FOA
1-760-451-3655 Fax 1-781-207-2421
www.foa.org   info@foa.org

More On Optical Time Domain Reflectometers (OTDRs)

We seem to not be able to say enough about OTDRs, since they are so poorly understood and routinely misused. These short articles are reviews of certain topics that you should understand in order to use them properly.

Setting up the OTDR parameters properly makes measurements easier to interpret.

The Optical Time Domain Reflectometer, or OTDR, is an essential instrument for characterizing long outside plant fiber optic cables. The OTDR is the only instrument capable of verifying inline splices on concatenated fiber optic cables and locating faults. An outside plant installer will have an OTDR on hand to test every splice made as its done, so bad splices can be fixed before the splice closure is sealed.

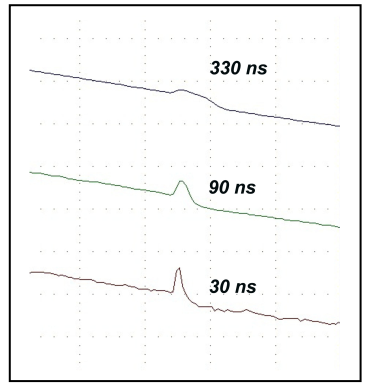
Why aren't OTDRs more common in premises cabling? First of all, premises cabling is almost never spliced. Continuous cable runs are terminated in connectors that interconnect cables at patch panels. Secondly, the OTDR has limited distance resolution, making it hard to even see short cables typical of premises applications. Finally, the OTDR uses an indirect measurement technique that gives different losses than a light source and power meter, the method that insertion loss is tested according to all standards. (We're not even addressing the high cost of the OTDR which has traditionally limited its use!)

But some end users and contractors persist in using OTDRs to test short premises cabling systems, in spite of the drawbacks. I'm personally aware of several instances where contractors used OTDRs improperly and rejected perfectly good cable plants, once at enormous cost. If you find yourself in a situation where you must use an OTDR, we can at least give some advice on how to minimize the chance for making a costly mistake.

The successful use of an OTDR on premises cabling requires knowing how to operate the instrument, choosing the proper measurement parameters and correctly interpreting the traces. All OTDR manufacturers have an "autotest" function on their instrument, similar to Cat 5e/6 UTP cabling certifiers. However, the OTDR does not always test virtually the same cabling setup, so its operation cannot be as easily simplified. The OTDR user should ever use the autotest function before analyzing one fiber trace from a cable to ensure the instrument is properly set up and the autotest function is giving valid data.

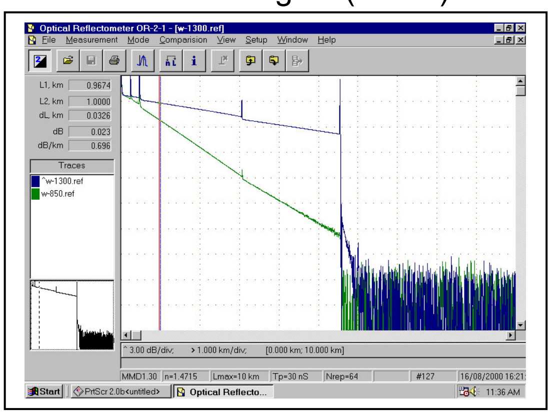
Let's assume you're trained on the operation of the instrument you are using and have some basic understanding of OTDR traces. (See Lennie Lightwave's Guide for more information on using OTDRs.) Connect the OTDR to the cable or cable plant you want to test with a reference launch cable at least 100 meters long for multimode cable and 1 km long for singlemode. The connectors on the launch cable should be tested occasionally to ensure they are in good condition, just like reference cables for insertion loss testing with a light source and power meter.

The first OTDR parameter to set is the range, which is the distance over which the OTDR will measure. The range should be at least twice the length of the cable you are testing, usually 2km for premises cabling. Longer ranges will make the resolution of the trace poorer and shorter ranges may create distortions in the trace.



