Dept. of Signal Theory and Communications and

Telematics Engineering

Higher Technical School of Telecommunications Engineers

GUIDED COMMUNICATION SYSTEMS

Testing fiber optic installations with OTDR

Noemí Merayo Álvarez

Juan Carlos Aguado Manzano

LEARNING GUIDE
TESTING FIBER OPTIC INSTALATIONS WITH OTDR

Index

1 Introduction

This guide is divided into two distinct parts. The first part explains the fundamentals of OTDRs, the main parameters that can be configured in most OTDRs and how the results obtained should be interpreted.

The second part constitutes the statement of the practice to be carried out, which will consist of facing an unknown configuration that simulates a plant fiber from which we want to obtain the most relevant events.

It is very important that you read the practice instructions carefully. It has been tried that the steps to follow and the procedures are very detailed. If you have any questions, ask the teachers who are in the laboratory with you, they will be happy to help you and explain a concept to you.

2 Objectives of the lab session

The objectives that are intended with this lab sessions are those that are detailed below:

- To get familiar with the OTDR (Optical Time Domain Reflectometer) equipment
- To configure an OTDR to obtain information about an installation with unknown events.
- To interpret the events that are obtained in the OTDR.

3 OTDR Operating principle

The OTDR (Optical Time Domain Reflectometer) is a device that will help us to verify that the optical links that we have in an installation meet a series of minimum requirements. These requirements are usually related to the total attenuation of the link, although it is not usually a good idea to use OTDRs to measure this attenuation. Rather, the OTDR is used to, once it has been verified that there is some type of problem in the fiber, to locate where this problem is and what it may consist of.

An OTDR is an optoelectronic instrument that visually represents different information about the plant fiber, such as the losses, length, position and condition of the splices and connectors and even the cuts that may have been produced in optical fibers. Therefore, OTDRs will be useful in certain situations such as:

- Long distance outdoor network installations, in which there are splices and connectors between cables, as OTDRs allows checking that they have been carried out correctly.
- The OTDR allows you to see stretching or bending in the fibers, caused by a bad installation.
- Locating cuts in fiber cables and checking repairs.

- In single mode fibers where reflections due to bad connectors can create serious problems, it allows them to be located very easily.

OTDRs, however, have a series of problems that must be known when using them, some of which we point out below:

- OTDRs should not be used to measure cable losses. This work is best done with a power source and meter.
- The limited distance resolution of the OTDR makes it relatively difficult for it to be used in LAN or building environments, where cables are typically a few meters long.

Unlike sources and power meters that measure fiber optic losses directly, the OTDR works indirectly. Its operating principles are based on the physical phenomenon of scattering. Dispersion is the most important factor in fiber losses. This phenomenon is due to the interaction between the laser photons and the fiber's own molecules or atoms. Thus, in the fiber the light is scattered in all directions, including backwards, as can be seen in the Figure 1. The OTDR uses this backscattered light to make its measurements. The procedure is relatively simple: the OTDR sends out a high-power optical pulse and measures the light that reaches it as an echo. At any instant in time the light that the OTDR sees is the light scattered by the pulse passing through a region of the fiber. This pulse can be thought of as a virtual source that progressively analyzes the fiber and sends the information to the OTDR. As it is possible to calibrate the speed of the pulse through the refractive indices, it is possible to establish a correlation between the instant of time in which the information reaches us and the point of the fiber in which it was produced.

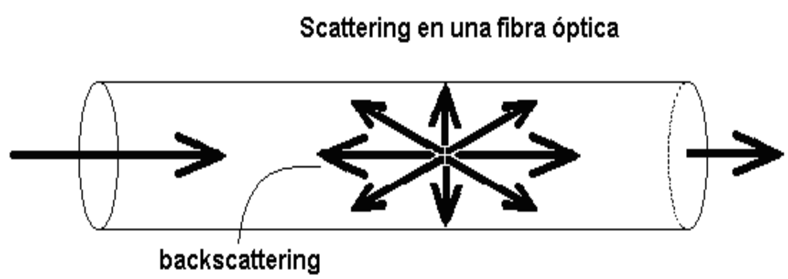

Figure 1. Light scattering in an optical fiber.

When we use an OTDR, what we are going to get is a graph like the one seen in Figure 2. In this type of graphs what we are going to locate are the so-called events. We will call event any situation in which there are reflections or losses other than the dispersion itself produced by the fiber. Examples of such events are all types of connectors as well as fiber failures such as bends or breaks. The vertical axis of the graph in Figure 2 gives us information on the power and the horizontal on the distance. In this particular trace we can highlight:

- Optical power decreases with distance.
- At the beginning and end we have two strong reflections.
- After the end of the fiber, the power level drops to the noise level of the device.

