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Europacable Technical newsletter

Optical time domain reflectometer (OTDR) Principle and good practices

October 2023

This document is part of a suite of Newsletters published by EUROPACABLE:
We encourage recipients to read all of them and to pay particular attention to the Newsletter "Optical Reliability of optical infrastructure" and "Understanding an optical fibre cable datasheet".

The description given in this technical newsletter concerns the characterisation of optical fibre links by optical time domain reflectometry (OTDR), covering its principle, implementation, interpretation of results and good practice.

1. Reflectometers - essential measuring tools

Optical Time-Domain Reflectometers (OTDRs) are widely used in the FttH networks. These devices are an essential tool for: **characterisation, certification, maintenance and monitoring optical networks.** They characterise the length, attenuation and return loss (overall reflectance or Optical Return Loss (ORL)) of an optical link.
They are particularly practical to:

- Analyse individual events along a link: connection points (splices, connectors), potential cable damages;
- Identify stressed sections;
- Determine link lengths and fibre attenuations.

2. Operating principle of an optical time domain reflectometer

• Basics

The measurement principle is based on the phenomenon of light scattering by particles much smaller than the wavelength of the radiation which is called Rayleigh scattering. Rayleigh scattering results from the electrical polarizability of the particles. The oscillating electric field of a light wave acts on the charges within a particle, causing them to move at the same frequency. The particle, therefore, becomes a small radiating dipole whose radiation is scattered light.
If there are inconsistencies in the glass (e.g. fluctuations in the refractive index or changes in its chemical composition) a tiny fraction of the light propagating through the fibre scatters in multiple directions.
For an optical fibre, a tiny fraction of the incident light wave is scattered and backscattered in the opposite direction from which it came and is then collected at the injection port of the reflectometer. The magnitude of this backscattered is quantified by the backscatter coefficient, whose value is specific to each type of fibre and manufacturer.

• Measurement principle

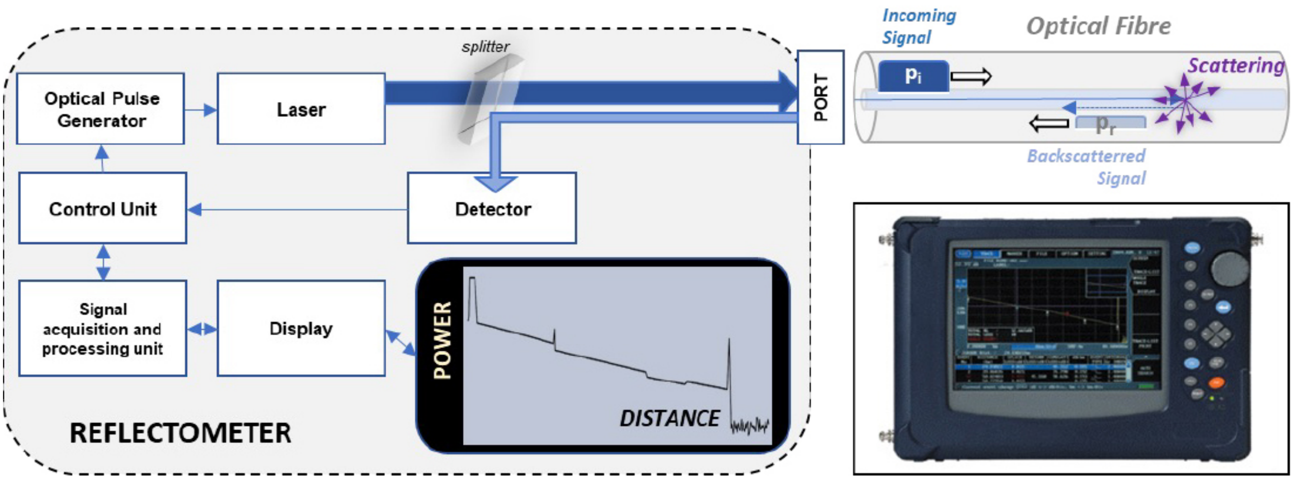

Figure 1: Diagram of an optical time domain reflectometer and example of an instrument (box)