Then set the OTDR test pulse width to the shortest pulse width available which will provide the highest resolution (right), giving the best “picture” of the fiber being tested. This is usually listed in nanoseconds (ns), with typical choices of 10-30 ns.

Next choose the wavelength. Normally you start with 850 nm on multimode fiber and 1310 nm on singlemode, since the shorter wavelength has more backscatter so the trace will be less noisy. After initial tests, you can make measurements at the longer wavelengths (1300 nm on multimode and 1550 nm on singlemode) and compare traces at the two wavelengths (below).



The final parameter is the number of averages for each trace. To improve the signal to noise ratio of the trace, the OTDR can average multiple measurements, but more averaging takes more time. Usually 16-64 averages are adequate.

Now take a test trace and look at the display and answer these questions:

Is the trace noisy? If so, more averaging may be needed.

Is the end of the fiber at the distance expected, based on you knowledge of the length of the cable? If you don’t know the approximate length of the cable, it is easy to become confused by trace artifacts like “ghosts” (my EC Column of April, 2006).

Are the connections visible? Connectors should have high reflection peaks to identify their positions. Are there any peaks where connectors should not be? Those could be ghosts.

Depending on the answers to these questions, you may need to change some of the parameters and take another trace. Once the trace looks good, measure the lengths of individual fiber links and the losses of all the connectors. Save that trace to compare with other fibers in the same cable, to make sure all have similar traces.

Finally, try the “autotest” function on the OTDR. If the results are similar to the results obtained from the first test, you can feel confident in using it for the other fibers, saving lots of testing time.

The Wrong Way To Use An OTDR.

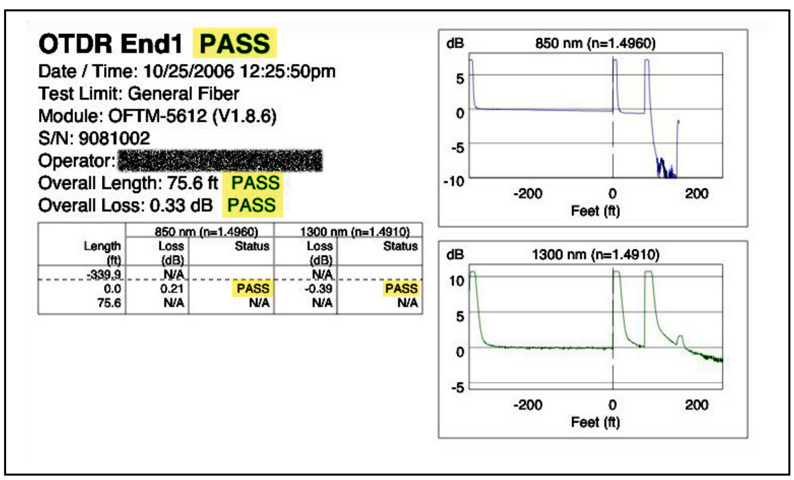
This is an example of the wrong way to use an OTDR and the kinds of trouble it can cause.

Since a Internet search on “fiber optic testing” will get you directly to me or to The Fiber Optic Association, which we help run, many people confused about fiber optic testing end up calling me. This is one such case. The first call was from an end user, and, as many do, started with “What is an acceptable loss for my fiber optic cables?” I immediately sent them to the FOA website for “Tech Topics” (http://www.thefoa.org/tech/) where there are two pages addressing this topic, calculating “loss budgets” from the standpoint of the network designer and “expected measurement results.”

The second call asked if they could send me some documentation submitted to them as confirmation that the installation was completed and would I examine it and give my opinion. After reviewing the OTDR traces they sent me, one of which is reproduced above, I asked if this was what the installer provided for documentation. It was.

Close examination of the traces tells us that the OTDR was connected to the cable being tested with a launch cable of adequate length to allow the OTDR receiver to settle down after the test pulse, but the cable under test was only about 76 feet long, awfully short for OTDR testing. The pulse width at 850 nm was short enough at least to see both ends of the cable, so we know that no receive cable was used in the testing. Thus the OTDR test was only useful for measuring the loss of the first connector and perhaps finding faults in the fiber of this short cable.

