Single-ended Bi-directional OTDR Measurements

Application Note

Agilent Technologies

Introduction

It is well known that different loss information is likely to be obtained when OTDR measurements are performed from opposite ends of a fiber. Therefore, for calculating the true splice loss as an average figure and for accuracy reasons, installation and acceptance test procedures for optical fiber links require OTDR loss measurements to be conducted from both directions.

This application note describes a new OTDR measurement technique that offers the advantage of yielding the two-way average splice loss by taking only one measurement from only one end of the fiber. This approach saves the network installer time, reduces the risk of misinterpreting the measurement results, and even allows for the examination of fiber segments that are hidden by the OTDR's dead zone.

Overview

Before an explanation of the basic principle is given, it is necessary to provide some definition of the used terms. The first signal seen by the OTDR is a first order backscatter signal, which is the immediate response of the fiber to the forward traveling probing pulse and is confined in a timeframe that corresponds to the length of the fiber given by the light's round trip time. This signal is the well-known fiber trace which ends after the expected fiber length, and which is generally used to examine optical fiber links with an OTDR [1]. Higher order signals are generated by a stimulus signal that is either an echo (i.e. a reflected part) of the original probing pulse, or an echo of a lower order backscatter signal. Thus, without reflections in a measurement setup or on a fiber link, higher order backscatter signals cannot show up. With OTDR measurements these higher order signals are generally very undesirable as it is often difficult to tell them apart from real fiber signals. They do, however, always extend their duration beyond the length which corresponds to the fiber under test.

[1] Optical Test and Measurement Handbook. Chapter 11, Dennis Derickson (Editor), 2001.

Different forms of backscatter shapes are possible

A fiber's impulse response is always a straight line on a logarithmic scale, whereas the response to a reflected backscatter signal shows up as a curved trace. In this note the focus is on pulse reflections only. A more detailed report about these higher order phenomena with OTDR measurements was published in an article by the author in 1998 [2].

Until now, the degree of a backscatter response has not been widely discussed in literature. Therefore, a brief explanation will help to understand the context of this paper. The first order backscatter is well understood and defined unambiguously as the direct response to the launched laser pulse. In this application note the second order backscatter is defined as a response generated by a probing pulse that has been reflected once. The simplest second order backscatter signal to imagine is generated by the probing pulse that hits the fiber end and reflects back towards the OTDR again. In this case, a new scatter signal is produced which then moves in the direction of the fiber end. There it is mirrored like the previous pulse and travels towards the OTDR. This signal does not start to appear on the OTDR display before the first order backscatter signal ends.

Accordingly, third order backscatter signals are a result of a probing signal that has been reflected exactly twice, e.g. the first time at the end of the fiber and the second time at the beginning of the fiber. It is clear that with higher order, the number of possible response signals increases. Also, with higher order, the amplitude of the echo signal declines. Only under very extreme reflective conditions can third-order response signals be seen with a state-of-the-art OTDR.

On the other hand, it is prudent to remember that these echo signals exist with each OTDR measurement. However, as long as the user takes care of connector quality, their amplitudes are too small to have any adverse effect on the measurement results.

In Figure 1 backscatter signals of various orders are shown for a fiber with strong front and end reflections. The upper arrows indicate the travel direction of the probing pulse that generates the backscatter signals, emphasizing the reverse character of the second order backscatter. The step size, i.e. the power loss, between the adjacent backscatter signals depends on the return loss of front and end reflection.

The next section explains how OTDR backscatter echoes can be generated with very little effort.