Figure 1 describes how this principle is implemented in the instrument:

- A short light pulse (p_i) generated by a laser is injected into one end of the fibre being tested. As the pulse propagates along the fibre, some of the light is absorbed by the material and is also attenuated at discrete positions (splices, connectors, stresses, curves, etc.).
- Some of the light is also backscattered (p_r) along the fibre and thus "reflected back" to the reflectometer.
- The OTDR collects the backscattered power from the moment of transmission, converts the time differences into positions (the speed of propagation in the fibre is known) to display the backscattered power depending on the position along the fibre. This information is displayed on the equipment screen as a trace representing the optical power according to the distance from the position of the injection port.

The resulting trace contains a wealth of information and can be analysed manually or automatically by the instrument. Individual events (connectors, splices, local stresses, fibre end ...) and their nature (reflective or attenuating) are detected, analysed and catalogued for comparison with the associated success and failure thresholds. All the traces and analyses can then be exported for the preparation of the data file.

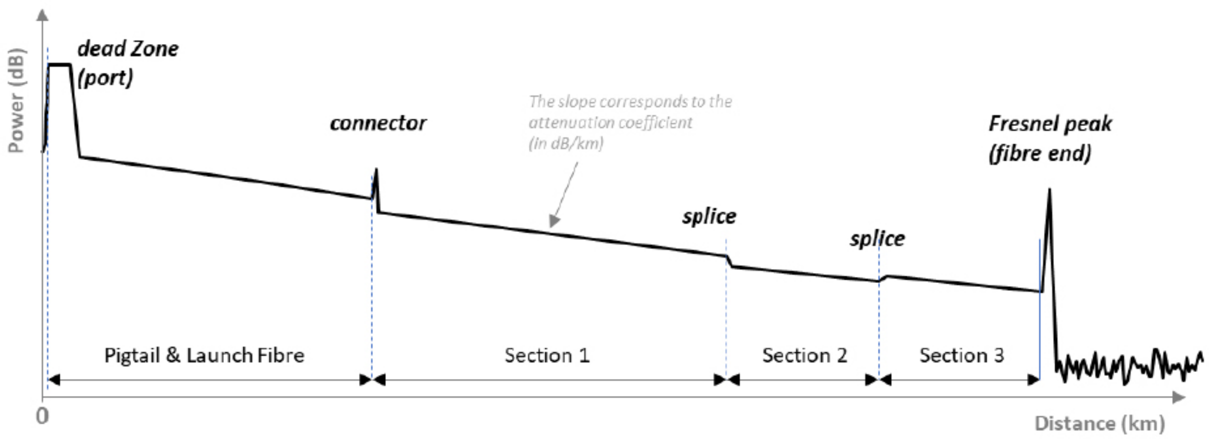

Figure 2: Example of a trace obtained by the instrument, for a link comprising three optical fibre sections. The linear attenuation coefficient (in dB/km) of the fibre over a given section is easily evaluated by the trace slope over the section.

Using different wavelengths (1310 nm, 1550 nm, and 1625 nm) is a way of evaluating the link in greater detail to detect more particularly issues of excessive loss due to bending or pinching - with attenuation increasing more strongly at longer wavelengths in the presence of stresses.

• Parameter setting

Setting the various parameters requires a compromise between the resolution and the dynamic range to be guaranteed. It also depends on the type of network to be characterised (overall length, density of optical devices). A larger pulsewidth will allow the measurement range to be increased and/or accommodate links to higher loss equipment but will result in degraded resolution and larger dead zones.
The table below summarises these interactions.

	Interaction between parameters	Increased pulsewidth ↗	Decreased pulsewidth ↘
Implications	Resolution	↘	↗
	Measurable fibre length	↗	↘
	Dead zone	↗	↘
	Dynamic range	↗	↘

Over the past decade, the acquisition and processing of measurements have simplified the development of new analytical and 'intelligent' testing capabilities. Reflectometers can now automatically perform link and feature recognition of the items in use, setting the optimal acquisition conditions (wavelengths and pulse duration), consolidating the results obtained for each optical link section and item present, giving a more reliable pass/fail decision for each parameter.

