not in the other. Dead zones occur when the OTDR detector is temporarily *blinded* by Fresnel reflections, which makes it difficult to accurately measure the low levels of backscattered light in that region of a link. They are particularly common at the optical interface between the OTDR and the fiber (at each end of a span under test).

In addition, it is worth noting that bidirectional analysis can highlight *0 dB events*, when a fiber splice shows neither a loss nor a gain on a single OTDR trace. In other words, as light crosses from one fiber to the next, the backscatter may increase just enough to compensate for the actual splice loss. In these circumstances, no single-ended OTDR acquisition is capable of detecting the event.

Although there are cost and time issues associated with bidirectional analysis—another test set and another technician being the most obvious— instrument vendors have taken important steps to make the technique more attractive to network operators. For example, many companies now offer dedicated analysis software to ensure that the task of averaging unidirectional results takes place (more or less) automatically. Several manufacturers also provide systems that add the OTDR traces obtained from opposite ends of a link. This *end-to-end* capability is particularly suitable for the longhaul fiber spans (in excess of 400 km) found in underwater cable networks.

Multimode Analysis

The physical principles that underpin bidirectional OTDR averaging on singlemode links do not apply to multimode fibers. Because of the way in which light propagates along multimode fiber spans, it is false to assume that the real loss of a splice between two fibers is the same for both propagation directions. In fact, transmission from an initial fiber to a larger one is likely to experience very low loss, while the transmission from a large fiber to a smaller one will experience very large loss. Another important point is that the true insertion loss (IL) between two fibers does not solely depend on the fibers themselves, but also on the actual mode distribution of light within the launch fibers.

While the impact of different backscattering ratios between two multimode fibers is removed by performing bidirectional analysis, the final result does not give the true loss of the splice, as opposed to singlemode fibers. In fact, true loss for a splice does not apply to multimode fibers because the loss depends on the direction of light propagation.

In any case, the potential increase in loss measurement accuracy will serve no meaningful purpose in the multimode world because multimode fibers and their respective applications involve much greater loss budgets than those typically found in networks. In fact, the attenuation for multimode fibers alone can be as much as 20 times higher than for singlemode fibers.

Furthermore, multimode fibers are typically used in premises networks where high-loss connector pairs substitute for low-loss fusion splices. The increase in loss-reading accuracy (±0.02 dB) with a bidirectional acquisition is therefore rendered pointless in such environments.

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