[2] Reducing backscatter echoes in OTDR measurements. Josef Beller 1998.
http://news.testandmeasurement.com/feature-articles/19980611-272.html

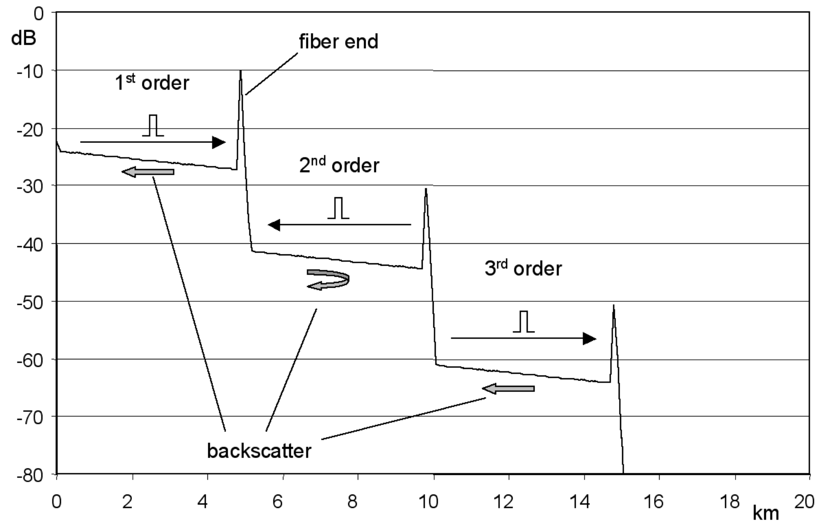

Figure 1: Backscatter signals of first, second and third order generated by a forward and backward bouncing probing pulse on a 5km fiber.

Simple backscatter echo measurements

A series of three easy-to-conduct OTDR measurements will explain how backscatter echoes can be generated and how they can be used advantageously for bi-directional measurements. Figure 2 shows the test setup: an OTDR and the fiber under test (a standard single-mode fiber of approximately 10km length) with FC/PC connectors.

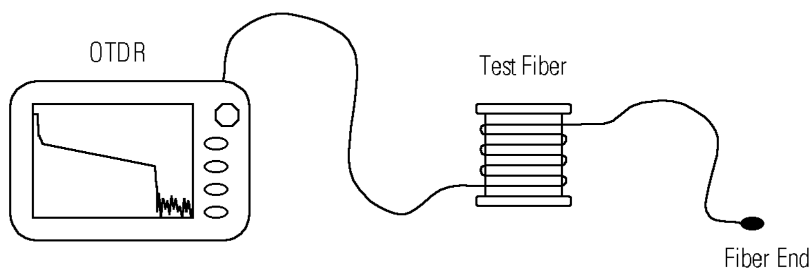

Figure 2: Test setup to generate a mirrored second order image of the fiber under test

For the first measurement, the fiber end is treated to suppress reflections completely. This can be conveniently achieved by wrapping the fiber around a mandrel several times. The following figures were taken with the OTDR set to 1310nm and 100ns pulse width. Of course, other wavelengths or pulsewidths are also possible. The acquired trace, displayed in Figure 3, shows the first order backscatter ending after 10.1km. As expected, no end reflection is visible. The straight FC/PC front connector exhibits a reflectance of approximately -35dB.