The main parameters and technical characteristics for measurement with an OTDR

1. The optical pulse width

The width of the optical pulse (pulse width) is the width (duration) of the pulse in the time domain (i.e. 10 ns corresponds to 1 m in single-mode fibres). It is defined by the laser emission time.

- The shorter the pulse, the less energy it carries and the shorter the maximum attainable distance, as the power of the backscattered signal at the end of the link is too low to be detected.
- Conversely, a longer pulse will carry much more energy and will allow the use over long distances (> 80 km).
- The pulsewidth also defines the resolution, or the ability to distinguish between two consecutive events close to one another. The smaller the width, the better the resolution will be.

2. Equipment dynamic range

The equipment dynamic range is defined by the maximum attenuation that the equipment will accept. It is also the maximum length of fibre that the longest available pulse can reach.

- The greater the dynamic range (in dB), the longer the attainable distance will be. Connectors, splices or splitters will reduce this theoretical maximum length in practice.
- The dynamic range of an OTDR for single-mode fibres is in the range of 25 to 40 dB, equivalent to typical link length from 50 to 100 km.

3. Acquisition time or averaging time

Time-domain averaging reduces the noise level and consists in acquiring thousands of individual traces and averaging them.

- A long averaging time will improve the signal-to-noise ratio, so that the analysis can result in a more detailed trace with more clearly defined events.

4. Attenuation dead zone

The attenuation dead zone is the distance over which the normal OTDR signal is distorted because the OTDR receiver is momentarily receiving too much power (temporary saturation of the receiver).

5. Event dead zone

The event dead zone is the minimum distance after a reflection event for which the reflectometer can accurately evaluate the individual characteristics of two consecutive reflection events.

- The smaller this dead zone, the more it will be possible to distinguish between two very close events. The length of the dead zone is related to the pulsewidth.

3. Precautions for use, implementation of a measurement

A good knowledge of the equipment and of the interpretation of results is essential to properly analyse and assess how relevant the results are; please see IEC TR 62316 Guidance for the interpretation of OTDR backscattering traces, for more information.

• Bi-directional measurement technology

The benchmark method for characterising link attenuation by reflectometry is to consider the average of the two OTDR traces obtained at each end of the link (i.e. bidirectional measurement).

Figure 3 illustrates this implementation for a link between two sites A and B: the first (unidirectional) measurement is made from site A and the second from site B. The results of each of the two measurements are then averaged.
In practice, a launch coil is inserted between the reflectometer and the network to be measured to avoid having a dead zone at the reflectometer output and to allow the characterisation of the first connector of the link.

- The coil length must be sufficient and adapted to the pulsewidth being used: 1,000 m is a typical used length for an FttH network. Similarly, adding a receive coil at the end of the link allows the last connector of the link to be measured by shifting the Fresnel reflection to the end of the coil.

