EXPERIMENT 7

FIBER SPLICING AND INTRODUCTION TO THE OTDR

OBJECTIVES:

The objectives of this experiment are to observe the steps used in making a fiber splice and to introduce the Optical Time Domain Reflectometer (OTDR).

EQUIPMENT REQUIRED

1- Fiber splicing machine.
2- Two short lengths of single fiber cables (multimode $50\,\mu m$ GI fiber cables, Orange).
3- Jacket stripers for fiber outer jacket, inner and buffer layer.
4. Heat shrink tube.
5- A 100m long multimode $50\,\mu m$ GI fiber (Orange).
6- OTDR: Agilent Technologies E6000 Mini OTDR Main Frame with E6005A Module (850/1300 nm High Performance Multimode Module).

PRELAB ASSIGNMENT:

Read the introduction to this experiment before attending the laboratory.

INTRODUCTION:

The first part of this experiment shows a demonstration of fiber splicing. In order to understand the steps involved in making a fiber splice, you need to know more about the structure of the optical fiber cable used in this experiment. The structure of the fiber cable is shown in Figure 1. The cladding surrounds the core and together they form a unit that cannot be separated. The fiber used in the demonstration has a standard cladding diameter of $125\,\mu m$ and a core diameter of $50\,\mu m$. The cladding is surrounded by a primary coating layer $250\,\mu m$ in diameter. The primary coating is surrounded by a protective inner jacket (blue) and the inner jacket is surrounded by textile fibers (kevlar) in order to strengthen the fiber cable. Kevlar is the strength member of the cable. Finally, the kevlar strength member is surrounded by the outer cable jacket (orange).

All the layers are designed to give protection to the fiber, starting from the fiber buffer layer up to the outer jacket. When the buffer layer is removed, the core/cladding combination becomes fragile and can easily break. Bare core/cladding combination is also very thin and sharp and can cause injuries (it is as sharp as broken glass). Protect yourself, specially your eyes when the fiber is cleaved.

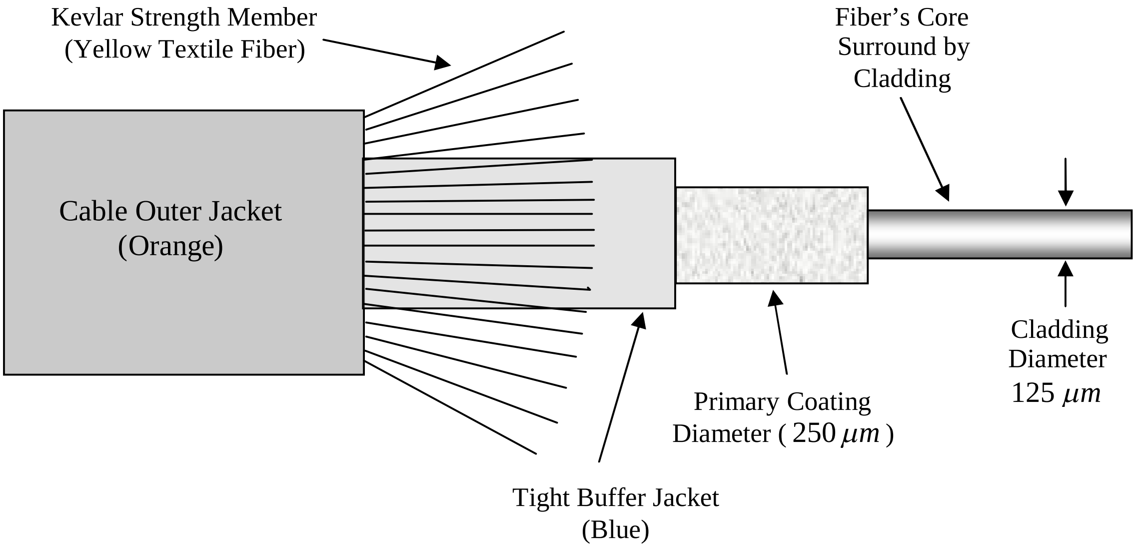

Figure 1: Structure of a Tight Jacket Single Fiber Cable with Kevlar Strength Member.

