***UNDERSTANDING THE PHYSICS (AND ERRORS) OF THE MEASUREMENT***

Don't let the title put you off, it's pretty basic. The amount of light scattered back to the OTDR for measurement is quite small, about one-millionth of what is in the test pulse, and it is not necessarily constant. This affects the operation and accuracy of OTDR measurements.

**Overload Recovery**

Since so little of the light comes back to the OTDR for analysis, the OTDR receiver circuit must be very sensitive. That means that big reflections, which may be one percent of the outgoing signal, will saturate the receiver, or overload it. Once saturated, the receiver requires some time to recover, and until it does, the trace is unreliable for measurement as shown in Figure 5.

The most common place you see this as a problem is at the connector on the OTDR itself. The reflection causes an overload which can take the equivalent of 50 meters to one kilometer (170 to 3000 feet) to recover fully, depending on the OTDR design, wavelength and magnitude of the reflection. It is usually called the "Dead Zone". For this reason, most OTDR manuals suggest using a "pulse suppresser" cable, which doesn't suppress pulses, but simply gives the OTDR time to recuperate before you start looking at the fiber in the cable plant you want to test. They should be called "launch" cables.

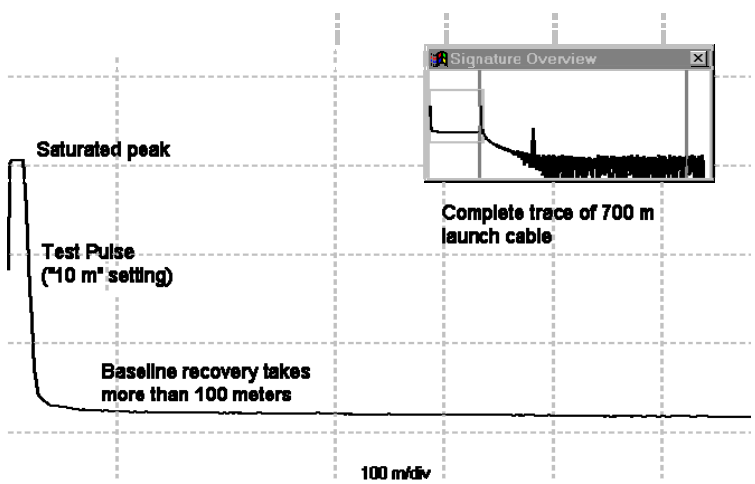


Figure 5.

OTDR launch pulse and launch cable

Do not ever use an OTDR without this launch cable! You always want to see the beginning of the cable plant and you cannot do it without a launch cable. It allows the OTDR to settle down properly and gives you a chance to see the condition of the initial connector on the cable plant. It should be long, at least 500 to 1000 meters to be safe, and the connectors on it should be the best possible to reduce reflections. They must also match the connectors being tested, if they use any special polish techniques.

If you are testing short cables with highly reflective connectors, you will likely encounter "ghosts" like in Figure 6. These are caused by the reflected light from the far end connector reflecting back and forth in the fiber until it is attenuated to the noise level. Ghosts are very confusing, as they seem to be real reflective events like connectors, but do not show any loss. If you find a reflective event in the trace at a point where there is not supposed to be any connection, then you have most likely encountered a ghost.

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Look for ghosts at multiples of the length of the launch cable or the first cable you test. You can eliminate ghosts by reducing the reflections, using a trick we will share later.

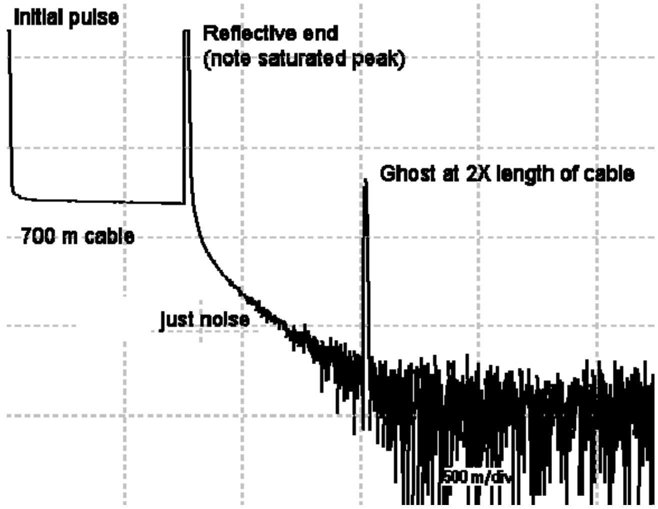



Figure 6. OTDR "ghosts"