At 1300 nm, the pulse width was so wide that the reflection at the connection between the launch cable and cable under test overwhelmed the OTDR, masking any details of this short 76 foot cable. Since the pulse stretched the full length of the cable under test, it was impossible to measure the connection loss or see any details in the cable itself.



But wait – at 5 points on the OTDR documentation it says “PASS” anyway. The 850 nm data gives a loss of 0.21 dB, but since we do not know the location of the markers, we don’t know if it’s just the loss of the connection to the launch cable or includes the fiber loss. Since 76 feet of fiber has only about 0.08 dB loss, it’s not important. Let’s give the OTDR the benefit of the doubt and say a “PASS” is OK here.

However, for 1300 nm, it shows a loss of “-0.39 dB” – that’s a GAIN, not a loss, but it says PASS anyway. Anytime an OTDR indicates a gain, it needs some operator interpretation of the actual trace. And a knowledgeable operator would have thrown this trace out because it's too short for the OTDR to measure at all.

To satisfy my own curiosity, I asked the OTDR manufacturer why the OTDR gave a "PASS" to this data. Bottom line, it's all in the programming. "Garbage in – garbage out."

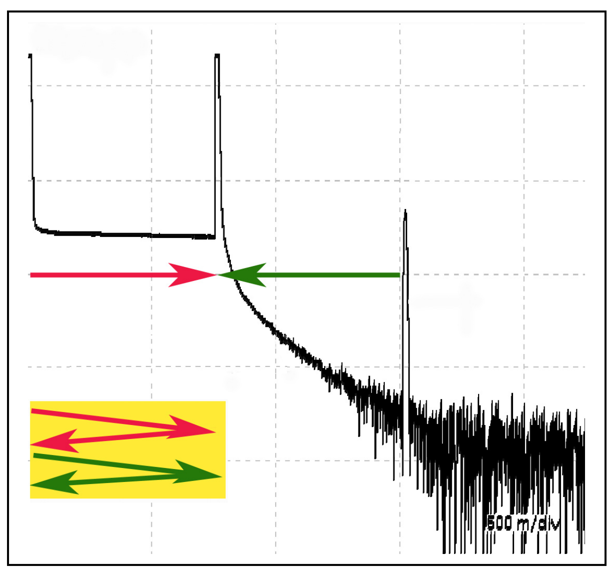
I explained all this to the caller, plus I pointed out that acceptance testing to industry standards required insertion loss testing, not OTDR testing. That caused another call, a conference call also involving the contractor, where we discussed the relevant testing standard and procedures for loss testing. In that conversation, it was revealed that there were about 30 cables with a total of 1,000 fibers involved in the installation, and the installer would be required to retest most of them.

All told, I spent about ten hours on this project. It became so frustrating to explain the proper methods that I created a new document on the FOA website to explain fiber optic testing methods: http://www.thefoa.org/tech/VDV4W.pdf. If you need to know about fiber optic testing procedures, I suggest you download this document and study it.

And if you think it sounds bad to have to retest 1,000 fibers, someday I'll tell you about a contractor on another installation and removed and destroyed about $100,000 worth of perfectly good cable due to a similar OTDR testing mistake.

Ghostbusters: interpreting ghosts OTDR traces

The optical time domain reflectometer (OTDR) has been an important tool for fiber optic testing and troubleshooting since it's invention 25 years ago. You should know by now that OTDRs use backscattered light from the fiber to imply fiber attenuation and splice or connector loss and they are not an acceptable substitute for insertion loss testing. You should also know that connectors are often characterized by a large reflective peak on the OTDR trace caused by the imperfect joint between two fibers.



That intensity of the reflection from a connector joint can be measured to determine the reflectance or return loss of the joint. If the reflection is too high, it can overload the OTDR receiver and cause errors in attenuation measurements or diminish the OTDR's ability to resolve close events. You can tell when a reflected peak is overloading the OTDR because the peak will be flat on top.

But a more confusing effect of reflections is what we commonly call "ghosts," confusing events that show up on the OTDR trace that really aren't there. Ghosts are caused when the OTDR tests a cable with two highly reflective events, one of which is often at the OTDR interface itself.