The Time Domain Reflectometer (OTDR) is a specialized piece of equipment used to test and diagnose optical fibers. It can be used to measure fiber attention and to locate splices, connectors, fiber's fault and fiber ends. The test is done from one end of the fiber with no need for measuring equipment on the output end of the fiber. The principle of operation of the OTDR is quite simple. However, actual implementation is quite complicated, leading to highly advanced piece of equipment.

The OTDR sends a narrow pulse of light into the fiber under test and then it measures the reflected light as a function of time, which is then converted to distance along the fiber and shows it graphically on the screen. This function is identical to the operation of the RADAR. Figure 2 shows a narrow pulse of light being launched by the OTDR at $t = 0$. Figure 2 also shows a fiber connector located a distance L along the fiber. A connector is known to cause part of the light energy to reflect back towards the OTDR. The launched pulse takes $t = L/v$ seconds in order to reach the connector, where v is the light velocity *inside the fiber*. When the pulse reaches the connector, a small portion of the light energy is reflected backwards towards the OTDR and most of the pulse energy continues to travel along the fiber. Figure 3, shows the reflected and transmitted light pulses in the time interval $L/v < t < 2L/v$ (i.e. after the light is reflected from the connector and before the reflected light reaches the OTDR). At $t = 2L/v$ the reflected light reaches the OTDR and the OTDR sensors measure the amount of reflected pulse power and the time of arrival. Using $t = 2L/v$, the OTDR then converts the time of arrival to length along the fiber (i.e. $L = vt/2$). The refractive index n of the fiber must be programmed into the OTDR, because $v = c/n$. If the refractive index is not entered correctly, then the OTDR obviously will display the wrong location of the connector.

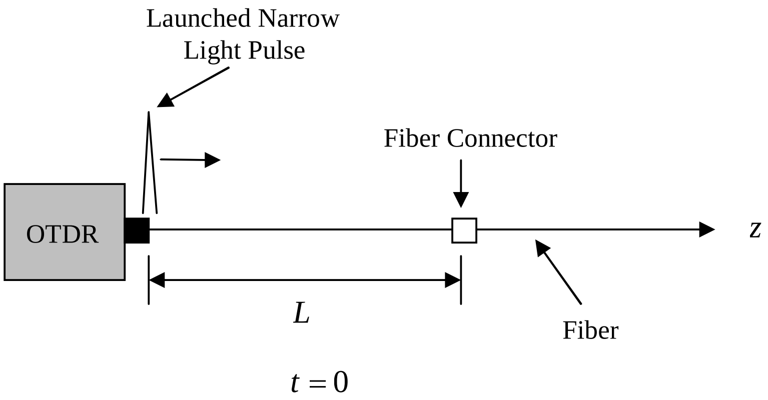

Figure 2: Launched Narrow Light Pulse at $t = 0$.

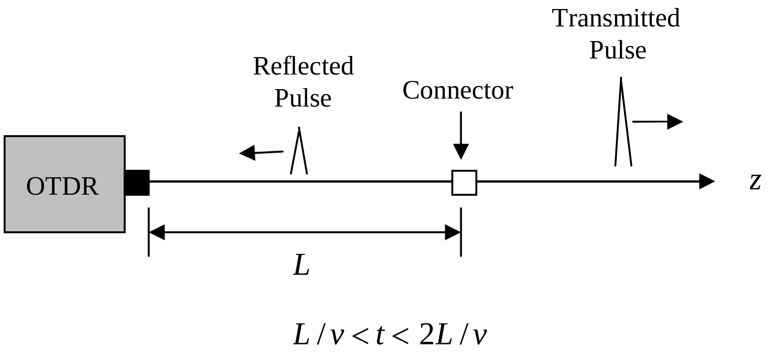

Figure 3: Reflected and Transmitted Light Pulses in the Time Interval $L/v < t < 2L/v$.