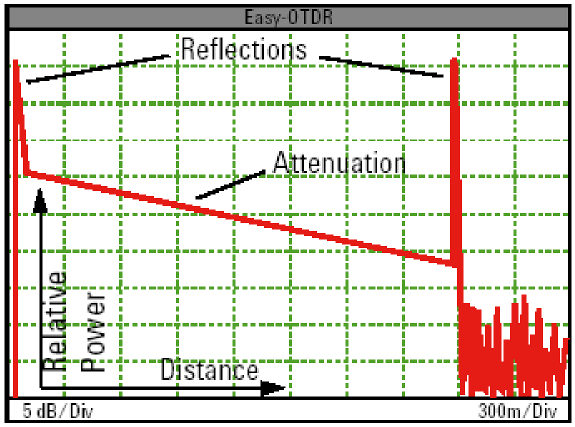

Figure 2. Typical result of a fiber link without any major events

This would therefore be the pattern for a link with a single fiber that is in perfect condition and does not have splices or connectors. But this is not usually the normal case. Mainly what we are going to be interested in is testing links in which there are usually splices and connectors, or if it is necessary to detect the location of a break or stress point. Let us therefore see each of the possible events that we are going to be able to find.

3.1 Types of Events

Connectors

The connectors are characterized by causing strong reflectivity (spike). Moreover, the normal situation in a fiber link is to have one connector at the beginning and one at the end of the link, so there will be two strong reflectivity peaks at both ends. The difference between the two is that at the extreme end, once the effect of the connector has passed, the signal level drops to the noise level of the device, as we can observe at the end of Figure 3.

Finally, fusion splices or mechanical connections are also characterized by a strong reflectivity peak that occurs in the middle of the plant fiber, but after that peak it is observed that the smooth descending line continues that indicates the normal losses of a fiber (Figure 4).

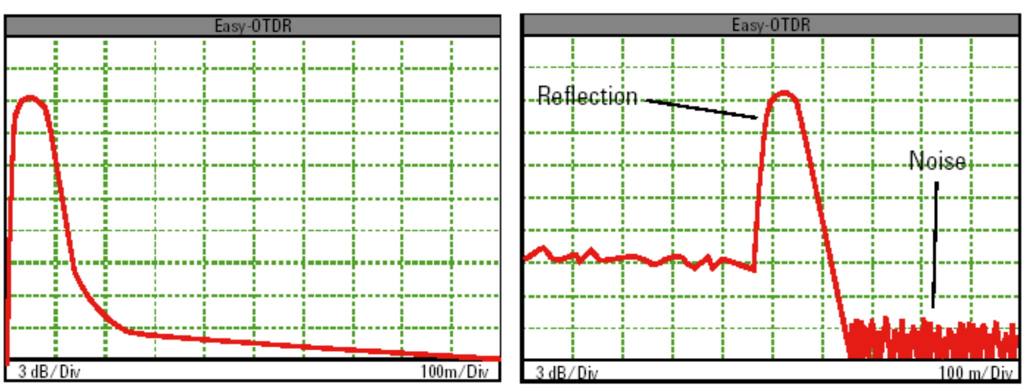

Figure 3. Reflectivity peak at the beginning and end of the fiber from the connectors

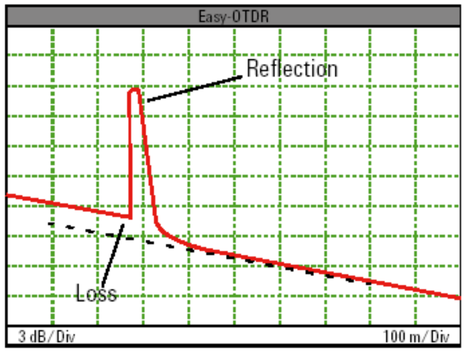

Figure 4. Pattern of a mechanical splice.

Cuts

Cuts are non-reflective events, there is a drop in intensity down to the noise level (Figure 5).

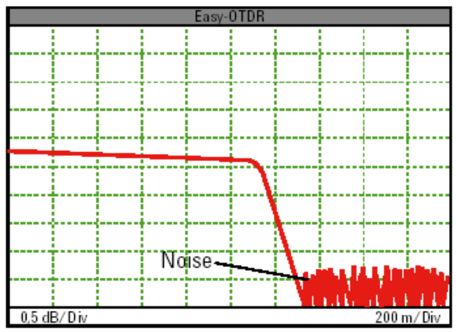

Figure 5. Pattern of a cut in a fiber.

