TEMPERATURE MEASUREMENT USING FIBER OPTIC SENSOR TECHNOLOGY

A PROJECT SUBMITTED TO THE DEPARTMENT OF PHYSICS, FACULTY OF PHYSICAL SCIENCES, IN PARTIAL FUFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE (B.Sc.) OF THE UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA.

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CERTIFICATION

This is to certify that this project work was carried out by Emuedo Crosdel (Jnr) in the department of Physics, University of Benin, Benin City, Edo State Nigeria under my supervision.

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EXTERNAL EXAMINER DATE

DEDICATION

This research work is dedicated first and foremost to God Almighty for his infinite mercy and grace bestowed upon me throughout this study period and to my Parents who have supported me morally, financially and spiritually

ACKNOWLEDGEMENT

I am grateful to God Almighty for his guidance and protection throughout the duration of my research.

This research work wouldn’t have been completed, but for supervision of my supervisor, Prof. S. O. Azi for his patience and contribution in the course of this project. I also want to give special thanks to Dr. Awodu Onuora for his kindness and selfless support.

My unreserved appreciation goes to my loving and wonderful parents for their financial, spiritual and moral support.

ABSTRACT

The study is focused on the measurement of temperature using fiber optic sensor using an OTDR to measure attenuation.

TABLE OF CONTENTS

CHAPTER ONE

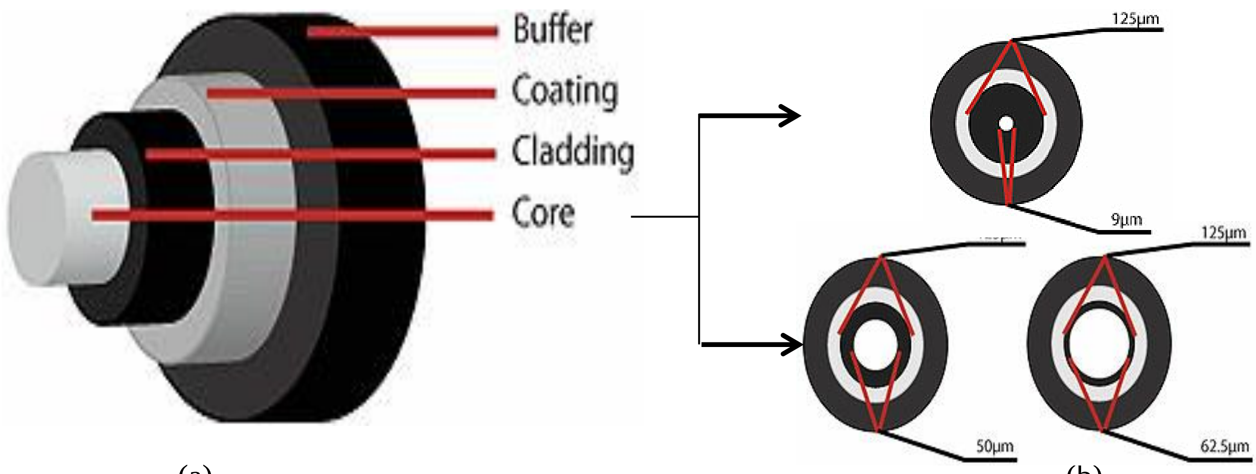
1.0 INTRODUCTION

Optical fiber is a highly transparent strand of glass that transmits light signals with low attenuation (loss of signal power) over long distances, providing nearly limitless bandwidth. This technology enables telecommunications service providers to send voice, data and video at ever increasing rate.

This chapter gives an overview of the fiber optics, splicing of the fiber cable and attenuation in a fiber optic cable.

1.1 BACKBROUND OF THE STUDY

The field of applied science and engineering concerned with the design and application of optical fibers is known as fiber optics. Optical fibers are made of glass or plastic for transmitting light signal over long and short distances. They are flexible strands, with the length roughly the diameter of a human hair. Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction as shown in the Figure 1.1



(a) (b)

Figure 1.1: fiber Optic Structure (a) fiber optic cable (b) Types of fiber Optic Cable

(Mahdikhani and Bayati, 2008)

Light is kept in the core by the phenomenon of total internal reflection. As light propagates through an optically dense medium, it is bound to hit the boundary at an angle greater than the critical angle as shown in Figure 1.2. The black light rays represent incident light at an angle with the normal greater than the critical angle(θ_c). The red and purple rays represent incident light at the critical angle.

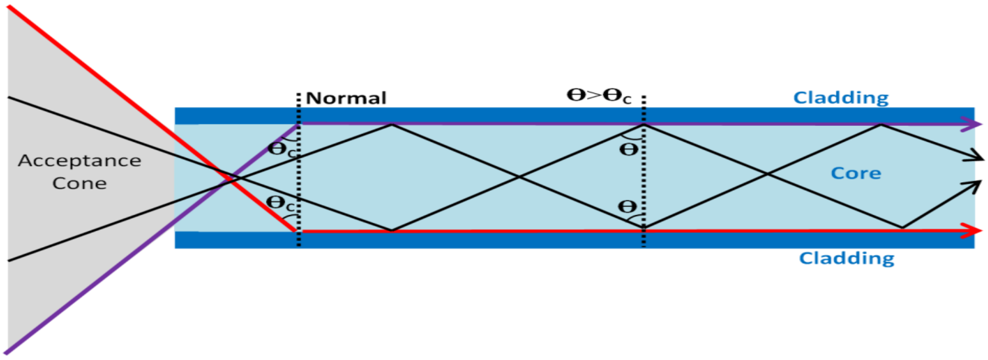


Figure 1.2: Total internal reflection in fiber optic cable (Brush, 2010)

Fibers that support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those that support a single mode are called single-mode fibers (SMF). A single-mode fiber has a core to cladding diameter of 9/125microns. It supports a wavelength 1310nm and 1550nm. Multi-mode has a core to cladding diameter of 50- 62.5/125microns and supports a wavelength 850nm and 1300nm as shown in Figure 1.1(b) (Mahdikhani and Bayati, 2008). Multi-mode fibers generally have a wider core diameter and are used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 1,000 meters (3,300 ft). (Zlatanov, 2016)

An important aspect of a fiber optic communication is that of extension of the fiber optic cables such that the losses brought about by joining two different cables is kept to a minimum. (Zlatanov, 2016). Joining lengths of optical fiber often proves to be more complex than joining electrical wire or cable and involves careful cleaving of the fibers, perfect alignment of the fiber cores, and the splicing of these aligned fiber cores.

For applications that demand a permanent connection a mechanical splice which holds the ends of the fibers together mechanically could be used or a fusion splice that uses heat to fuse the ends of the fibers together could be used (Zlatanov, 2016). Temporary or semi-permanent connections are made by means of specialized optical fiber connectors

1.2 FIBER SPLICING

To begin, the standard definition of splicing in optical fiber is the joining of two fiber optic cables together. Splicing is most commonly used in the field but has application in cable assembly houses. In field installations, splicing is a faster and more efficient method and is used to restore fiber optic cables when buried cables are accidentally severed. The technique used to combine fiber cables is complex and tedious and requires precise and accurate cleaving, alignment and coupling of the fiber. A fusion splicing machine is used by using an electric arc to melt the ends of the fibers together or using fiber connectors as shown in Figure1.3 below

Figure 1.3: Fusion splicing machine (Kawanishi, 2013)

The fusion splicer works by using high-temperature heat which is generated by an electric arc To fuse two glass fibers together (end to end with fiber core aligned precisely). The tips of two fibers are butted together and heated so they melt together. The fusion splicer mechanically aligns the two fiber ends, then applies a spark across the fiber tips to fuse them together. Some commonly used connectors are Ferrule Connector (FC), Standard Connector (SC), Straight Tip (ST) and Lucent Connector (LC). The splicing machine has a display screen that shows the pictorial view of the cable been fused as shown in Figure 1.3. When fiber cables are not properly spliced, it results to high attenuation. A mechanical splice is another technique, which requires the ends of the fibers to be held in contact by mechanical force (John et al, 2009). The fiber is first stripped, cleaned carefully and cleaving has to be precisely. It is fast and easy to install. The fiber ends are aligned and held firm using a precision-made protective cover. The connector is installed by inserting the fiber end to the rear of the connector surface. An adhesive is often used to hold-firm the fiber securely, and a strain relief to secure the fiber rear. Once the adhesive sets-in, the fiber end is polished to a mirror finish.