On very short cables, multiple reflections can really confuse you! We once saw a cable that was tested with an OTDR and deemed bad because it was broken in the middle. In fact it was very short and the ghosted image made it look like a cable with a break in the middle. The tester had not looked at the distance scale or he would have noted the "break" was at 40 meters and the cable was only 40 meters long. The ghost at 80 meters looked like the end of the cable to him!

### Backscatter Variability Errors

Another problem that occurs which is a function of the backscatter coefficient (a big term which simply means the amount of light from the outgoing test pulse that is scattered back toward the OTDR.) is described below. The OTDR looks at the returning signal and calculates loss based on the declining amount of light it sees coming back.

Only about one-millionth of the light is scattered back for measurement, and that amount is not a constant. The backscattered light is a function of the attenuation of the fiber and the diameter of the core of the fiber. Higher attenuation fiber has more attenuation because the glass in it scatters more light. If you look at two different fibers connected together in an OTDR and try to measure splice or connector loss, you have a major source of error, the difference in backscattering from each fiber.

To more easily understand this problem, consider Figure 7 showing two fibers connected. If both fibers are identical, such as splicing a broken fiber back together, the backscattering will be the same on both sides of the joint, so the OTDR will measure the actual splice loss.

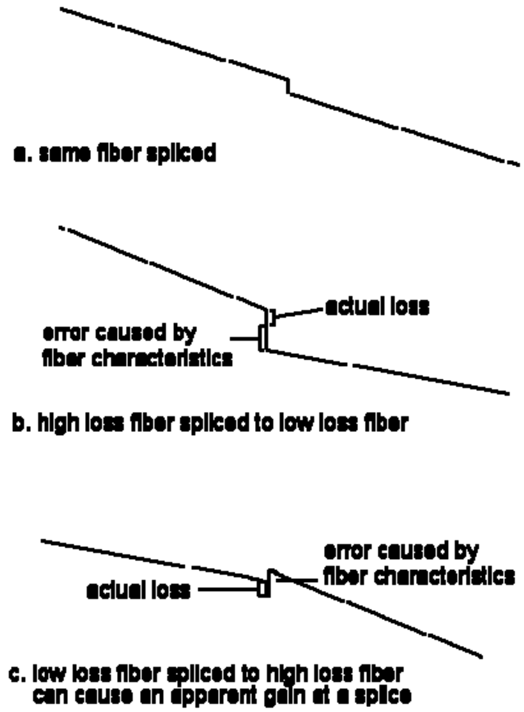



Figure 7. Loss errors in OTDR measurements

However, if the fibers are different, the backscatter coefficients will cause a different percentage of light to be sent back to the OTDR. If the first fiber has more loss than the one after the connection, the percentage of light from the OTDR test pulse will go down, so the measured loss on the OTDR will include the actual loss plus a loss error caused by the lower backscatter level, making the displayed loss greater than it actually is.

Looking the opposite way, from a low loss fiber to a high loss fiber, we find the backscatter goes up, making the measured loss less than it actually is. In fact, this often shows a "gainer", a major confusion to new OTDR users.

The difference in backscatter can be a major source of error. A difference in attenuation of 0.1 dB per km in the two fibers can lead to a splice loss error of 0.25 dB! While this error source is always present, it can be practically eliminated by taking readings both ways and averaging the measurements, and many OTDRs have this programmed in their measurement routines. This is the only way to test inline splices for loss and get accurate results.

Another common error can come from backscatter changes caused by variations in fiber diameter. A variation in diameter of 1% can cause a 0.1 dB variation in backscatter. This can cause tapered fibers to show higher attenuation in one direction. We have in the past seen fiber with "waves" in the OTDR trace caused by manufacturing variations in the fiber diameter.