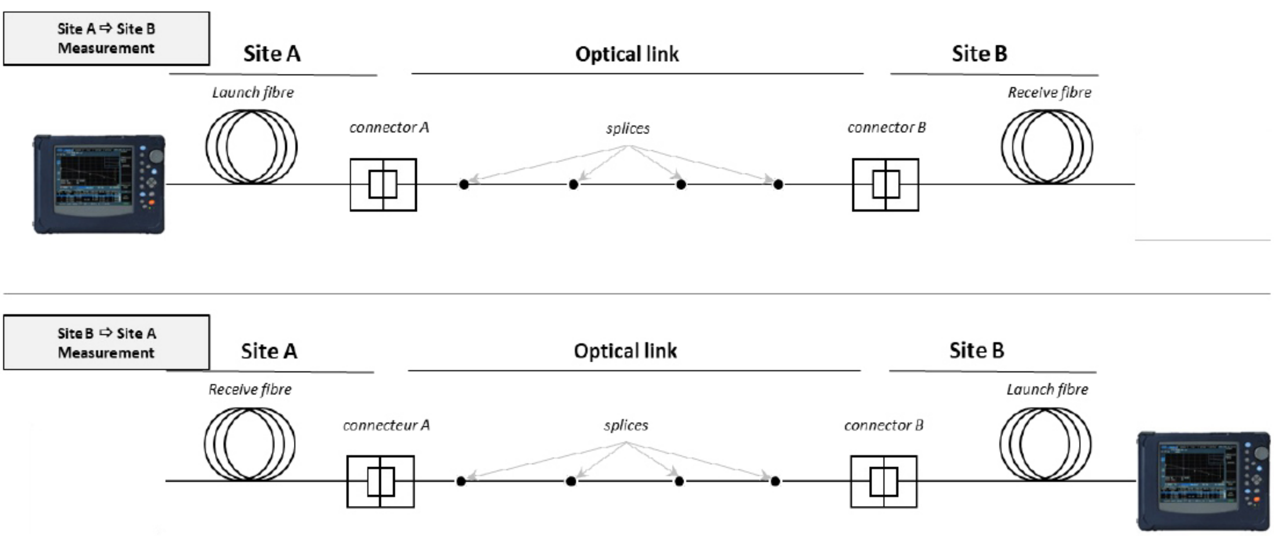

Figure 3: Illustration of the bidirectional measurement implementation by acquiring two unidirectional measurements at each end of the link.

Another method, known as looping, involves measuring two fibres simultaneously by connecting one fibre to the other, using an intermediate coil. This reduces the number of measurements and the need to move equipment from one end of the link to the other.

- For link lengths between 2 and 10 km, the recommended pulsewidth is between 20 and 100 ns.
- In the case of looping, the pulsewidth is less than 300 ns.

4. Interpretation of results: apparent losses and gains

In the optical distribution or access segments of FttH networks, it can be difficult and expensive to make bidirectional measurements as one end of the network can be neither connectorized nor accessed at the commissioning stage (in house termination). Using a single unidirectional trace is still feasible as a way of quickly assessing the optical continuity and estimating the attenuation coefficients, but the reliability of the event analysis may be affected by several phenomena, in particular the presence of fibres of different types and/or the difference between the backscatter coefficients of the connected fibres. **It is important to bear in mind that an OTDR measures the apparent losses of an event indirectly by indicating the power variations of the backscattered signal and implicitly assumes that the backscattering coefficients of the fibres upstream and downstream of the event are identical.**

If this is not so, the measurement may be inaccurate. If the fibres have different mode field diameters, two types of discontinuities may be visible at the splice.

Either the mode field diameter in the downstream fibre is smaller or it is bigger than the upstream fibre, meaning that a leading edge discontinuity (or apparent gain) can be indicated or otherwise a trailing edge discontinuity (or apparent loss). This effect is illustrated in Figures 4a and 4b. The effect is also due to the backscatter coefficient varying with the mode field diameter; the backscatter increases as the mode diameter decreases [6].

Depending on the direction of measurement, the apparent loss estimated by the instrument will be either a gain or a loss. To work around this situation, it is simply matter of taking into consideration the average value of the splice losses seen in both measurement directions. Although these backscatter coefficient differences do not always cause a gain on the OTDR trace, they can still produce a false splice loss reading, even if it is a loss.

Depending on the differences between the mode field diameters, the maximum contribution (see Figure 4c) linked to the difference in backscatter coefficients is:

- ±0.2 dB for fibres of the same type (same nominal diameter value and tolerance of ±0.4µm)
- up to ±0.3 dB for nominal mode diameter values (8.8 and 9.0 µm and tolerance of ±0.4 µm)
- The expected real splice losses are ≤ 0.1 dB.