1.3 ATTENUATION IN OPTICAL FIBER

Efficient transmission of light at the operational wavelength(s) is the primary function of fiber optics needed for a range of applications (e.g. long-haul telecommunications, fiber lasers, optical delivery for surgical or biomedical applications). Reduction in the intensity of light as it propagates within the fiber is called “attenuation”. The finite attenuation present in any optical fiber requires that fiber system design address degradation in signal strength through such approaches as signal amplification, interconnect optimization, fiber geometry design, and environmental isolation. An understanding of attenuation mechanisms and the potential for their minimization is, thus, of great importance in the efficient and economic use of fiber optics. There are different factors responsible for signal loss in fiber optics, these include scattering, absorption, radiation etc

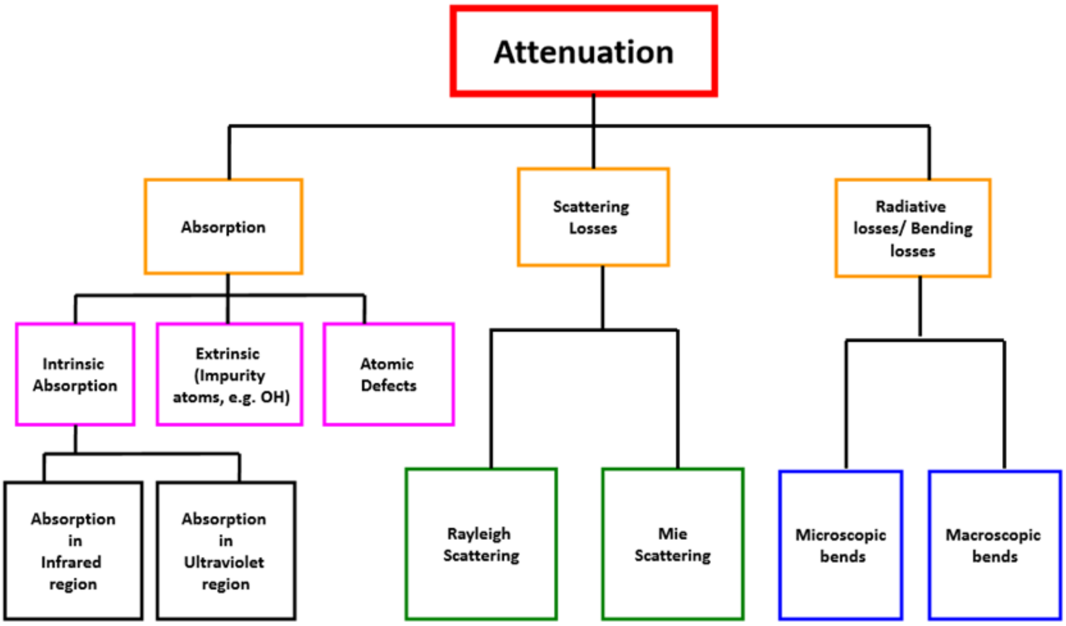


FIGURE 1.4 Flow chart showing Attenuation (Ezekiel, 2016)

1.3.1 Absorption

This is caused by the absorption of the light and the conversion to heat by molecules in the glass. Primary absorbers are residual OH+ and dopants used to modify the refractive index of glass. Material absorption can be divided into two(2) categories namely; Interinsic absorption and extrinsic absorption.

- Intrinsic absorption results from electronic absorption bands in the UV region and atomic vibration bands in the near infrared region. It is the loss associated with the pure fiber material, and therefore sets the lower limit on absorption. –In other words, loss due to absorption cannot be reduced below this limit.
- Attenuation caused by intrinsic absorption in the UV and IR regions is wavelength dependent as follows:

Absorption losses: intrinsic

α UV= AUV exp(λ UV / λ)

α IR= AIR exp(λ IR / λ)

Lattice absorption through a crystal structure –The EM wave (near infrared light) forces ions to vibrate at the frequency of the wave; some energy is then lost by being coupled into lattice vibrations (heat).

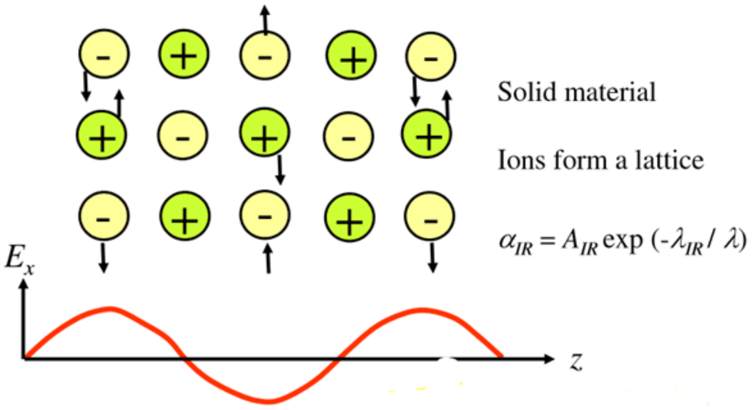


FIGURE 1.4: Lattice absorption through crystal structure (Stavros Iezekiel 2016)

Absorption of ultraviolet light leading to electronic transitions:

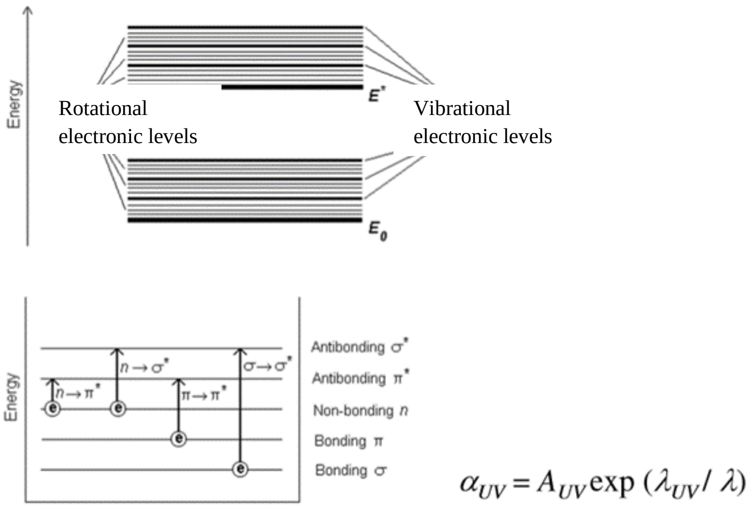


FIGURE 1.5 Absorption of ultraviolent light leading to electronic transitions (Stavros Iezekiel 2016)

1.3.2 Scattering

In fiber optic transmissions, scattering is the loss of signal caused by the diffusion of a light beam, where the diffusion itself is caused by microscopic variations in the transmission medium. Scattering typically happens when a light signal hits an impurity in the fiber (vangie beal). There are basically two types of light scattering; elastic and inelastic scattering. Elastic scattering is due to microscopic variations in the density of fiber optics, e.g. Rayleigh and Mie. Inelastic scattering results from change in the inner energy of the scattering particle, e.g. Brillouin and Raman. Rayleigh scattering is the predominantly elastic scattering of light or other electromagnetic radiation by particles smaller than the wavelength of the particles. As light travels in the core, it interacts with the silica molecules in the core. These elastic collisions between the light wave and the silica molecules result in what we know as Rayleigh scattering. Rayleigh scattering accounts for about 96% of attenuation in optical fiber (Alwayn 2004). Mie scattering on the other hand refers to the elastic scattering of light molecules from atomic and molecular particles whose diameter is larger than about the wavelength of the incident of light. In contrast to Rayleigh scattering, large water droplets in clouds causes Mie scattering. Clouds are white or gray because Mie scattering is far less wavelength dependent than Rayleigh scattering. A rough interface between the core and cladding causes excess scattering. With the introduction of fiber optic cables made of silica glass, the Mie scattering caused by impurities and surface roughness has been eliminated. Although the inelastic scattering is used in distributed fiber optic sensors, the frequency of scattered light is different from that of the incident light.