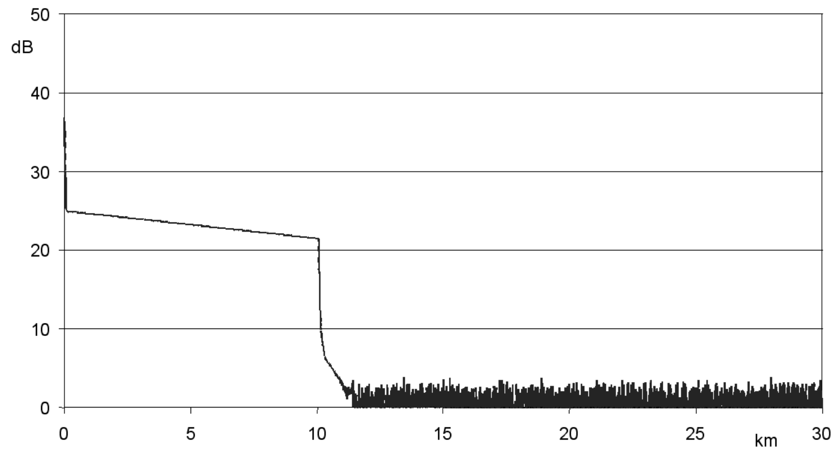

Figure 3: OTDR trace of a 10km fiber with terminated, non-reflecting end

In the second step, the mandrel wrap at the end has been removed. The OTDR measurement result shown in Figure 4 now reveals a clear end reflection. It is well known that a glass-to-air transition with a right-angled fiber end reflects roughly 4% of the light back into the fiber. This is equivalent to a -14dB reflection that exhibits a height of approximately 20dB on the OTDR screen with the chosen settings. Interestingly, compared to Figure 3, an additional signal extends after the fiber end. A closer look reveals a 14dB loss when comparing the power levels of the original and this second order backscatter signal. It is quite easy to understand that the difference in the power levels corresponds exactly to the reflectivity value at the fiber end. When comparing Figures 1 and 4, the different form of the echo signal is significant. The curved transition from the end reflection to the settled power level is the response of the OTDR receiver to a large change in optical power. Depending on instrument settings, i.e. pulsewidth or wavelength, and type of OTDR, the shape of the transition region of the second order signal varies.

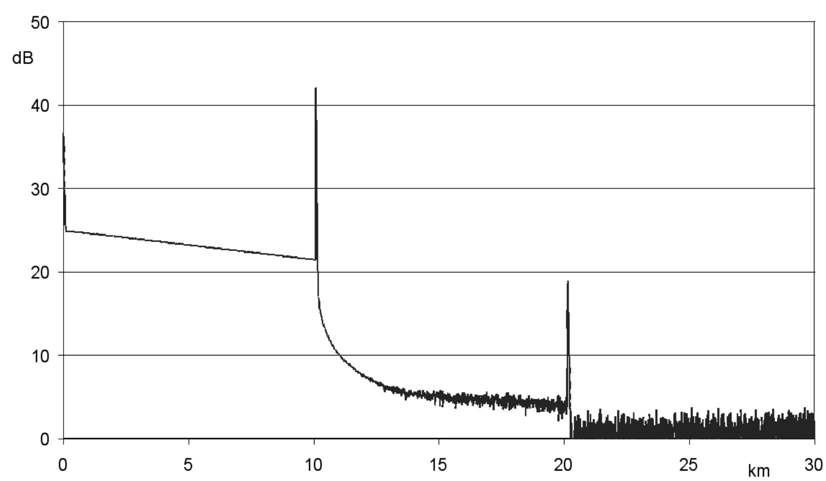

Figure 4: OTDR trace of a 10km fiber with open, unterminated end

Figure 5 gives a more detailed explanation of how the second order backscatter develops. As long as the probing pulse travels towards the fiber end, the backscattered signal which is traveling in the opposite direction provides the information for the fiber signature seen from A to B. At the very moment the pulse reaches the mirror, it is reflected with an amplitude in proportion to the reflectance value.