Actually, the OTDR can also sense the backscattered light due to Rayleigh scattering and uses it to display the reflected light power and the amount of optical power remaining in the fiber and a function of distance along the fiber. A typical OTDR trace is shown in Figure 4. The bold curve is called the OTDR trace, which shows the *reflected* light power in dB as a function of distance from the OTDR. The line is continuous because of the continually scattered light which travels backwards to the OTDR sensor.

The vertical axis is a dB scale which shows the dB level of the reflected power and the horizontal scale represent the distance along the fiber in meters or kilometers. All the sudden *discontinuities* in OTDR trace are called *events*, which can be caused by splices, connectors, fiber breaks or fiber ends. Events can be reflective ($z = L_2$ and $z = L_3$) or non-reflective ($z = L_1$). Reflective events are characterized by spikes (sudden *increase* in the dB power level). The height of the spike is related to the amount of the reflected power. Reflective events may be due to a *poor splice*, fiber connector, fiber break or fiber end. Non-reflective events are characterized by a sudden *decrease* in the power level. Non-reflected events may be due to a *good splice* or fiber *bends*.

The slope of the straight line segments between any two events gives the fiber attenuation in dB per unit length. For instance, we know that the dB power level at

$z = L_1$ is P_1 and the dB power level at $z = L_2$ is P_2 . We can then calculate the fiber attenuation per unit length using:

$$\propto_{dB} = \frac{P_1 - P_2}{L_2 - L_1} = \frac{|\Delta P|}{|\Delta L|} \qquad (1)$$

Thus lines with high slopes have large fiber attenuations in dB per unit length and vice versa. Non-reflective events can be caused by fiber splices. The splice loss can be calculated by taking the difference in the dB power level. For instance, the non-reflective event immediately to the left of $z = L_1$ causes a dB loss of $\Delta P = P_o - P_1$. The fiber end ($z = L_3$) can be reflective or non-reflective. The fiber end is typically followed by background noise trace.

The OTDR is a very sophisticated piece of equipment that needs care, cleaning and sufficient training to operate it correctly. There are many parameters that must be correctly set in order to obtain a reliable and correct trace. For instance, the OTDR must be given information about the fiber, particularly the refractive index and the operating wavelength. An error in the refractive index leads to error in the display of distance. The OTDR can be run either in manual or automatic modes. It has a number of facilities such as trace printing and storage. In this experiment you will learn how to generate a trace and measure the fiber's length and attenuation from the generated OTDR trace.