Since the fiber optic connector on the OTDR will have cables plugged into it every time the OTDR is used, it generally becomes dirty and scratched, even if it's regularly cleaned – as it should be. Likewise the launch cable used to reduce the effect of the reflection at the OTDR connector often suffers from too many connections to cables under test, so it becomes reflective too.

When the OTDR sends a test pulse down the cable, the big reflection from the far end comes back to the OTDR where it shows up on the trace as a overloaded reflection, then is reflected from the OTDR interface back down the cable for a second trip - effectively becoming a second "test pulse" – which is reflected back from the far end yet again, going back to the OTDR to be recorded as a second trace. If the reflections are big enough, this process can go on 3 or 4 times, each time producing a "ghost" event on the OTDR trace.

A ghost trace looks like this one, which shows the absolute worst case, a cable plugged directly into the connector on the OTDR. You can see the initial pulse at the OTDR is flat-topped, as is the first pulse at the end of the cable, indicating both are beyond the range of the OTDR and are saturated. The colored arrows allow you to follow the path of the OTDR test pulse. Red shows the initial outgoing pulse and it's first reflection, green is the reflection from the OTDR that makes the second trip causing the ghost. The ghost appears at exactly twice the length of the actual cable on the OTDR trace. This location is the way most OTDR ghosts are unmasked.

The uninitiated OTDR user might think this trace shows a fiber with a break in the middle – a not uncommon assumption. I've known several users who replaced cables under these circumstances, when they mistakenly used an OTDR where a meter and source should have been used for a insertion loss test. One user asked me to test such a cable, wondering why it showed 20 dB loss in the middle of the cable on the OTDR trace. When an insertion loss test showed normal readings for a terminated cable, he was surprised. "Did you check the length on the OTDR," I asked? He retested the cable with the OTDR and he was astounded to find the trace to the "end" was twice the actual cable length, exactly what you expect with an OTDR ghost. He was tricked into thinking the cable had a break rather than checking the length and comparing it to the known length of the cable.

Of course, this is another good point: always compare test data to cable plant documentation. If you know the cable is a given length, you will look at that point for the trace and not be fooled by ghosts. Using an OTDR to measure cable length without documentation is asking for trouble.

And always, without exception, never connect a cable under test directly to the OTDR. Using a launch cable of known length and knowing the approximate length of the cable(s) under test will help isolate ghosts and prevent their confusing the actual test data.

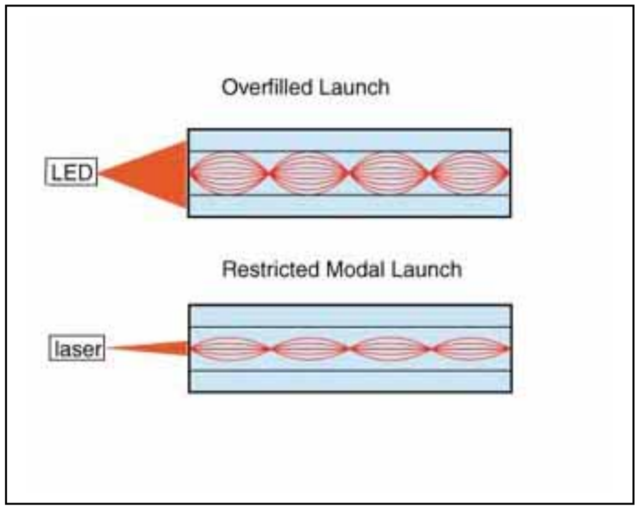
OTDR Vs. Insertion Loss Measurements

The problem always cited with OTDR measurements, especially on multimode premises cable plants, is they generally do not agree with insertion loss measurements made with a light source and power meter. The indirect measurement of the OTDR depends on the backscatter of the fiber which may not be a constant from fiber to fiber.

In addition, the laser source of the OTDR does not fill the modes of the fiber in quite the same way as most test sources and loss of both the fiber and connectors is highly dependent on mode fill.