Fusion Splices

Fusion splices don't cause a strong reflectivity (spike) since a refractive index jump does not occur. In this situation, it is normal to detect some type of loss (small) in the fiber (Figure 6).

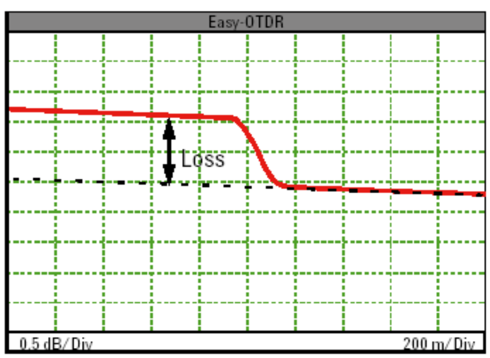

Figure 6. Possible graphs for the fusion splice event.

Curvatures

Curvatures are also non-reflective events. Therefore, the graph that we will see will be the same as in the case of a fusion splice. To distinguish both types of events there are two possible ways:

- Checking the installation and maintenance reports. These reports usually reflect all the splices and connections that the fiber has.
- Testing the system at different wavelengths since curvatures have greater losses at a higher wavelength, compared to splices whose losses are independent form the wavelength.

Cracks

A fiber that is partially damaged but whose continuity has not been completely destroyed, so it will introduce reflections and losses, as it can be observed in Figure 7.

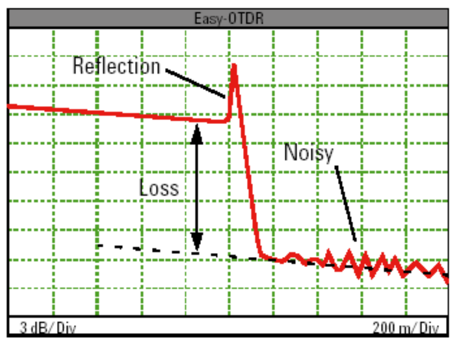

Figure 7. Crack patter in an optical fiber

Pigtails

We call relatively short lengths of fiber pigtails that have mechanical connections at both ends. This will cause strong reflection at both ends. However, they are not usually easy to see due to the low resolution of OTDRs in terms of distance, or rather, because one event usually masks the next due to its proximity. If the two events are far enough apart or if we establish adequate configuration in the OTDR we would see a pattern like Figure 8.

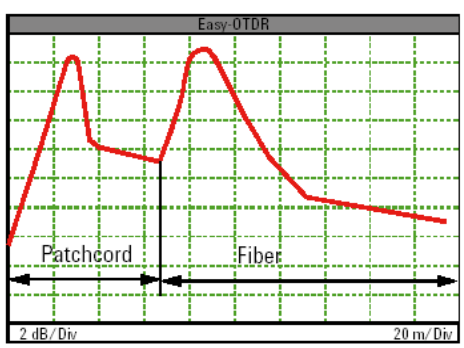

Figure 8. Patter of a pigtail.

A pigtail is usually placed between the OTDR and the plant fiber to be able to check said fiber from the beginning, since most OTDRs are not capable of analyzing the first meters that are located after their departure. In some cases, this pigtail can measure up to 1 km.

3.2 Configurable parameters in the OTDR

In the previous section we have learned what are the possible events that can be found in an installed optical fiber and how to distinguish one from the other. But to be able to locate these events it is necessary to establish a suitable OTDR configuration. The objective of this section is to know each of these parameters and their influence on the measure that is going to be carried out.

Refractive index

An OTDR calculates distances by measuring the time elapsed from the transmission of a light pulse to the reception of its reflection and the calculation of distance from time is done by means of the refractive index. Therefore, it is necessary to know exactly the fiber that we are using to calculate the distance. The calculation of the distance from time is done by means of the refractive index according to the following equation

$$n = \frac{c}{v} \Rightarrow dist = \frac{tiempoxc}{n}$$

This means that a change in the refractive index supposes the modification of the computed distance and therefore in the obtained trace. Therefore, it is necessary to know exactly the fiber that we are using to calculate the distance. Any variation in the refractive index will lead to large inaccuracies. Besides, since the refractive index is temperature dependent, it is possible in some OTDRs to set the total length of the fiber instead of giving the refractive index. In this way, the OTDR performs the calculation of the refractive index of the fiber based on this known data.