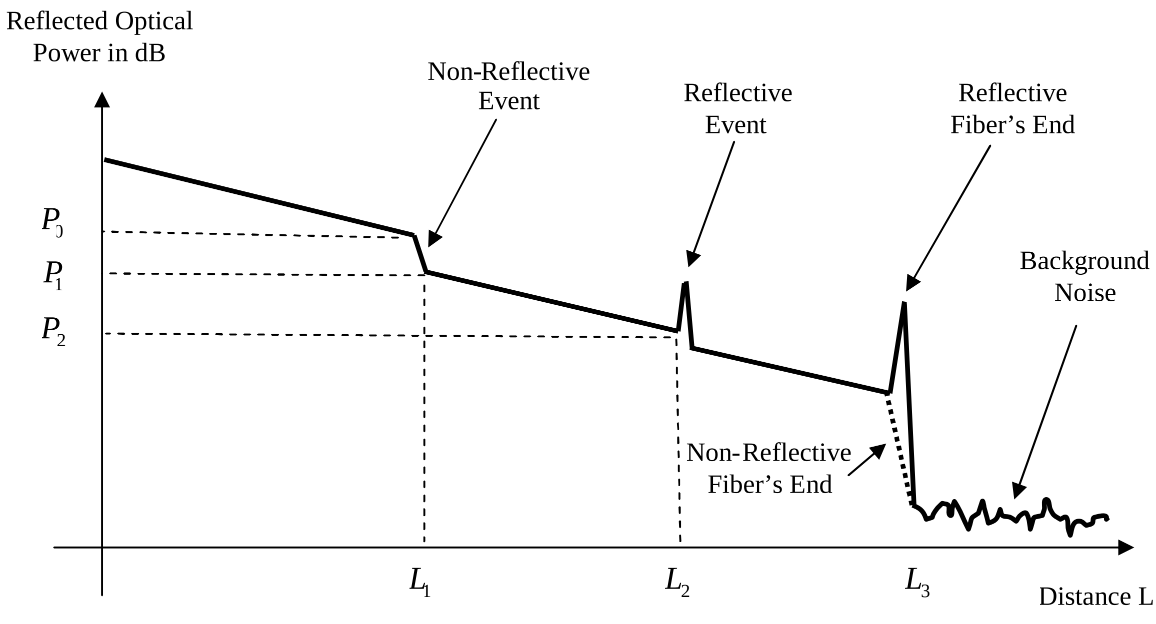

Figure 4: Typical OTDR Trace Showing the Locations of Reflective Events, Non-Reflective Events and Fiber's End.

The spectral loss in dB/Km of the fiber used in this experiment is shown in Figure 5.