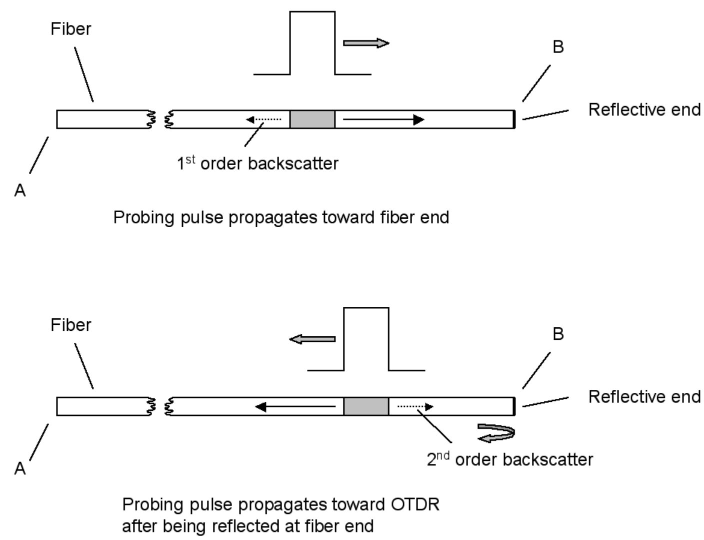

Figure 5: Pulse propagation in fiber with mirrored end

In order to reach the OTDR, the newly-generated second order backscatter needs to be bounced back at the reflective end. It is easy to understand that the signal that is acquired by the OTDR now represents the fiber's signature seen from B to A, and is proportional to the strength of the end reflection.

Consequently, if the reflection at the fiber end becomes stronger, the echo signal must develop in intensity too. Pushing this idea to the extreme case of a total reflection at the fiber end, the backscatter signal should continue without noticeable loss. As a matter of fact, the measurement result in Figure 6 reveals this detail clearly. In this case, a connector coated with a thin layer of gold with almost 100% reflectivity was attached to the fiber end. The OTDR displays a fiber signature, which at a first glance would make one believe that there were two pieces of fiber with a total length of about 20km, coupled with a defective (strongly reflective) connector. Actually, as is known, there is only one fiber segment of 10km in length, which has also been used for the measurements in Figures 3 and 4. The dead zone caused by the extremely strong reflection is also visible. As this dead zone hides the beginning of the echo signal, the evaluation of the distant fiber end from the reversed direction is prevented. To avoid this drawback a lead-out fiber can be used to cover the affected region. Furthermore, residues of the third order backscatter can be seen starting after the last reflection.

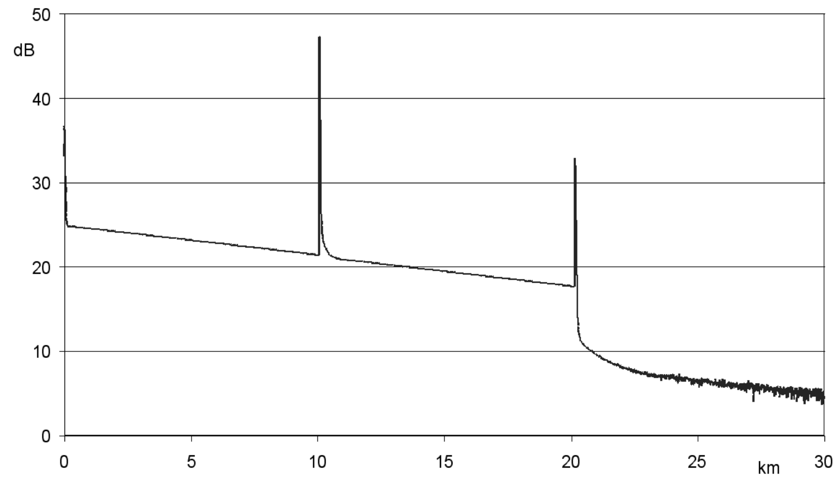

Figure 6: OTDR trace of a 10km fiber with 100% reflection at fiber end

True splice loss derived from one single OTDR measurement

With this basic understanding in mind, the real advantages of this method can be grasped at once with an advanced measurement setup shown in Figure 7. We now slightly modify the previous test setup. Two fiber segments, each with a length of 1.55km, are coupled via a splice and a connector to the 10.1km fiber spool of Figure 2. A 100% mirror is connected to the very end of the fiber link. The last fiber is added as a lead-out fiber to absorb the dead zone effect of the strong mirror reflection. In order to experience the effect of a direction-dependent splice-loss, fiber A and fiber B must not be of the same type. Only in such a case will the different mode field diameter of the fibers lead to different loss figures.