Dynamic range

The dynamic range of an OTDR determines how long a fiber can be measured (it is listed as a dB value) and larger values generally mean longer distance measurement capability. It determines the maximum power loss between the beginning of the backscatter and the noise peaks. If the tested system has a lot of losses, the end point is indistinguishable from noise. If you don't have as many losses, the end appears clearly above the noise and the breaks are clearly detectable.

The concept of dynamic range can be easily understood in Figure 9. It is important to note that the trace is affected close to the noise level. This is why the trace is often required to be about 6 dB above the noise level in order to measure a 0.1 dB splice attenuation, and 3 dB is needed to detect a break. Therefore, the dynamic range of the OTDR has to be at least 3 to 6 dB greater than the total losses of the system.

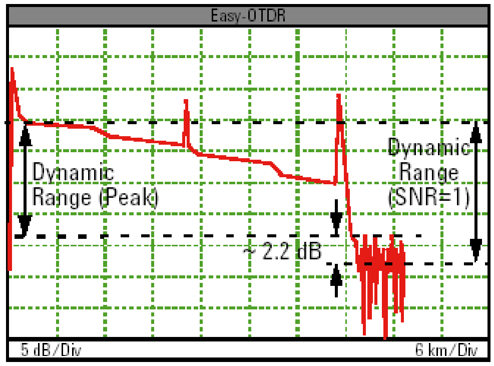

Figure 9. Dynamic range of an OTDR. It is the difference between the power at the beginning of the fiber and the noise level

The dynamic range is dependent on the instrument settings. The main influences are:

- Pulse width.
- Wavelength used.

Pulse width

This parameter determines the duration of the pulse emitted to the fiber optic link. A shorter pulse width is selected for short lengths as this maximizes resolution while minimizing power output. Short pulse widths are especially useful for evaluating cable segments closer to the OTDR and for detecting events near a connector or splice. Besides, longer pulse widths are useful when testing longer fiber links, as more optical power is required to produce sufficient backscatter at long distances from the OTDR.

Averaging time

In general, more accurate measurements are usually achieve by calculating the average of several repetitions of the same test. This principle is also valid for OTDR measurements. Longer averaging times, that is, based on a greater number of repetitions of the same test, will provide a measurement with a better signal-to-noise ratio, but require more time (Figure 10).

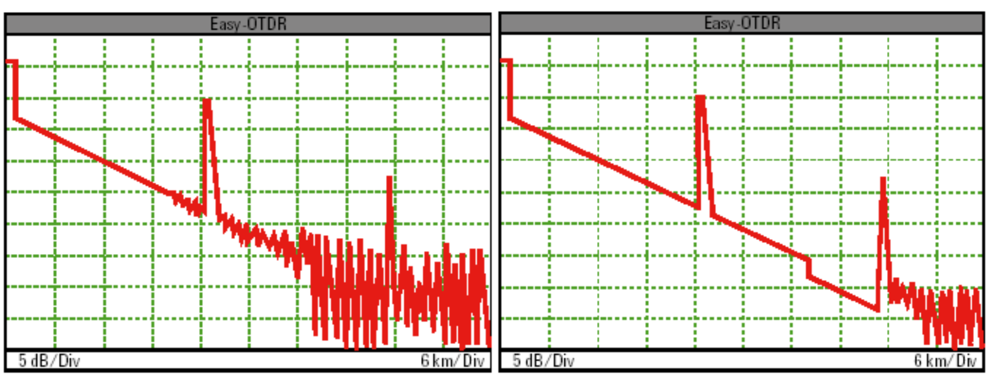

Figure 10. Result of a trace with a small averaging time and with a large averaging time

Scattering coefficient

The scattering coefficient is a measure of how much light is scattered back through the fiber. This affects the value of the return losses as well as the reflectance measurements. It is calculated as the ratio of the optical power of the pulse at the OTDR output to the backscattering power at the near end of the fiber. It is expressed in dB, and it is inversely proportional to the width of the pulse.

Deadzone

The event deadzone is the minimum distance needed to distinguish two events of the same type separately. For example, if we have two connectors separated by a couple of meters and we obtain a trace like the one shown in Figure 11, it can be interpreted as a reflection that has two intensity peaks. If the events were very close together, these reflection peaks would appear to be only one, so we would be unable to detect the second connector. This parameter depends fundamentally on the OTDR configuration and specifically on the pulse width that we use.