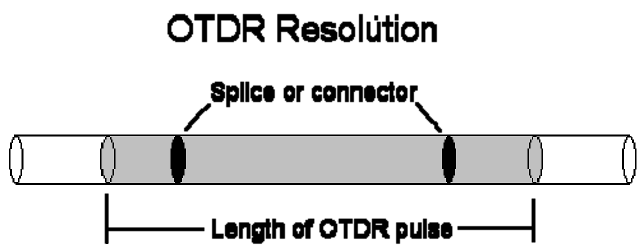
### Overcoming Backscatter Errors

One can overcome these variations in backscatter by measuring with the OTDR in both directions and averaging the losses. The errors in each direction cancel out, and the average value is close to the true value of the splice or connector loss. Although this invalidates the main selling point of the OTDR, that it can measure fiber from only one end, you can't change the laws of physics.

### Resolution Limitations

The next thing you must understand is OTDR resolution. The OTDR test pulse, Figure 8, has a long length in the fiber, typically 5 to 500 meters long (17 to 1700 feet). It cannot see features in the cable plant closer together than that, since the pulse will be going through both simultaneously. This has always been a problem with LANs or any cable plant with patchcords, as they disappear into the OTDR resolution. Thus two events close together can be measured as a single event, for example a connector that has a high loss stress bend near it will show up on the OTDR as one event with a total loss of both events. While it may lead you to think the connector is bad and try to replace it, the actual problem will remain.

Another place this problem shows up is in splice closures. An OTDR may show a bad splice, but it can actually be a crack or stress point somewhere else in the splice closure.




There is a tool that will help here. It is called a "visual fault locator". It injects a bright red laser light into the fiber to find faults. If there is a high loss, such as a bad splice, connector or tight bend stressing the fiber, the light lost may be visible to the naked eye. This will find events close to the OTDR or close to another event that are not resolvable to the OTDR. It's limitation is distance too, it only works over a range of about 2.5 miles or 4 km. If you are using an OTDR, you must have one to use it effectively.

### Special Consideration for Multimode Fiber

Most OTDR measurements are made with singlemode fiber, since most outside plant cable is singlemode. But building and campus cabling are usually multimode fiber using light emitting diode sources for low and medium speed networks. The OTDR has problems with multimode fiber, since it uses a laser source to get the high power necessary to cause high enough backscatter levels to measure.

The laser light is transmitted by multimode fiber only in the center of the core (Figure 9) because its emission angle is so low. LEDs, however, are transmitted throughout the core of the multimode fiber, due to their wider radiation pattern. As a result of the OTDR light being concentrated in the center of the fiber, the loss of connectors is lower because the typical connector offset errors are not in effect. And even the fiber has lower loss, because the light in the center of the core travels a shorter path than the light at the outer edges of the core

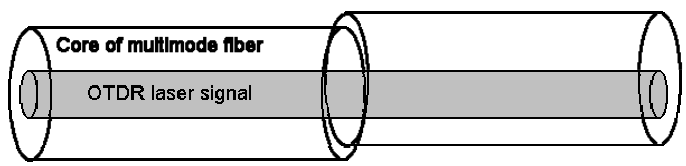



Figure 9. OTDRs only see the middle of the multimode fiber core

Several projects have tried to determine how to corellate OTDR measurements to source and power meter measurements, without success. Our experience is an OTDR will measure 6-7 dB of loss for a multimode cable plant that tests at 10 dB with a source and power meter.

### Measuring Fiber, not Cable Distance

And finally, OTDRs measure fiber not cable length. While this may sound obvious, it causes a lot of problems in buried cable. You see, to prevent stress on the fiber, cable manufacturers put about 1% more fiber in the cable than the length of the cable itself, to allow for some "stretch." If you measure with the OTDR at 1000 meters(3300 feet), the actual cable length is about 990 meters (3270 feet). If you are looking for a spot where the rats chewed through your cable, you could be digging 10 meters (33 feet) from the actual location!