But the renewed interest in using OTDRs in premises applications has spurred some research into the problem that may help bring OTDR measurements closer to insertion loss measurements. At a recent international standards meeting, I received some information from work done in the UK that indicates that some changes in test methods may finally offer hope for correlation of OTDR and insertion loss measurements.

First, one must deal with the modal distribution of the test source. Mode fill is a way of describing how light is carried in the core of the fiber. Light traveling in the center of the fiber travels a shorter path than light carried in modes that go all the way to the outside of the core and travel longer paths. The longer path the light takes going through the fiber, the higher the loss. To measure loss consistently, it is necessary to have the test source conditioned to always launch light the same way.



Even insertion loss measurements cannot be consistent unless the source launch power is properly conditioned, so multimode test standards specify the source characteristics to ensure all sources are similar. The same methods used to condition light sources for insertion loss measurements, mode scramblers and filters usually implemented by a mandrel wrap of the launch fiber, can be used with OTDRs. The mandrel wrap method is not as consistent as one would like, as its effect may depend on the cable design of the launch cable, including the stiffness of the jacket and amount of strength member fill in the cable. A reputed more consistent method, using mode conditioning patch cords, is now being used in Europe and is now becoming available in the USA.

Modal conditioning only affects the outgoing test pulse, however. At the current time, we can only speculate on the mode fill of the backscatter signal that sends light back to the OTDR for measurement. Educated guesses are the backscatter light has a higher mode fill, making loss in the return direction higher than the conditioned outgoing pulse. Enough interest in this question exists that it should be researched and answered in the near future, but while we may be able to understand it, we have no way of controlling it.

Having dealt with mode conditioning, we now have to deal with the different backscatter coefficients of different fibers. Scattering is the primary loss mechanism of fiber and the light scattered back to the OTDR provides the mechanism for OTDR testing. The backscatter coefficient is a result of two major fiber characteristics, core diameter (or more correctly, mode fill in the core) and the material itself. In addition, backscatter is wavelength dependent, but the wavelength of the test source is controlled by the manufacturer of the test equipment, which chooses sources in the proper range.

A difference in backscatter coefficient in two fibers causes a measurement error at joints (connectors or splices) between the two fibers. If more light is scattered after a joint, the measured loss will be less, or even show as a “gainer.” If less light is scattered, the measured loss will be higher. Either case can cause significant measurement error.

But, when testing a single cable with the OTDR, one has a launch cable on the OTDR and a receive cable on the far end of the cable under test, with both launch and receive cables made from a single fiber cut to length, the differences in backscatter coefficient cancel out. Simply cutting both the launch and receive cables, one after the other, from the same spool of cable allows the OTDR to test individual cables end to end without worrying about the backscatter coefficient errors.

All this may sound complicated, but it’s no more complicated than correctly setting up a light source and power meter for insertion loss testing. Test results I have seen from the UK indicate that on premises length runs, OTDRs can offer reasonably good correlation to insertion loss tests, but we have not been able to duplicate these results in our own tests (see next section.) We do not recommend using an expensive OTDR to test your installed cable plant when a light source and power meter will make measurements with less uncertainty, but use OTDRs for their troubleshooting capability.

Comparing OTDRs and Insertion Loss Tests With Multimode Fiber
From FOA-Sponsored Mode Conditioning Tests
By Eric Pearson and Jim Hayes
August 5-6, 2006

The FOA purchased two Arden Photonics “ModCon” modal controllers (http://www.ardenphotonics.com/products/mod_con.htm) for experimentation in loss and bandwidth testing on multimode fibers, comparing measurements made with different methods of mode conditioning.

For our first tests, we decided to try to repeat the correlation studies done in the UK that were referenced in the justification of elevating OTDR loss measurements to being equal to LSPM (OLTS) testing in new international standards.

Fiber: We obtained current generation OM2 and OM3 50/125 fiber from a major manufacturer for testing. Each fiber was spooled into 250m, 500m and 1000m segments and terminated with adhesive/polish ST connectors. Tested with the Tek OTDR, the attenuation rate of the OM3 fiber was 850 nm 2.13 dB / km, 1300 nm 0.43 dB/km.