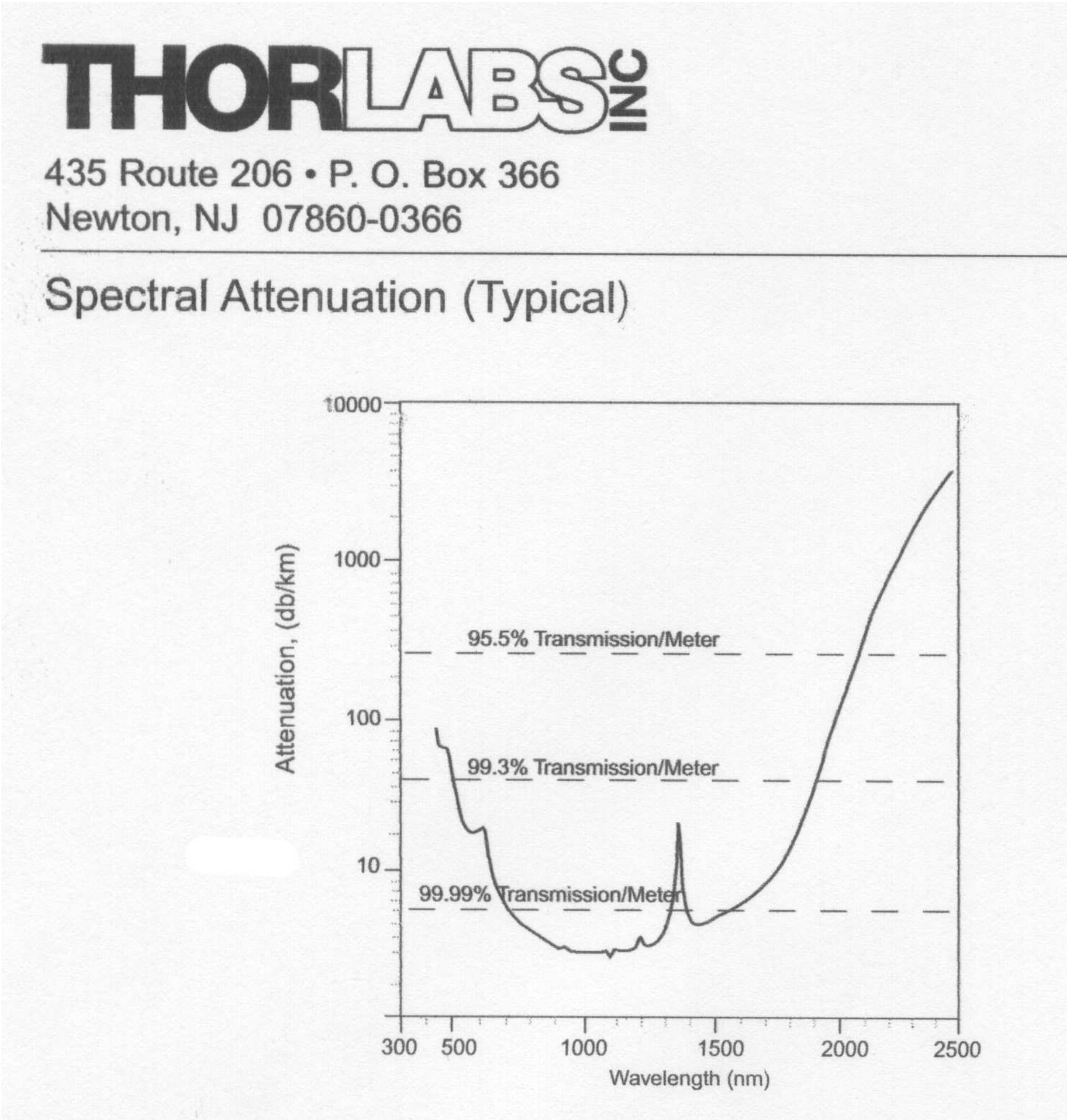

Figure 5: Spectral Loss in dB/Km for the Test Fiber (Manufacturer's Data).

<u>PROCEDURE:</u>

PART A: FIBER SPLICING (DEMONSTARATION ONLY).

1- Before the fiber is spliced, the layers surrounding the cladding must be removed and the fiber must be properly cleaved. The laboratory instructor will demonstrate the steps involved in the removal of the various layers, which are briefly summarized below:

- Cut and remove the outer jacket (orange) with the outer jacket remover tool.
- Cut and remove the extra kevlar with sharp scissors.
- Cut and remove the inner jacket (blue) with the inner jacket remover tool.
- Cut and remove *part* of the primary coating with the primary coating removal tool.
- Cleave the fiber end with the fiber cleaving tool.
- Clean the fiber with an appropriate chemical.

- Repeat the above steps for the second fiber.

2- Now the two fibers are ready to be inserted into the fiber splicing machine. The splicing machine is largely automatic. The machine uses precession optics and precession movements to insure that fiber misalignment losses are minimal, before the two fibers are fused together. The fibers ends are permanently spliced by application of heat using highly controlled electric discharge. Observe the procedure used to make the fiber splice. The splicing machine gives a reading of the splice loss after the splice is formed. [**Read and record the splice loss. Include the splice loss in your report**].
3- After the fibers are successfully spliced, a special tube is inserted around the spliced section of the fibers and heat shrunk in order to protect the recently formed splice.

PART B: INTRODUCTION TO THE OTDR.

[**The following is an introductory OTDR practice session that you should perform with the help of your laboratory instructor. If you have any difficulties consult with your instructor or refer to the appropriate page in the OTDR manual. This practice session is necessary to successfully do the next experiment (experiment 8). Pages 39-54 of the OTDR manual contain all you need to know to run this practice session. Ask the laboratory instructor to give you a copy].**

1- The 100 m long fiber (orange) reel should only be connected to the OTDR by the laboratory instructor or the laboratory technician. The fiber connector and the input end of the OTDR are very sensitive, especially to dirt, even by a small amount. They should be both cleaned before the fiber is connected to the OTDR. There is a special cleaning procedure, which the laboratory instructor or the laboratory technician should do before connecting the fiber to the OTDR. ***Do not remove the fiber from the OTDR***.
2- Turn the OTDR on and wait for the self test to end.
3- You should see the "OTDR Application Screen", which provides a number of selections.
4- Select the "OTDR MODE". Use the "CURSOR" key to highlight the "OTDR MODE" and press the "SELECT" key. [*To learn how to use the "CURSOR" key and the "SELECT" key, refer to pages 46-48 of the OTDR manual*].
5- You should now see an *empty* trace window. Push the "POPUP MENU" key.
6- You should now see the "POUP PANEL". [*To learn more about the "POUP PANEL", refer to pages 48-49 of the OTDR manual*].
7- Use the "CURSOR" key to highlight "SETTINGS", and then press the "SELECT" key.
8- You should now see the OTDR "SETTINGS MENU", including wavelength. The wavelength should be set to 855 nm for the first part of this session. If the wavelength already reads 855 nm, then don't change it. If it is set to 1310 nm, change it to 855 nm.
9- Use the "CURSOR" key to highlight "AUTO" near the bottom left hand side of the screen. Then press the "SELECT" key.
10- Highlight "OK" and press "SELECT".
11- You should now see the blank trace window again. You are now ready to run your first OTDR measurement.