1.3.3 RADIATION LOSSES

Neutron or alpha particle radiation absorbed by optical fibers can also cause additional loss. It will mainly damage optical fiber matrix structure and produce atomic structure defects and release electrons. This makes it is very difficult to detect the light due to weak intensity along optical fiber axis. Radiation losses usually occur at bends in the optical fiber as shown in FIGURE below

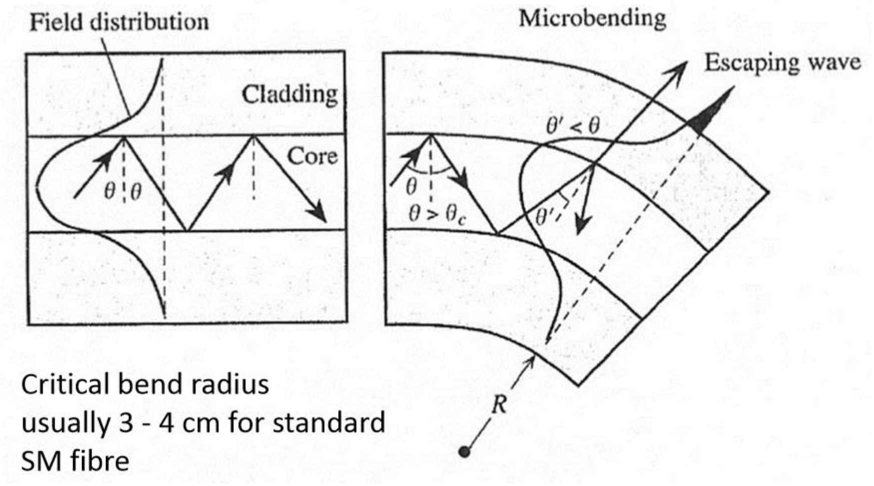


FIGURE 1.6**:** Radiation loss in bends (Stavros Iezekiel 2016)

Radiation losses also occur at microbends introduced due to uneven pressures in cabling of fiber

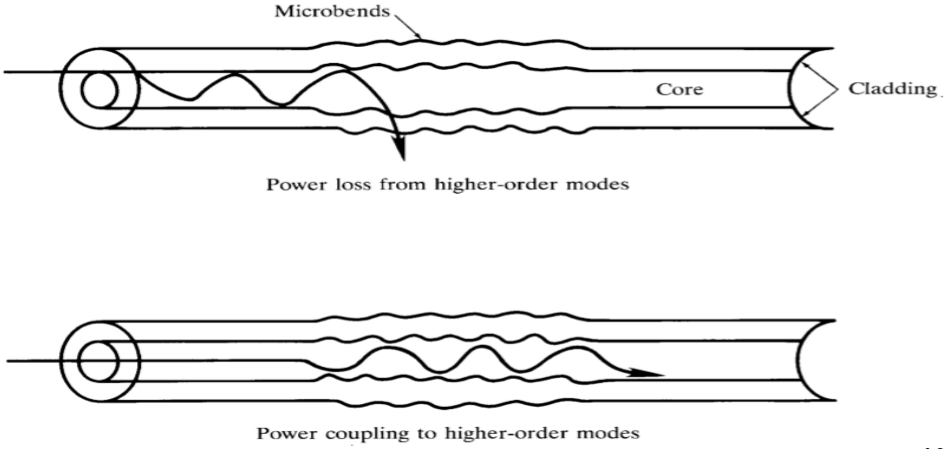


FIGURE 1.7 Radiation loss in micro bends (Stavros Iezekiel 2016)

1.4 OPTICAL TIME DOMAIN REFLECTOMETER (OTDR)

The OTDR is the most important investigation tool for optical fibers, which is applicable for the measurement of fiber loss (attenuation), connector loss and for the determination of the exact place and the value of cabel discontinuities. By means of very short pulses it is also possible to measure the modal dispersion of multimodal fibers. The structure of a typical OTDR equipment is shown below:

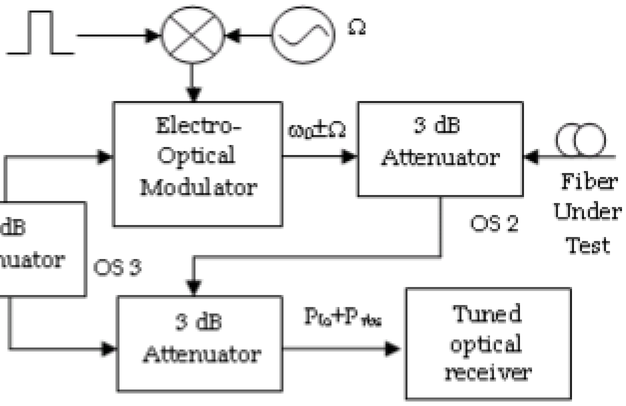


Figure 1.9: Structure of OTDR with two frequencies filling of probing pulse (Jasenek, 2000)

1.4.1 MEASUREMENT OF ATTENUATION BY MEANS OF OTDR

It is possible to localize abrupt attenuation changes and to determine its value. This way, it is possible to localize fiber welds and connectors as well their attenuations. This abrupt attenuation change generates a step on the OTDR display. Its height is proportional to the attenuation. When there is a Fresnel reflection as well, a sharp edge can be found before the step. Finally, it is important to emphasize that the OTDR attenuation measurements radically differ from the two-port measurements. So, it is also possible that positive steps can be found, as the fiber would amplify. This can be experienced when the numerical aperture of the fiber changes (so S changes). This problem can be solved by measuring the fiber from both ends and averaging the two attenuations.

1.4.2 THE RESOLUTION OF THE OTDR– THE DEAD ZONE

The resolution of the OTDR system is the distance of two reflecting points that still can be distinguished by the instrument. This depends on the width of the transmitted impulse, since the impulse must not overlap. Let us consider two reflecting points that are close to each other and an impulse (with length of Δz) propagating towards them. When the impulse reaches the first point, a certain part of its power is reflected. This reflection lasts as long as the impulse travels through the reflecting point, i.e. the length of the pulse. It means that the reflected pulse is also Δz long. Meantime, the non-reflected part of the transmitted pulse reaches the second reflection point. If the front of the second reflected pulse, also with Δz length, reaches the end of the first reflected pulse, then the two pulses cannot be distinguished as they overlap. It means that the locations of the two reflections cannot be distinguished either. So, the theoretical limit of the resolution is the half of the length of the impulse ($\Delta z/2$). The decrease of the pulse length increases the resolution, however the signal power decreases, too. Thus, the good resolution results narrow dynamic range. This problem can overcome by means of code modulation which is commonly used in radar technology.

The dead zone closely connects to the resolution: the instrument cannot measure accurately during the transmission of the test impulse as the width of the pulse at the input of the fiber changes continuously. Besides, during the transmission there is a strong reflected signal at the input of the instrument from the Fresnel reflection at the input of the fiber, which overloads the receiver. The detector needs some time after the transmission for accurate measurements (on the display the reflection peak covers the real signals). During this time only very high level signals (e.g. other reflection peaks) can be detected. In practice, the dead zone is a multiple of the resolution.