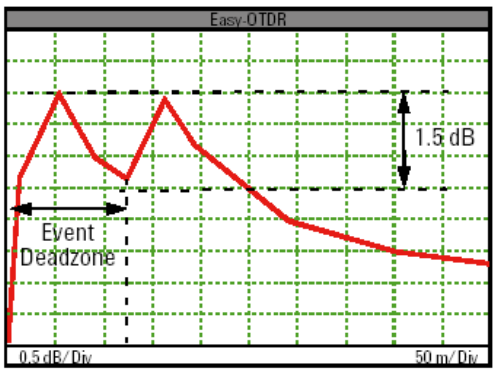

Figure 11. Dos eventos del mismo tipo juntos pero que se pueden distinguir.

3.3 Trace Errors and Measurement Considerations

A trace can lead to a misinterpretation, leading us to believe that there is a problem where it does not exist, or vice versa. The objective of this section is to review the most common mistakes that can be made in the interpretation of the traces, some of which have already been partially stated in previous points.

Launch fiber

As already mentioned, to measure the beginning of our fiber, it is interesting to use a launch fiber, which normally has a length of 500 m. The reason for doing this is that the power at the beginning of the fiber is very high, so that small reflections can saturate our receiver, creating quite large deadzones. In this order of things, the connectors used in this launch fiber must be with the minimum possible reflections.

Ghosts

When measuring short cables with highly reflective connectors it is very easy to find "ghosts". These are caused by light reflected from the far end connector, which is reflected back along the fiber until it is attenuated to the noise level. The "ghosts" are very deceptive, as they look like reflective phenomena as connectors, but they do not show any loss. If a reflective phenomenon is found at a point where no connector is assumed and a launch cable with highly reflective connectors is being used, ghosting may appear in multiples of the launch cable length. An example can be seen in Figure 12.

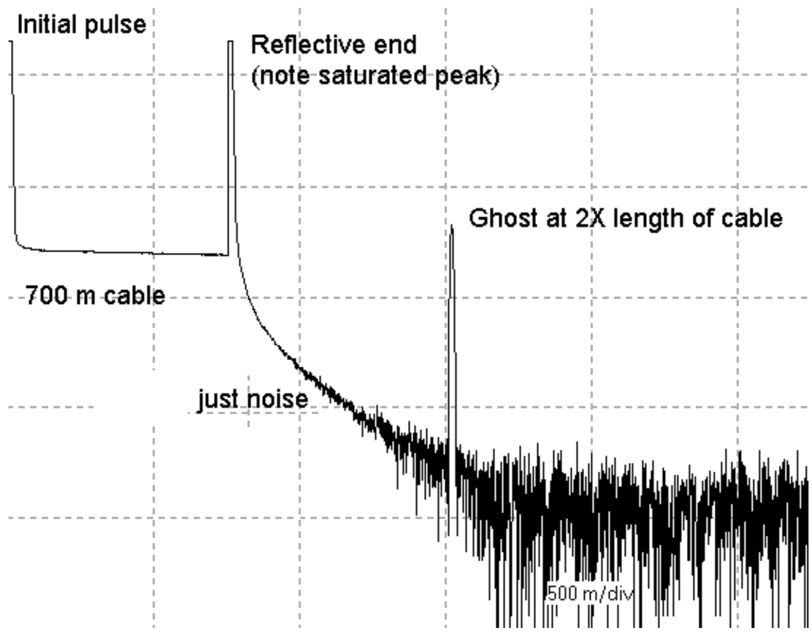

Figure 12. Phantom produced between the OTDR connector and the launch fiber connector with the fiber to be measured

Errors in the attenuation measurement in connectors

This problem is related to the differences in the backscatter coefficient. This parameter, as we have already said before, is an indicator of the light that is scattered backwards (towards the OTDR). The light returning to the OTDR is only one millionth of the amount emitted, and that amount is not constant. This quantity that we have indicated is a function of the attenuation of the fiber and the diameter of the core. Each fiber has a different attenuation because glass is also slightly different, so the way the light is scattered varies from fiber to fiber.

If you have two different fibers connected and you try to measure the losses caused by the splice or connector, there is a source of error which is the difference in the dispersion coefficient between both fibers. If this coefficient is the same for both fibers, there will be no such error. In Figure 13, this concept is perfectly explained. If the fibers are different, a different percentage of light will return to the OTDR. If the first fiber has more losses than the second, the losses that the OTDR will indicate will be greater than what they really are, on the other hand if we look at the fiber in the opposite direction, that is, from lower to higher dispersion coefficient, we will see that the trace it goes up as if it were a profit.