12- Press the blue (RUN/STOP) key to start the trace and wait until it ends or the trace is free of noise. [*This may take sometime, so be patient*].
13- You should now see an OTDR trace similar to the one shown in Figure 6, which has been generated using a 100m long fiber (the same type of fiber you are using) at $\lambda = 855nm$. The OTDR trace shown in Figure 6 has been annotated for clarity.

14- In Figure 6, the *current vertical scale* is set to 5 dB/division and the *current horizontal scale* is set to 19.99 meter/division.
15- Push the *upper* "CURSOR" key to select "MARKER A" and move it the fiber's start (at z = 0), using the "CURSOR" *right/left* keys. [*Don't move it if it is already there*].

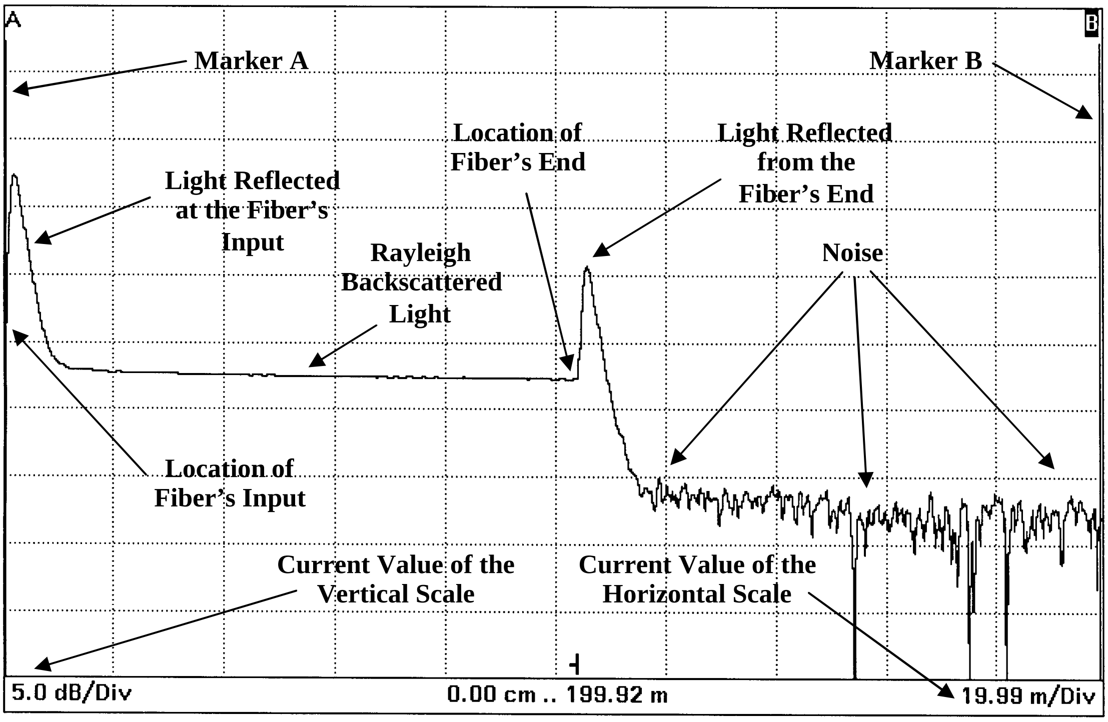

Figure 6: OTDR Trace for a 100 Meter long $50\mu m$ GI fiber Showing Reflected Light from both the Input and Output Fiber's Ends and the Current Locations of Markers A and B. The Trace was Generated at $\lambda = 0.855\mu m$.