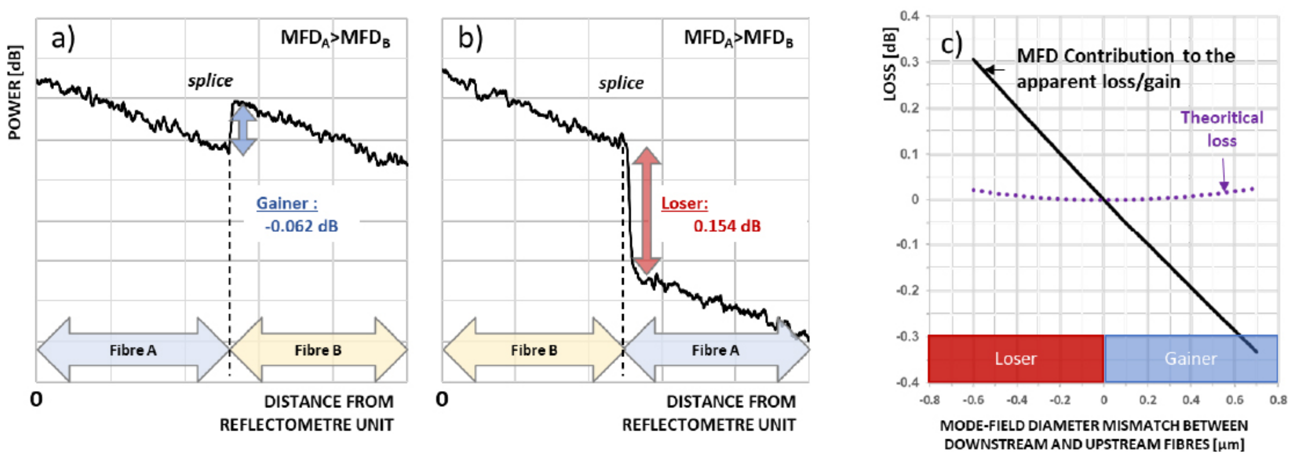

Figure 4: Example of a splice between two fibres A and B, with mode diameter mismatches of 0.2 µm (MFDA> MFDB):

a) Measurement direction A → B: apparent gain of -0.062 dB,
b) Measurement direction B → A: apparent loss of 0.154 dB. The average loss is ½- (-0.062+0.154) = 0.046 dB for a contribution of ±0.108 dB related to mode diameter mismatches for a unidirectional measurement.
c) Apparent contribution related to mode diameter mismatches for a unidirectional splice measurement (according to IEC TR 62316)

5. Good practice:

- **Recommendations for the implementation of access network optical reflectometry measurements**

Bi-directional measurements at 1310 nm and 1550 nm are recommended.
However, on the distribution optical segment a simple unidirectional measurement (at 1550 nm) is often performed to reduce the measurement time and cost. The unidirectional measurement is more accurate when using the same type of fibres (e.g. G.657.A2 with G.657.A2), in the case of a fibre type mixing (e.g. G.657.A2 with G.652.D), the apparent gain and loss strongly impact the results.
If there is any doubt about a loss due to an event, during a survey, only measurements in both directions

and an average of these measurements can be used to determine the real loss and to characterise an issue.
The quality of the preparation work and the proper maintenance of the equipment are essential to guarantee the quality of the measurements

- **All measurements should be made with instruments that have a valid calibration certificate. The conformity of the equipment used is mandatory to avoid the risk of deterioration of the network and its equipment.**
- **Connector cleanliness is an essential parameter to prevent any deterioration of the network and to guarantee the quality of the measurements. A large majority of issues encountered on an optical link are due to the connector cleanliness problems.**

Finally, the use of an OTDR requires prior training in both operation and interpretation of results. Such training is available from training centres and some equipment vendors.

References

[1] Standard EN IEC 61280-4-2: Fibre optic communication subsystem test procedures - Part 4-2: Cable installations - Measurement of optical reflection loss and single-mode fibre loss (link).
[2] Standard EN IEC 60793-1-40 Optical fibres - Part 1-40: Measurement methods and test procedures - Attenuation (link).
[3] IEC Technical Report TR 62316:2017: Guidance for the interpretation of OTDR backscattering traces for single-mode fibres. (link).

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