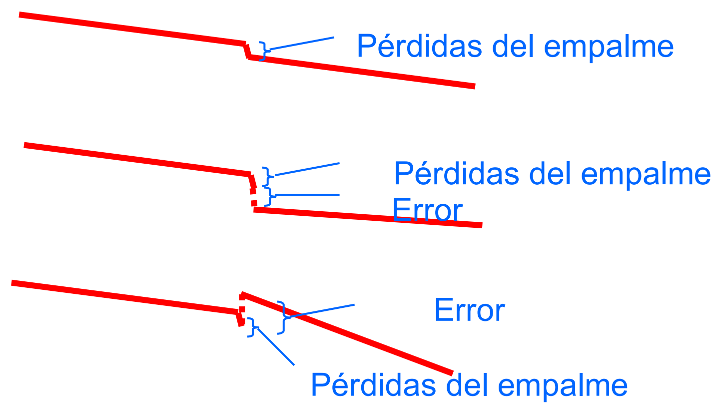

Figure 13. Three different situations: a) fibers with the same attenuation b) more losses in the first fiber and less in the second fiber c) less losses in the first fiber and more in the second

Differences in fiber dispersion can be the biggest source of error. An attenuation difference of 0.1 dB/km between the two fibers can lead to an error of 0.25 dB in estimating splice losses. Although this error is always present, it can be practically eliminated by taking readings on both sides and averaging the results. In this way the errors in each direction are canceled, and the average value is quite close to the value of the losses of the splice or connector.

Pulse width

The size of the pulse somehow indicates the distance between two consecutive distinguishable events. This is because in two events that are at a distance less than the size of the pulse, the pulse will go through both simultaneously. This has always been a problem on LANs or in any configuration with pigtails. For example, suppose a connector with a strong bend. Since the two events are close, they will be measured as one, the losses of both will add up, making us think that the connector is bad, when the cable is simply too bent.

4. Steps of the lab sessions

4.1. Characterization of a multimode fiber optic link using a multimode OTDR

Turn on the multimode OTDR, whose appearance is shown in Figure 14 by pressing the red button at the bottom for a couple of seconds.

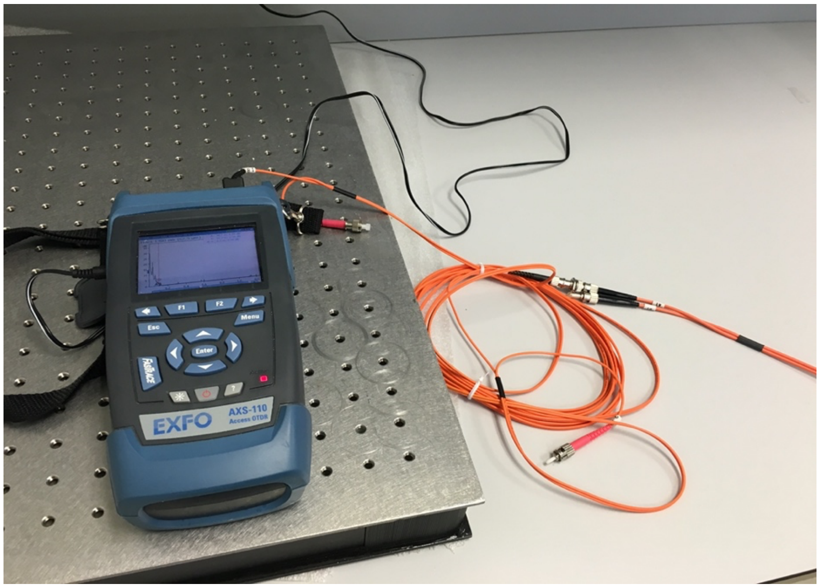

Figure 14. Appearance of the multimode OTDR

Then, perform the following steps to characterize the multi-mode fiber link that the teacher has proposed to you and that is shown in the following photo of Figure 15.

Figure 15. Multimode fiber link to be characterize using the OTDR

The scheme of the global experimental setup is shown in Figure 16. This first experiment consists of a launch fiber of around 500 meters, followed by two fiber cables of 5 and 30 meters respectively. This is followed by three spools of multimode fiber connectorized/fusioned among together, each of them of approximately 500 meters. The total of the link is around 2 kilometers of fiber.