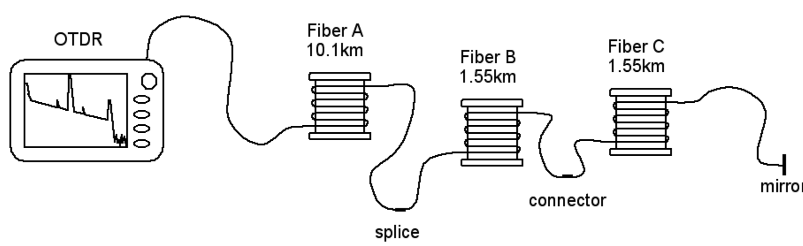

Figure 7: Test setup to reveal the true splice loss from a single-ended bi-directional measurement

The result of the OTDR measurement is shown in Figure 8. At approximately 13km distance, the strong mirror reflection divides the trace into two halves.

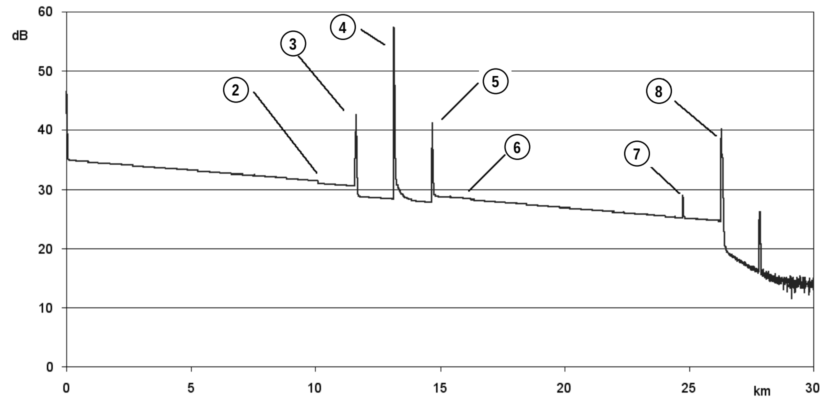

Figure 8: Concatenated fibers with splice (2) and connector (3)

Although the picture shows a fiber link more than 25km long, the total length of the concatenated fibers is only about 13km. The highest reflection 4 stems from the mirror at the end, which redirects the OTDR pulse back into the opposite direction. The probing pulse moving away from the OTDR generates a splice 2 which can be seen at a distance of 10.1km. The same splice 6 shows up again at a distance of 16.2km but this time created by the pulse on its way back towards the OTDR. Another event, namely the connector reflection 3 is likewise represented a second time as reflection 5, again seen from the opposite direction. The smaller single reflection 7 is a ghost signal that does not correspond to a real event on the fiber link but is due to multiple reflections.

From this measurement result it also becomes clear that a lead-out fiber is helpful to cover the long decay after the mirror reflection 4 with a reflectance close to 0dB. Another point that catches the eye is the reflection 8 at the end of the echo. It occurs at the very moment when the pulse has traveled along the fiber twice in both directions and eventually hits the OTDR again. The near-end zone of fiber A is fully visible before this reflection without any blinding by the front connector peak.

Some quantitative results from the OTDR trace analysis software are listed in Table 1. When looking at the insertion loss of event 3 one undoubtedly thinks of a particularly bad or dirty connector. Later, however, we will see that with the additional loss information gained from the other direction, i.e. from event 5, the true insertion loss actually turns out to be quite normal.

Event no.	Position km	Event Type	Insertion Loss dB	Reflectance dB
2	10.10	Splice	0.389	NA
3	11.65	Reflection	1.690	-35.0
4	13.20	Reflection	0.074	- 0.8
5	14.75	Reflection	-1.111	-34.6
6	16.30	Splice	0.151	NA