Test equipment:

Tektronix Tekranger OTDR spec with filled launch
(http://www.tek.com/site/ps/0,,22-10554-INTRO_EN,00.html)
EXFO OTDR with non-specified launch (Model?)
Fotec S710 source + FM310 meter

Fotec source CPR is Category 2 at 850 nm,Category 1 at 1300 nm
OLTS launch and receive reference cables 2m, terminated by EP.
Mandrel: AFL Noyes plastic part for 50/125 fiber per TIA-568.

All OTDR tests were done with a 500m launch and 250m receive (tail) cable and analyzed manually.

We will present all data and comment, then conclude with comments, questions and recommendations.

Test Results

Test 1 - OTDR vs OLTS-short 250 m at 850 nm only. Test includes 250 m of fiber and two connections.

Fiber C250mC (C means connector)– Spool B fiber-OM3 - launch OM2 500M wOTDR @ 850 nm only

	OTDR Tek	OLTS
Mode Cond	Loss	Loss
None	1.30	1.45
Mandrel	1.25	0.88
Arden MC	1.29	1.26

For this low loss test, the OTDR and OLTS results are similar to the MC, but vastly different from the source with mandrel wrap. Neither the mandrel nor the mode conditioner has significant effect on the OTDR measurements.The OTDR does not seem to be launching with a fill as great as the Fotec 850 nm LED source. The vast difference in the source alone, mandrel and Arden MC are indicative of the difference between the mode fills of the modal conditioning methods.

Test 2 - OTDR vs OLTS – long, concatenated, 1 km, at 850 and 1300 nm

Fiber C250mC+C500mC+C250mC - B fiber-OM3 -1008m- launch OM2 500M

	OTDR			OLTS
Wavelength	Mode Cond	Loss (TEK)	Loss (EXFO)	Loss
850	None	4.16	4.10	5.06
	Mandrel	4.07	4.07	4.35
	Arden MC	4.14	3.98	5.02
1300.00	None	2.43		3.44
	Mandrel	2.54		2.52
	Arden MC	2.47		3.08

For this test, we added testing at both 850 and 1300 nm and tried a second OTDR. For these longer lengths of fiber with two intermediate connections, the differences between OTDR and OLTS are greater, as are the differences in OLTS tests with different mode conditioning.

Test 3 - OTDR vs OLTS - long - no midspan connections, 1.3 km - launch OM2 500M

Wavelength	Mode Cond	OTDR Loss (TEK)	OTDR Loss (EXFO)	OLTS Loss
850	None	3.41	2.13	3.12
	Mandrel	3.30	2.49	2.90
	Arden MC	3.38	2.11	3.29
1300	None	1.09	0.55	0.99
	Mandrel	1.01	0.41	0.72
	Arden MC	0.95	0.47	1.21

On the final test, we used a single length of fiber (1.295 km) to see what happens without connections. Note that the two OTDRs now differ greatly, with the Tek measuring loss significantly higher than the Exfo. Again, the mandrel wrap method with the OLTS has significantly lower loss.

Conclusions

Well, the first conclusion is that this comparison merits a lot more time than the weekend that we devoted to it because of the questions it raises. The data itself appears trustworthy, as the equipment and methodology were well controlled and measurements were reproducible within expected limits. However, we lacked time and more selection of equipment and components to gather more data and we lacked the equipment to measure actual mode fill to compare the different test conditions at the launch cables.

The second conclusion is that neither the bare source, mandrel wrap nor Arden MC should be accepted as a standard method of testing until more definitive research is done. As this is written (3/2007) a TIA subcommittee is being set up to do exactly that.

Thirdly, allowing an OTDR to be used instead of an OLTS for any cable plant based on the current data available is a premature conclusion. Two OTDRs can't always agree among themselves, a necessity before allowing them to be compared to OLTSs.

VDV Works offers an OTDR Self-Study Program with an OTDR Simulator that explains OTDR use. See http://www.vdvworks.com/vdvacademy/OTDRsim.html for details.