16- Push the *upper* "CURSOR" key to select "MARKER B" and move it the location of the fiber's end, using the "CURSOR" *right/left* keys. [*To learn how to select and move a marker, consult the OTDR manual, page 46*].
17- Read the A-B distance in the "PARAMETER WINDOWS" *below the trace* (not shown in Figure 6). This gives the length of the fiber. Record the value in the first row of table 1.
18- The straight line between the fiber's start and fiber' end is due to Rayleigh backscattered light. The *slope* of this line gives the loss in dB per unit length.
19- In Figure 6, the line *appears* to have a zero slope (i.e. horizontal). In reality it has a non-zero slope. Use the "ZOOM" feature of the OTDR to decrease the vertical scale down to 0.1 dB/division for better details. The generally decreasing nature of this line should be very clear now. [*To learn how to change the vertical as well as the horizontal scale, read about ZOOMING, on page 49 of the OTDR manual*].

20- Move marker A to about 20 m.
21- Move marker B to about 90 m.
22- Read and record the distance (distance A-B) between the two markers in the 2nd row of table 1.
23- In the OTDR "PARAMETER WINDOWS", read the value of the "**2pt.L**" (i.e. two point loss or the loss in dB between markers A and B). Record the value in the 3rd row of table 1.
24- Calculate the fiber's attenuation in dB/Km (using equation 1) and record its value in the 4^{th} row of table 1. Compare the result with the manufacturer's data (see Figure 5).
25- **Print the OTDR trace and include the printout in your experimental report.**
26- Go to the "SETTINGS" menu again and change the wavelength to 1310 nm. Highlight "AUTO" and select "OK". [*To learn how to change the wavelength, refer to pages 48-52 of the OTDR manual*].
27- Repeat steps 12-25. Of course, this time the trace should be generated at $\lambda = 1310\,nm$. [*Make sure that the printed trace to be included in your experimental report indicates the correct wavelength*].
28- Compare the fiber lengths measured using $\lambda = 855\,nm$ and $\lambda = 1310\,nm$.
29- Compare the fiber loss in dB/Km at the two different wavelengths.
30- Discuss the experimental results and make appropriate comments and conclusions.

Fiber's Length (m)	
Distance A-B (m)	
Fiber's Attenuation Over Distance A-B (dB)	
Fiber's Loss (dB/Km) [Measured]	
Fiber's Loss (dB/Km) [Manufacturer's Data]	

Table 1: Summary of OTDR Measurements for $\lambda = 855\,nm$.

Fiber's Length (m)	
Distance A-B (m)	
Fiber's Attenuation Over Distance A-B (dB)	
Fiber's Loss (dB/Km) [Measured]	
Fiber's Loss (dB/Km) [Manufacturer's Data]	

Table 2: Summary of OTDR Measurements for $\lambda = 1310\,nm$.

QUESTIONS:

1- The fiber used in this experiment is 100m long. Suggest two reasons for why the OTDR measurements of the fiber's length is not exactly 100 m. [Hint: $v = c/n$].

2- Estimate how long (in seconds) it takes (from the moment of pulse launch) before the reflected light from the fiber's end reaches the OTDR detector. [Hint: first estimate the speed of light inside a silica fiber. The refractive index of silica glass is *approximately* 1.5].

3- The OTDR has a feature for changing the pulse width. OTDR pulses range from nanosecond to microseconds. Estimate the spatial length (in meter) of a 5 nanosecond pulse inside the fiber.

4- Repeat question 3 for a 5 microsecond pulse.

5- Briefly explain why the *slope* of the Rayleigh backscattered light changes when λ changes? Why is it important to know the slope?