1.5 FIBER OPTIC SENSOR (FOS)

Recent advances in fiber optic technology have significantly changed the telecommunications industry. The ability to carry gigabits of information at the speed of light increased the research potential in optical fibers. Simultaneous improvements and cost reductions in optoelectronic components led to similar emergence of new product areas. Last revolution emerged as designers to combine the product outgrowths of fiber optic telecommunications with optoelectronic devices to create fiber optic sensors. Soon it was discovered that, with material loss almost disappearing, and the sensitivity for detection of the losses increasing, one could sense changes in phase, intensity, and wavelength from outside perturbations on the fiber itself. Hence fiber optic sensing was born [Geib, D, 2003].

Beside advantages; recent advances, and cost reductions has stimulated interest in fiber optical sensing. So, researchers combined the product outgrowths of fiber optic telecommunications with optoelectronic devices to emerge fiber optic sensors. Numerous researches have been conducted in past decades using fiber optic sensors. In parallel with these developments, fiber optic sensor technology has been a significant user of technology related with the optoelectronic and fiber optic communication industry [Culshaw, B, et al, 1989]. Many of the components associated with these industries were often developed for fiber optic sensor applications. Fiber optic sensor technology in turn has often been driven by the development and subsequent mass production of components to support these industries. As component prices have decreased and quality improvements have been made, the ability of fiber optic sensors to replace traditional sensors have also increased.

Fiber optic sensors offer many advantages over conventional electronic sensors as listed below:

• Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry. • Inability to conduct electric current.

• Immune to electromagnetic interference and radio frequency interference. • Lightweight.

• Robust, more resistant to harsh environments. • High sensitivity. • Multiplexing capability to form sensing networks.

• Remote sensing capability.

• Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.

1.5.1 Fiber Optic Sensor Types

Fiber optic sensors are of different types:

(a). Intensity Based Fiber Optic Sensor

Intensity-based fiber optic sensors rely on signal undergoing some loss. They are made by using an apparatus to convert what is being measured into a force that bends the fiber and causes attenuation of the signal. Other ways to attenuate the signal is through absorption or scattering of a target. The intensity-based sensor requires more light and therefore usually uses multimode large core fibers [Krohn, D. 1988]. There are a variety of mechanisms such as microbending loss, attenuation, and evanescent fields that can produce a measurand-induced change in the optical intensity propagated by an optical fiber. The advantages of these sensors are: Simplicity of implementation, low cost, possibility of being multiplexed, and ability to perform as real distributed sensors. The drawbacks are: Relative measurements and variations in the intensity of the light source may lead to false readings, unless a referencing system is used [Casas J. R., and Paulo, J. S., 2003]. One of the intensity-based sensors is the microbend sensor, which is based on the principle that mechanical periodic micro bends can cause the energy of the guided modes to be coupled to the radiation modes and consequently resulting in attenuation of the transmitted light. As seen in Figure 1.10, the sensor is comprised of two grooved plates and between them an optical fiber passes. The upper plate can move in response to pressure. When the bend radius of the fiber exceeds the critical angle necessary to confine the light to the core area, light starts leaking into the cladding resulting in an intensity modulation [Berthold, J. W., 1995].

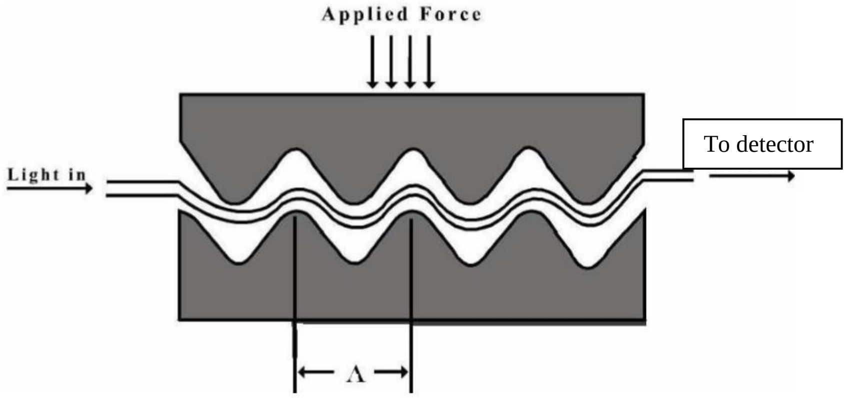


FIGURE 1.10 Intrinsic fiber optic sensor. (Berthold, J. W., 1995)

Another type of intensity based fiber optic sensor is the evanescent wave sensor (see Figure 1.11) that utilizes the light energy which leaks from the core into the cladding. These sensors are widely used as chemical sensors. The sensing is accomplished by stripping the cladding from a section of the fiber and using a light source having a wavelength that can be absorbed by the chemical that is to be detected. The resulting change in light intensity is a measure of the chemical concentration. Measurements can also be performed in a similar method by replacing the cladding with a material such as an organic dye whose optical properties can be changed by the chemical under investigation.

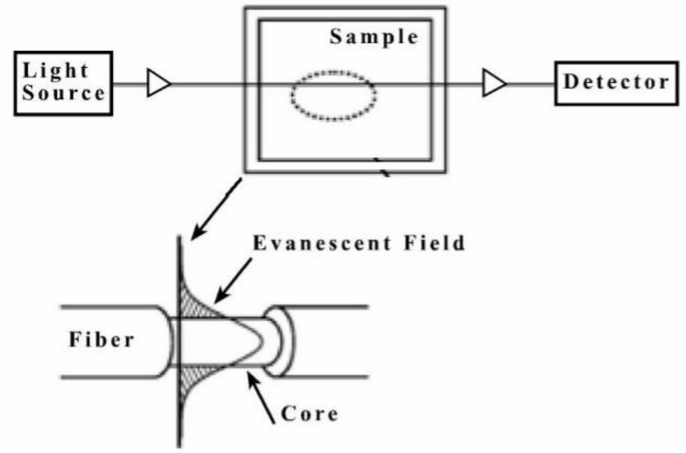


FIGURE 1.11 Evanescent wave fiber optic chemical sensor. (Connelly, M. C, 2005)

(b). Wavelength Modulated Fiber Optic Sensors

Wavelength modulated sensors use changes in the wavelength of light for detection. Fluorescence sensors, black body sensors, and the Bragg grating sensor are examples of wavelength-modulated sensors. Fluorescent based fiber sensors are being widely used for medical applications, chemical sensing and physical parameter measurements such as temperature, viscosity and humidity. Different configurations are used for these sensors where two of the most common ones are shown in Figure 1.12. In the case of the end tip sensor, light propagates down the fiber to a probe of fluorescent material. The resultant fluorescent signal is captured by the same fiber and directed back to an output demodulator.

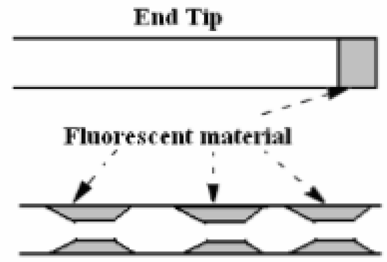


FIGURE 1.12 Fluorescent fiber optic sensor probe (Udd, E., et al, 1998)

One of the simplest wavelength based sensor is the blackbody sensor as shown in Figure 1.13. A blackbody cavity is placed at the end of an optical fiber. When the cavity rises in temperature it starts to glow and act as a light source. Detectors in combination with narrow band filters are then used to determine the profile of the blackbody curve. This type of sensor has been successfully commercialized and has been used to measure temperature to within a few degrees centigrade under intense RF fields.

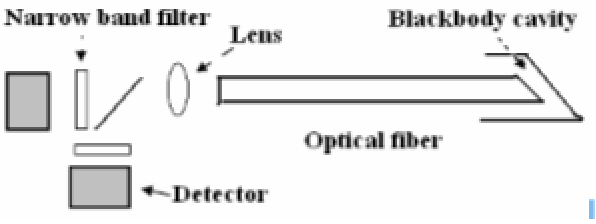


FIGURE 1.13 Blackbody fiber optic sensor

The most widely used wavelength based sensor is the Bragg grating sensor. Fiber Bragg gratings (FBGs) are formed by constructing periodic changes in index of refraction in the core of a single mode optical fiber. This periodic change in index of refraction is normally created by exposing the fiber core to an intense interference pattern of UV energy. The variation in refractive index so produced, forms an interference pattern which acts as a grating.