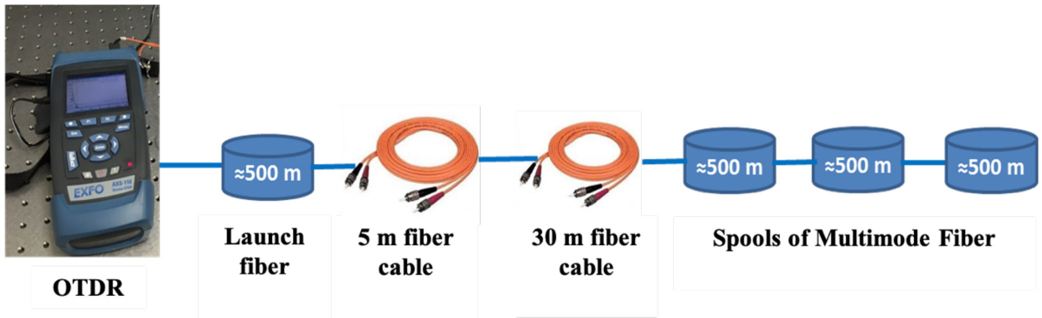

Figure 16. Scheme of the first experimental setup

The steps you should follow to characterize the multimode fiber link are the next:

- *Set the suitable configuration parameters of the OTDR (as explained in the previous section) to correctly visualize the events in the optical link.*
- *Perform a battery of tests on the optical link taking the following situations:*
    - *Long pulse width and long averaging time*
    - *Short pulse width and long averaging time*
    - *Long pulse width and short averaging time*
    - *Short pulse width and short averaging time*
- *In each of the previous situations, locate the events and make a table with the following characteristics:*
    - *For the complete trace: estimated the length of the link and the total losses.*
    - *For reflective events: position of the event, losses that occur in the event and maximum reflectivity that occurs.*
    - *For non-reflective events: Position of the event and losses that occur in it.*

Then modify the previous setup, as shown in Figure 17. As seen in this second setup, the 500 meter launch fiber is placed just behind the 5 and 30 meter fiber cables. Now, take the measurements again and see what differences you see from the previous setup. Justify these differences and the phenomena that occur.

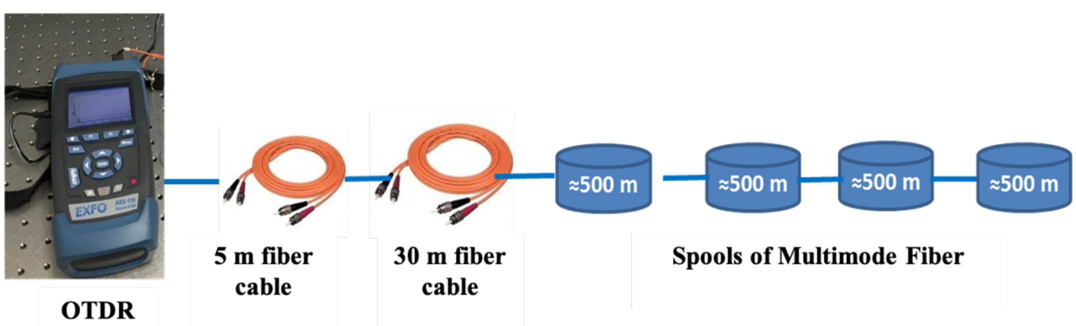

Figure 17. Scheme of the second experimental setup

4.2. Characterization of a Passive Optical Network (PON) using a single-mode OTRD

In this second part, a single-mode OTDR will be used to characterize an access network based on optical fiber both in downstream and in the upstream link. This access network, called PON (Passive Optical Network) is a passive network architecture that connects an OLT (Optical Line Terminal), located in a Central Office and responsible for connecting the access network to the metropolitan and a set of end subscribers, which are connected to the access network through an ONU (Optical Network Unit) or ONT (Optical Network Terminal) at home. The passive architecture follows a tree topology, in which communication on the downstream (from the OLT to the ONUs) is carried out in broadcast mode, and communication on the upstream (from the ONUs to the OLT) is point-to-point. The wavelengths of both channels are different, since the downstream channel is 1490 nm and the upstream channel is 1310 nm. Specifically, we will analyze the events that appear throughout the 25 km of the GPON deployed in the laboratory using the single-mode OTDR.

The deployed GPON follows the scheme of Figure 18. The network was set up with equipment from the manufacturer Telnet-RI. We use the SmartOLT 350, that complies with the ITU-T G.984 and G.988 specifications and implements a GPON interface of 2.488 Gbps in the downstream and 1.244 Gbps in the upstream. It includes 4 ports and each port supports up to 64 ONTs. To connect the OLT with the optical splitter we have deployed three spools of Standard Single Mode fiber, two spools of 5 km and one of 10 km, to give flexibility in configuring the total length of the GPON (plus the length of the distribution fiber, as later described). The GPON testbed also has two optical splitters (1:8) deployed to configure a two-stage splitting topology. Then, the splitters are connected to the ONTs by distribution fibers. The length of each link can be individually configured by a connection panel from 100 meters up to 5 km. In this way, the GPON testbed can be used to configure realistic network scenarios where users are located at a different distance from the OLT. Finally, our GPON testbed is equipped with 4 Level 3 model ONTs (Wave Access 3021), which means that they integrate router functionalities and 2 L2 (without router functionalities) ONTs (Wave Access 512) that comply with the ITU-T G.984.x/G.988 recommendations as it is observed in Figure 19.