Table 1: Excerpt from the OTDR's Event Table

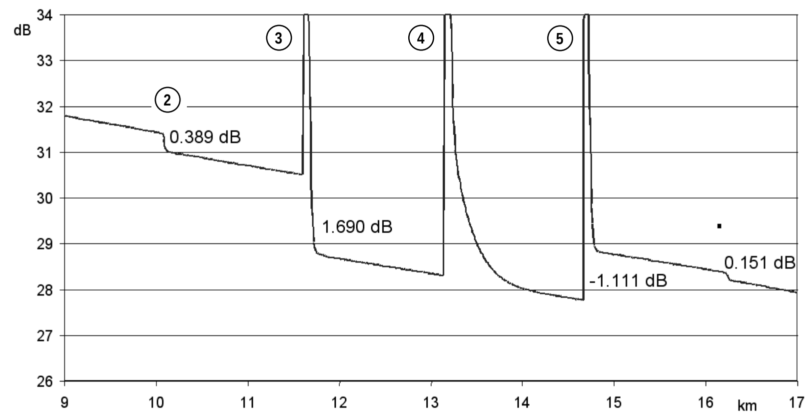

Figure 9: Detail from Figure 8.

Table 1 delivers the two unidirectional insertion loss figures for both events **2** and **3** that are needed to calculate the average true loss values. A simple calculation yields for the average splice loss of event **2**

$IL_2 = 0.5 \times (0.389 + 0.151) = 0.270$ dB

and for the average connector loss of event **3**

$IL_3 = 0.5 \times (1.690 - 1.111) = 0.289$ dB

Event no.	Position km	Event Type	True Insertion Loss dB	Reflectance dB
2	10.10	Splice	0.270	NA
3	11.65	Reflection	0.289	-35.0

Table 2: Re-calculated true loss figures for events **2** *and* **3**

As the complete measurement data is acquired and stored in one file, and the corresponding events seen from both directions are positioned symmetrically to the mirror reflection, the mapping of events and the calculation of the average loss figures can be accomplished with ease.

From the measurement results given in Figures 8 and 9 a few interesting but also obvious facts can be extracted:

- with a 100% reflection at the fiber end a second order backscatter signal with maximum strength can be generated
- the second order signal is a mirrored image of the first order backscatter signal
- dead zones are completely eliminated, as affected fiber segments can be fully inspected in the echo part from the reverse direction
- with different types of fiber the splice loss figures are directional
- the averaged bi-directional insertion loss data can be determined with one measurement

For fiber installation and acceptance tests, this converts into the following advantages:

- only one OTDR at one fiber end is required
- immediate results, fast and easy splice verification
- unequivocal pairing of measurements and fiber events from A to B and B to A
- elimination of dead zones
- complete result is contained in one measurement and saved in one file
- reduction of total test time

It must be remembered though, that the mirror at the end of the fiber link increases the susceptibility for ghost reflections. Also, as a fiber now is displayed as twice its length, the applicable distance range with a given OTDR is cut in half. To compensate for that, an OTDR with a higher dynamic range can be used.

Conclusion

Determining the true insertion loss requires OTDR measurements that probe the fiber under test from both directions. With the conventional approach a fiber link is tested from both ends leading to two measurement results taken at different times and under different environmental and ambient conditions at two locations. With the method proposed in this note, by means of a mirror device at the fiber end, just one measurement from a single end delivers all the information required to calculate the true average loss. This single-ended measurement offers a huge advantage in terms of time, logistics, result reliability and processing effort.

Related Hardware

Agilent 81000BR Reference Reflector.

Related Literature

E6000C Mini-OTDR	Brochure	5988-2238EN
N3900A Modular Network Tester	Brochure	5988-8188EN
N3900A Modular Network Tester	Data Sheet	5988-8190EN
J2126A/J2127A Transmission Test Sets	Brochure	5988-7946EN
J2126A/J2127A Transmission Test Sets	Data Sheet	5988-2570EN
Ethernet in Telecommunications Transmission Networks	White Paper	5988-7800EN
Unlocking Business Opportunities in the Metro Market	White Paper	5988-7820EN
Identifying non-revenue generating circuits in SONET networks	Application Note	5988-8681EN
SONET networks - their structure and ability to report information on traffic status	White Paper	5988-8889EN

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