The Bragg grating sensor operation is shown in Figure 1.14 where light from a broadband source (LED) whose center wavelength is close to the Bragg wavelength is launched into the fiber. The light propagates through the grating, and part of the signal is reflected at the Bragg wavelength. The complimentary part of the process shows a small sliver of signal removed from the total transmitted signal. This obviously shows the Bragg grating to be an effective optical filter.

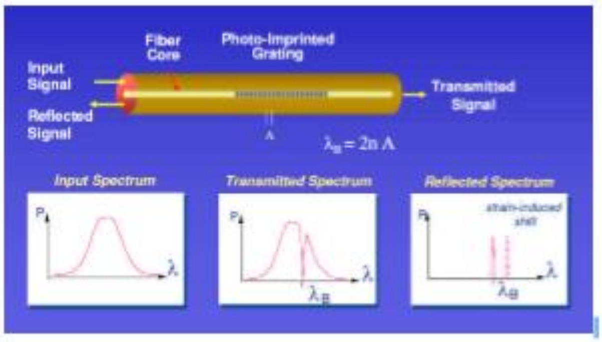


FIGURE 1.14 Bragg grating response.(Méndez, A., 2007)

(C). Phase Modulated Fiber Optic Sensors

Phase modulated sensors use changes in the phase of light for detection. The optical phase of the light passing through the fiber is modulated by the field to be detected. This phase modulation is then detected interferometerically, by comparing the phase of the light in the signal fiber to that in a reference fiber. In an interferometer, the light is split into two beams, where one beam is exposed to the sensing environment and undergoes a phase shift and the other is isolated from the sensing environment and is used for as a reference. Once the beams are recombined, they interfere with each other [Krohn, D. A., 1988].

Mach-Zehnder, Michelson, Fabry-Perot, Sagnac, polarimetric, and grating interferometers are the most commonly used intereferometers. The Michelson and Mach-Zehnder interferometers are shown in Figures 1.15 (a) and 1.15 (b), respectively.

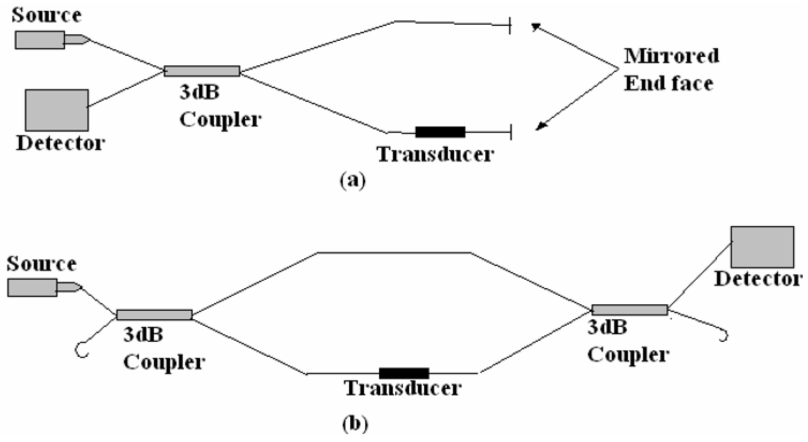


FIGURE 1.15 Shematic diagrams of (a) Michelson, and (b) Mach-Zehnder interferometers

There are similarities and differences between the Michelson and Mach–Zehnder interferometers. In terms of similarities, the Michelson is often considered to be folded Mach–Zehnder, and vice versa. Michelson configuration requires only one optical fiber coupler.

Because the light passes both through the sensing and reference fibers twice, the optical phase shift per unit length of fiber is doubled. Thus, the Michelson can intrinsically have better sensitivity. Another clear advantage of the Michelson is that the sensor can be interrogated with only a single fiber between the source-detector module and the sensor. However, a good-quality reflection mirror is required for the Michelson interferometer [Yu, F. T. S., and Shizhuo, Y., 2002].

Another commonly used interferometer based sensor is the Fabry-Perot interferometric sensor (FFPI) and is classified into two categories: Extrinsic Fabry-Perot interferometer (EFPI) sensor and intrinsic Fabry-Perot interferometer (IFPI) sensor. In an EFPI sensor, the FabryPerot cavity is outside the fiber. Fiber guides the incident light into to the FFPI sensor and then collects and the reflected light signal from the sensor. In an IFPI sensor, the mirrors are constructed within the fiber. The cavity between two mirrors acts both as sensing element and waveguide. In this case, the light never leaves the fiber [Wang, Z., 2003]. Figure 1.16 shows a typical EFPI sensor based on capillary tube.

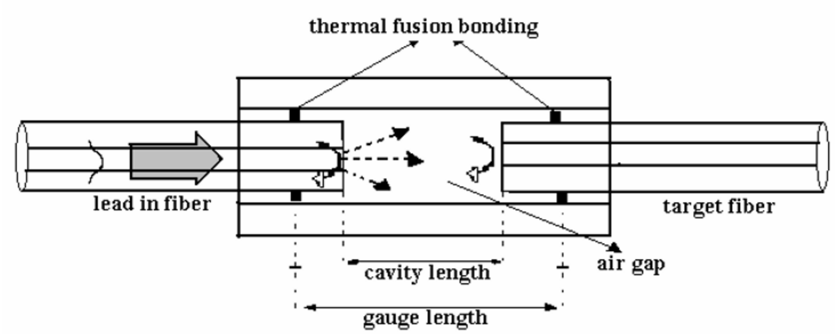


FIGURE 1.16 Capillary tube based EFPI sensor (Wang, Z., 2003)

One cleaved fiber end (lead-in) is inserted into a glass capillary tube and another cleaved fiber end (target) is inserted into the tube from the other end. Both lead-in and target fibers are thermal fusion bonded with the tube. The cavity length between the two fibers is controlled using a precision optical positioner prior to the thermal fusion bonding. One of the advantages of this EFPI strain sensor is that its gauge length and cavity length can be different. The strain sensitivity is determined by the gauge length, while the temperature sensitivity is determined only by cavity length since the fiber and tube have the same thermal expansion coefficients. Hence, by making the gauge length much longer than the cavity length, the sensor temperature sensitivity becomes much less than the strain sensitivity. So, no temperature compensation is required.

An IFPI sensor contains two mirrors separated by a distance within a fiber core. The earliest IFPI sensor probably is the spliced TiO2 thin film coated fiber IFPI sensor. In this sensor internal mirror is introduced in fiber by thin film deposition on the cleaved fiber end followed by fusion splicing as shown in Figure 1.17. Several other methods are also used to produce internal mirror, such as using vacuum deposition, magnetron sputtering, or e-beam evaporation.

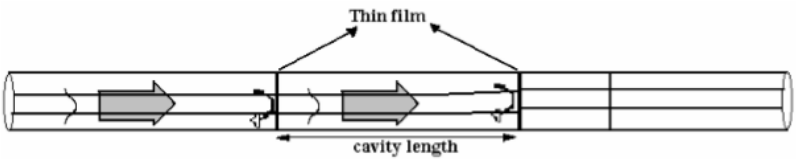


FIGURE 1.17 Thin film based IFPI sensor (Wang, Z., 2003)

Sagnac interferometric sensors are based on fiber gyroscopes that can be used to sense angular velocity. Fiber gyroscopes are based on the principle that application of force changes the wavelength of light as it travels around a coil of optical fiber. It may also be occupied to measure time varying influences such as acoustics and vibration. Two types of fiber optic gyros have been developed: Open loop fiber optic gyro and closed loop fiber optic gyro.