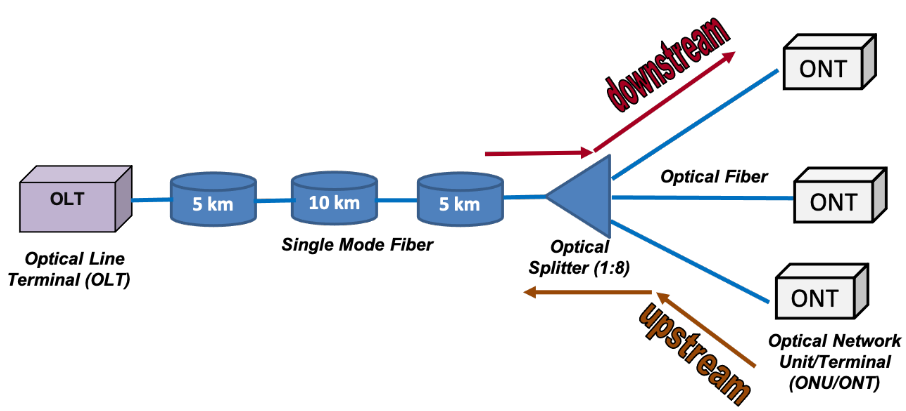

Figure 18. Scheme of the GPON infrastructure

Figure 19. Appearance of the GPON deployed in the optical communication laboratory

First, we will analyze the trace and events that appear in the downstream channel using the OTDR shown in the Figure 20.

Figure 20. Appearance of the OTDR used to analyze the GPON link.

The steps you should follow to characterize the GPON network in the physical layer are the next:

- *Set the suitable configuration parameters of the OTDR to correctly visualize the events in the downstream channel of the GPON.*
- *Perform a battery of tests on the downstream channel taking the following situations:*
  - *Long pulse width and long averaging time*
  - *Short pulse width and long averaging time*
  - *Long pulse width and short averaging time*
  - *Short pulse width and short averaging time*
- *From the achieved traces in the downstream link, you should determine what type of events it is, that is, a connector, a fusion, a cut, a tension zone, and so on.*
- *Analyze the upstream channel following the same procedure.*

It should be noted that a launch fiber has been placed just outside the OTDR, as explained in previous sections. Then, the diagram of said launch fiber in the actual assembly is shown in the following photograph of Figure 21.

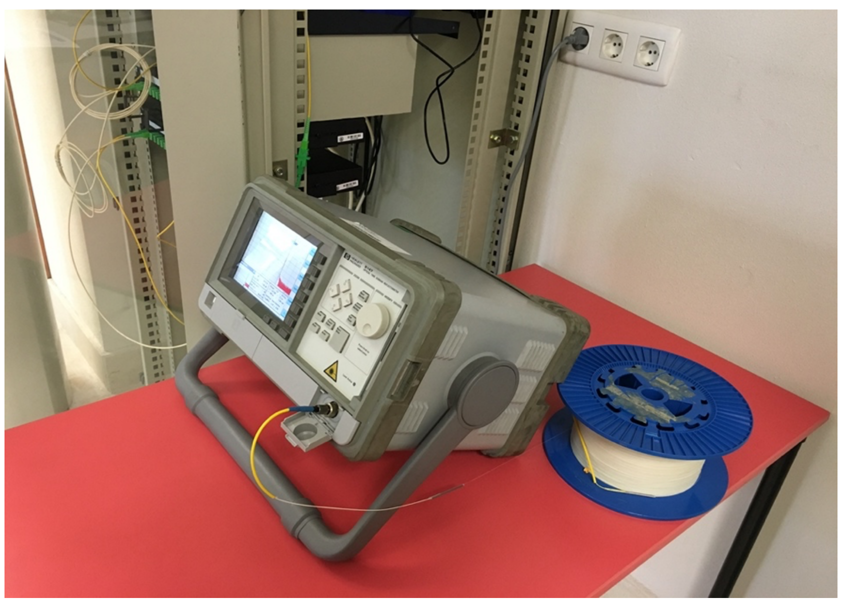

Figure 21. Appearance of the launch fiber just after the OTDR.