The open loop fiber optic gyro is shown in Figure 1.18. A broadband light source is used to inject light into an input or output fiber coupler. The input light beam passes through a polarizer which is used to make certain the mutuality of the counter propagating light beams through the fiber coil. The second central coupler shares the two light beams into the fiber optic coil where they pass through a modulator. It is used to produce a time altering output signal indicative of rotation. The modulator is offset from the center of the coil for emphasizing a proportional phase difference between the counter propagating light beams. After light beams propagate from modulator, they rejoin and pass through the polarizer. Finally, light beams are guided onto the output detector.

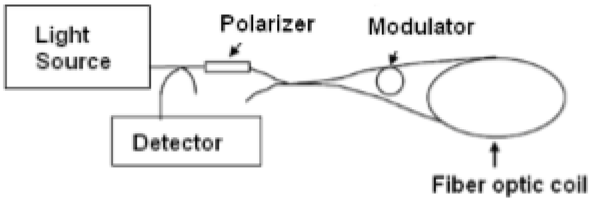


FIGURE 1.18 Open loop fiber optic gyro (Udd, E., 1996)

The second type is the closed loop fiber optic gyro that is primarily aimed at vacuum to high accuracy navigation applications. They have high turning rates and need high linearity and large dynamic ranges. In Figure 1.19, a closed loop fiber optic gyro is illustrated. This type of sensor is used as a modulator in the fiber optic coil to produce a phase shift at a certain rate. When the coil is rotated, a first harmonic signal is contributed with phase which depends on rotation rate. This manner is similar to open loop fiber optic gyro which is described before.

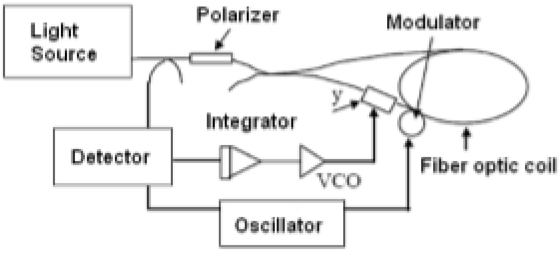


FIGURE 1.19 Closed loop fiber optic gyro (Udd, E.,et al, 1998)

(d). Polarization Modulated Fiber Optic Sensors

The direction of the electric field portion of the light field is defined as the polarization state of the light field. Different types of polarization states of the light field are linear, elliptical, and circular polarization states. For the linear polarization state, the direction of the electric field always keeps in the same line during the light propagation. For the elliptical polarization state, the direction of the electric field changes during the light propagation. The end of the electric field vector forms an elliptical shape; hence, it is called ‘‘elliptical polarized light”.

The refractive index of a fiber changes when it undergoes stress or strain. Thus, there is an induced phase difference between different polarization directions. This phenomenon is called photoelastic effect. Moreover, the refractive index of a fiber undergoing a certain stress or strain is called induced refractive index. The induced refractive index changes with the direction of applied stress or strain. Thus, there is an induced phase difference between different polarization directions. In other words, under the external perturbation, such as stress or strain, the optical fiber works like a linear retarder. Therefore, by detecting the change in the output polarization state, the external perturbation can be sensed [Yu, F. T. S., and Shizhuo, Y., 2002].

Figure 1.20 shows the optical setup for the polarization based fiber optic sensor. It is formed by polarizing the light from a light source via a polarizer that could be a length of polarization-preserving fiber. The polarized light is launched at 45 degrees to the preferred axes of a length of bi-refrigent polarization-preserving fiber. This section of fiber is served as sensing fiber. Under external perturbation such as stress or strain, the phase difference between two polarization states is changed. Then, the output polarization state is changed according to the perturbation. Hence, by analyzing the output polarization state at the exit end of the fiber, the external perturbation can be detected.

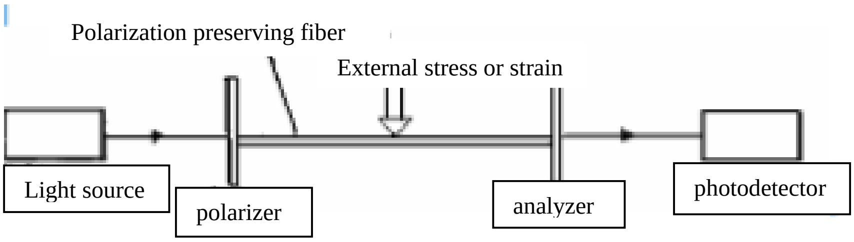


FIGURE 1.20 Polarization-based fiber optic sensor (Yu, F. T. S., and Shizhuo, Y. 2002)

1.5.2 APPLICATIONS OF FIBER OPTIC SENSOR (FOS)

Fiber optic sensors are used in several areas. Specifically:

- Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size.

- Monitoring the physical health of structures in real time.

- Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring, prestressing monitoring, spatial displacement measurement, neutral axis evolution, long-term deformation (creep and shrinkage) monitoring, concrete-steel interaction, and post-seismic damage evaluation.

- Tunnels: Multipoint optical extensometers, convergence monitoring, shotcrete / prefabricated vaults evaluation, and joints monitoring damage detection.

- Dams: Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring, and distributed temperature monitoring.

- Heritage structures: Displacement monitoring, crack opening analysis, post-seismic damage evaluation, restoration monitoring, and old-new interaction.

Nurulain et al. (2017) reviewed some fiber optic sensor topology and techniques to determine their suitability for various applications as stated in Table 1.1

Table 1.1: Different classifications of FOS

Working Principle [a]	**Spatial Positioning [b]**	**Measured Parameters [c]**
Intensity-modulated sensors: Detection through light power	Point sensors: Discrete points, different channels for each measurement	Physical sensors: Temp., strain, pressure, force, speed and displacement (amplitude) sensors, Acoustic and vibration sensors, humidity etc.
Phase-modulated (interferometric) sensors: Detection using the phase of the light beam	Distributed: Measurement is determined along a path, surface, or volume	Chemical sensors: pH content, gas sensors, liquid level, spectroscopic study, etc.
Polarimetric sensors: Detection of changes in the state of polarization of the light	Quasi-distributed: Variable measured at discrete points along an optical link	Biosensors: DNA, blood flow, glucose sensors etc.

Spectrometric sensors: Detection of changes in the wavelength change of the light	Integrated: Measurement integrated along an optical link giving a single value output	Chemical and Biosensors

Source: (a) Ginu, (2015) (b) Nurulain et al. (2017) (c) Patra, (2013; Hisham, (2018)

1.6 SCOPE OF THE STUDY

The study is focused on the measurement of temperature using fiber optic sensor using an OTDR to measure attenuation. In order to achieve this one end of the fiber optic cable inside a refrigerator at freezing temperature and allowing it to freeze while the other end was connected to a patch panel which was connected to an OTDR to interpret the signals, the cable was then brought out of the freezer and allowed to warm up. The was carried out in the University of Benin Department of Physics Lab B

1.7 AIM AND OBJECTIVES

The aim of this research work is to measure and analyse the effect of temperature on optic fiber cable using 50 nano seconds

The attainable objectives in this study are;

I) Log snapshots of the stochastic signal in the cable using a short and long pulse width of 20ns and 50ns respectively with OTDR

II) Match the timing of each excitation with the time interval

III) Analyze Otdr trace using Fiberizer Cloud software at various events

IV) Calculate the spectral analysis of the stochastic signal caused by temperature variation

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

Many material properties show strong temperature dependence. In order to utilize or compensate temperature effects, its measurement is required. Examples of such temperature dependencies are dew point, density, electrical conductivity, refractive index, rigidity and diffusion. Temperature measurement also plays an important role in health monitoring of electric circuits or civil structures. Most measurement tasks in industrial applications and research can be carried out using conventional electric temperature sensors such as thermocouples, junction temperature sensors, resistance temperature detectors or thermistors. But conventional temperature sensors have their limitations especially if

− large distances have to be covered as is the case of many distributed measurements,

−large numbers of sensors have to be integrated in order to monitor many system states or even temperature fields or gradients,

−electromagnetic interference decreases the signal to noise ratio significantly,

−explosive environments prohibit the application of electric devices,

− light-weight structures and monitoring equipment with low mass impact are desired. Particularly under these conditions fibre optic temperature sensors are able to show their full potential. But depending on the actual application, different types of fibre optic temperature sensors can be used. The most common fibre optic temperature sensors are:

− fibre Bragg gratings, where the temperature dependence of distributed optical reflection is used,

− extrinsic interferometric optical structures, which show a temperature dependent behaviour,

− Raman scattering distributed temperature sensors, that use the temperature dependence of inelastic scattering on optical phonons,

− Brillouin scattering distributed temperature sensors, using scattering on acoustic phonons,

− semiconductor band gap technology, based on the temperature dependence of the band gap of semiconductor crystals. Fibre-optic sensing has already found wide access to monitoring applications of civic structures (especially Raman scattering based sensors). A good overview of this field is given in (Measures, R. 2001). Application of fibre optic temperature sensors in process control or machine monitoring has increased to date but still shows great potential for growth. This article exemplarily looks at fibre Bragg gratings and thin-film interferometric point temperature sensors as well as at distributed temperature measurement based on Raman scattering. For each sensor type the basic working principle is explained and performance is discussed. Besides that, examples of recent applications are presented.

2.1 OPERATING PRINCIPLES OF THE FIBER OPTIC TEMPERATURE SENSOR

Fiber-optic probes are among the more interesting temperature measurement devices in current use. Here’s the way one company’s products work.

Fiber-optic temperature sensors are based on the light absorption/ transmission properties of gallium arsenide (GaAs). The effects of temperature variations on this semiconducting crystal are well known and predictable. At the measurement end of the fiber-optic temperature sensor is a GaAs crystal. As the crystal’s temperature increases, its transmission spectrum (i.e., the light that is not absorbed) shifts to higher wavelengths. At any given temperature, transmission jumps from essentially 0% to 100% at a specific wavelength. This jump is called the absorption shift (see Figure 2.1). The relationship between the temperature and the specific wavelength at which the absorption shift takes place is very predictable.

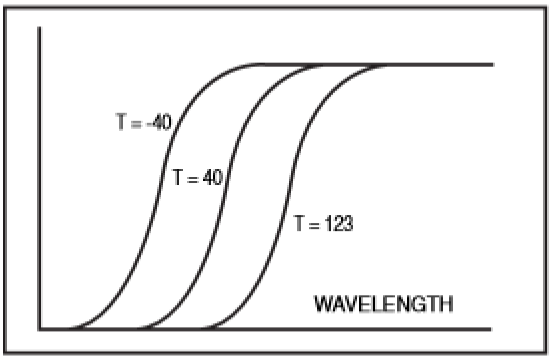


Figure 2.1 Fiber-optic temperature sensors operate on the absorption/ transmission properties of gallium arsenide crystal semiconductors. increases in the crystal’s temperature have the effect of shifting its transmission spectrum to higher wavelengths, jumping from essentially 0% to 100% at a specific wavelength. The three temperatures shown here are in ºC.

To understand why the absorption shift occurs, it is necessary to look at the variation in the semiconductor’s energy band gap. This band gap refers to the energy required to bump the electrons in the material from a relaxed, steady state into an excited state. As more energy in the form of heat enters the crystal, the band gap becomes narrower—less additional energy is needed to excite an electron.

The photons entering the crystal are what actually excite the electrons. If a photon is carrying enough energy to get an electron across the gap, it will be absorbed. If it is not carrying enough energy, the photon will be transmitted. The shorter a photon’s wavelength, the more energy it carries. Because the band gap narrows as the crystal’s temperature increases, and less energy is needed to jump the gap, photons with less and less energy (longer and longer wavelengths) are absorbed by the band. The effect is to move the absorption shift to longer wavelengths. Consequently, measuring the position of the absorption shift gives a measure of the crystal’s temperature.

2.1.1 PROBE DESIGN

A fiber-optic temperature probe must be in contact with the material it is measuring. The more intimate the contact, the faster the crystal will respond to the temperature changes. A tiny crystal of GaAs with a dielectric mirror is bonded to one end of a cleaved optical fiber (see Figure 2.2). PTFE is then used to cover the entire assembly, serving as an excellent buffer.

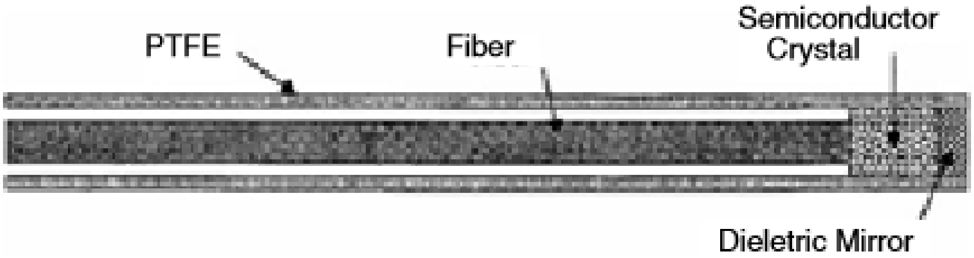


Figure 2.2. The fiber-optic temperature sensor probe consists of a gallium arsenide crystal and a dielectric mirror on one end of an optical fiber and a stainless steel connector at the other end. The entire assembly is coated with PTFe as a buffer.

At the opposite end of the probe is a stainless steel ST-type connector, through which white light is injected into the probe.

The light travels down the probe's optical fiber, where some of it is absorbed by the GaAs crystal. The dielectric mirror reflects unabsorbed light, which returns down the probe to the coupler and is directed to a spectrometer (see Figure 2.3).

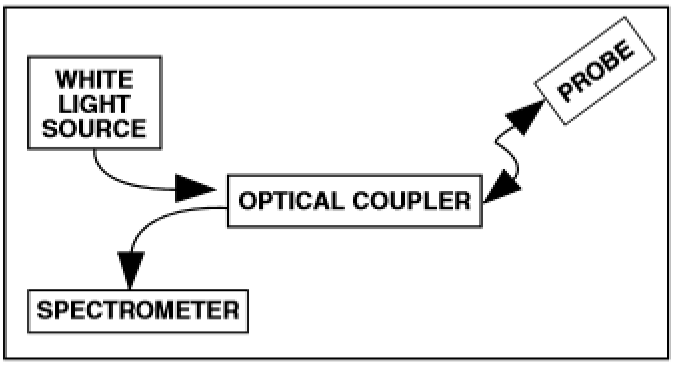


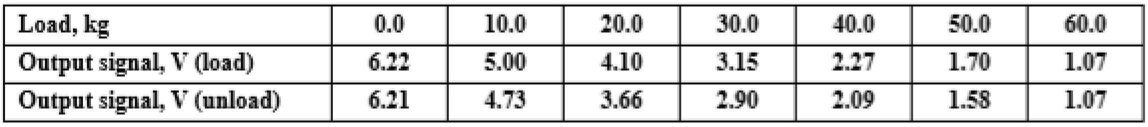
Figure 2.3. A white light source injects light into one of the branches of the coupler. This light travels down the probe's optical fiber to the gallium arsenide, which absorbs some of it. Unabsorbed light is reflected by the dieletric mirror and returned down the probe to the coupler, where it is directed to a spectrometer.

The position of the absorption shift is then analyzed and correlated back to temperature. Computation of the absorption shift does not depend on signal intensity; essentially, only the reflected light signature is of interest. Therefore, the various factors that contribute to attenuation on optical fibers (e.g., fiber length, number and quantity of connections, fiber diameter and composition, bending) do not impose any serious constraints. Furthermore, since the GaAs crystal’s response is universal and constant, no probe calibration is required.

2.2 SENSOR OUTPUT CHARACTERISTICS

Load characteristic was measured from the SENSOR LINE SPT fiber optic sensor by means of a SL Transducer (optical interface) optical signal analyser developed by SensorLine GmbH [SENSOR LINE GmbH product description]. The measuring length of the sensor was 49 cm, and the special instalment was made for the experiments. The optical signal analyser, which is connected to the sensor, has a transmitter and receiver of the light beam, as well as an electronic circuit which converts the change of the optical path to voltage change. The load was varied from 0 to 60 kg in a pitch of 10 kg. The results of one experiment are presented in Table 1. The data received from other experiments was similar.

Table 2.1: Load characteristic of the SENSOR LINE SPT [SENSOR LINE GmbH product description] fiber optic sensor



Load, kg	0.0	10.0	20.0	30.0	40.0	50.0	60.0
Output signal, V (load)	6.22	5.00	4.10	3.15	2.27	1.70	1.07
Output signal, V (unload)	6.21	4.73	3.66	2.90	2.09	1.58	1.07

A graphic representation of the received experimental data is presented on Fig. 2, where the solid line is the load characteristic, and the dashed line is unloading characteristic. As it can be seen from the figure, the sensor has a nonlinear output characteristic and significant hysteresis, which reaches 10.7-10.9% in the middle of curve lines. A common feature of numerous data, obtained in experiments, is that as far as the load increases, the first derivate of load curve line approaches to 0, reminding an exponent by itself. Therefore the increase of the output voltage under heavy load does not make it possible to reliably distinguish one load from another:

$$\Delta U / \Delta G = k \rightarrow 0, \qquad \Delta U = \Delta G \cdot k \rightarrow 0 \qquad (1)$$

Consequently, even if you use this sensor with the analyser as the threshold device in order to select the overloaded axes, one cannot guarantee it will work consistently.

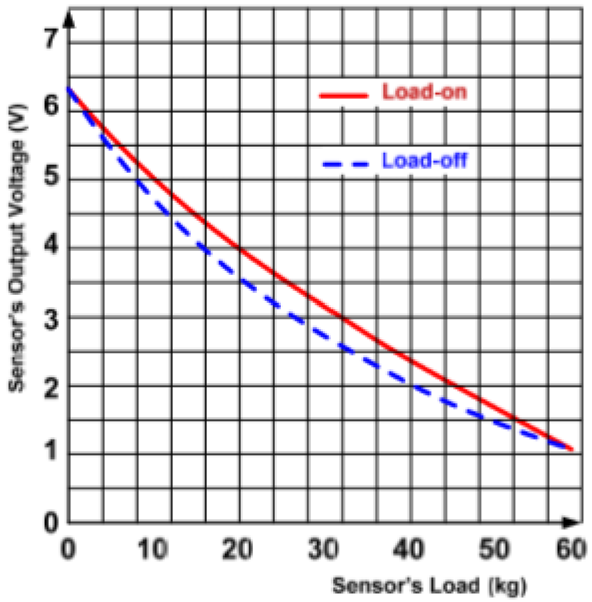


Figure 2.4**:** Output characteristic of the fiber optic sensor: solid line is the load characteristic, and the dashed line is unloading characteristic

The approximation upon the least square method of the stress sensor output U from the applied load F by the second-order polynomial during the load increment gives the following expression**:**

$$U(F) = 5.642845 \cdot 10^{-4} \cdot F^2 - 0.119143 \cdot F + 6.19929. \qquad (2)$$

Modern microelectronics, particularly the PIC-processors, make it possible to overcome this drawback and to create an optical signal analyser with a linear output characteristic. Such an analyser together with the fiber optic sensors will find use not only in vehicle weigh-in-motion systems, but also in many other spheres of industry, agriculture, medicine and everyday life. The guarantee of this is the fact that all currently existing monitors of strain gauge scales are adapted for use with strain gauge sensors having a linear characteristic of direct action: the more power – the more output. If you set a goal to replace the expensive strain gauge sensors with the cheap fiber optic sensors, the fiber optic sensors should have similar characteristics. Only this property allows fiber optic sensors to compete with strain gauge sensors and will not specify any special requirements for existing monitors. In other words, the weighing system does not have “to be aware of” the replacement of sensors. In the overwhelming majority of applications the presence of hysteresis is not an obstacle, because the weights user is only interested in weighing the load, laid on the scales. For example, during the multicomponent dosing the weight loading is gradual, with interruptions – a component by component. But as for the process of unloading, when the scales bottom is opened, nobody cares. After unloading the pause is performed, the scales are “reset” and the next weighing begins. As you can see, hysteresis does not get in the way. The different picture can be seen in the axis weighing systems of vehicles in motion. Several axes of one vehicle or multiple axes of traffic flow can pass through the sensor in a very short period of time when the vehicle speed is high. In this case the load changes from zero to maximum values. Therefore the deformed sensor needs to recover in time before it will be crossed by the next wheel set. The ideal for this application would have been the sensor, generally with no hysteresis. The task of creating elastomeric polymer light conductor, changing the transparency under the loads, arises from that fact.

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2.3 ADVANTAGES OF FIBER OPTIC TEMPERATURE SENSOR

Following are the benefits or advantages of fiber optic temperature sensor;

It is immune from electromagnetic (EM) and stray radiation

It can be used in environments where high levels of electrical interference exists or where intrinsic safety is a concern

It offers greater accuracy and faster response time

It is light in weight and compact in size

It is cheaper due to manufacturing cost

It supports wide temperature range of measurements from -10 C to 300 C. The GaAs offers better wavelength variation with temperature.

2.4 APPLICATIONS OF FIBER OPTIC SENSORS

2.4.1 MEDICAL

Fiber optic sensors offer complete immunity to RF and microwave radiation with high temperature operating capability, so they can be used for measurement on patients and materials in magnetic resonance scanner (MRI). In strong magnetic fields, there is a small offset in the temperature reading approximately proportional to the strength of the magnetic field squared. The magnitude of the offset is also affected by the orientation of the GaAs crystal within the magnetic field, the geometry of the GaAs crystal, and impurities in the GaAs. Metallic sensors can breed errors at the image acquisition. For special cancer treatment sensors with a diameter of 0.5 mm are available. These can be used minimally invasive for monitoring of tissue temperature. Another application of fiber optical measurement technique is laser therapy. Through an endoscope, laser energy is coupled and the temperature will be measured via a fiber optic probe at the location of therapy (Optocon AG 2012)

2.4.2 ENVITONMENTAL

Industrial areas often contaminate the soil with oil, toxic and persistent organic compounds. To clear these fields, soil heating by radio waves is frequently used. Fibre optical sensors are deployed to monitor and control this process. A high-power generator will deliver energy in the radio frequency range. The polluted soil is covered with electrodes, which will heat the surface dielectric. Besides, several fibre optical probes are put in the soil. Depending on the measured value different values of temperature and temperature distribution can be realized in the soil. Depending on the level of contamination the temperature will be increased slightly to activate a higher decomposition of soil organisms, alternatively, the soil water will condensate in a temperature range up to 150 °C together with non-steam resistant organic contaminations. A perforated soil air extraction system takes the steams away and recirculates them into a filter system.

2.4.3 CHEMICAL AND PETROLCHEMICAL

Fibre optic temperature probes are designed to withstand harsh and corrosive environments. The sensors are intrinsically safe. There are no components that create sparks, leading to explosions. They consist of completely non-conductive components and can therefore be used in hazardous areas. They can have a length up to 2.5 miles so that the analysis can be placed outside the hazardous area.

2.4.4 MICROWAVE AND RADIOFREQUENCY ENVIRONMENTS

In microwave heated installations chemical digestion under pressure and temperature for the determination of trace and ultra-trace analysis in downstream processes will be executed, for that reason, it was found that under certain pressure and temperature conditions, the yield or efficiency of extraction or digestion processes could be significantly improved. So fibre optical temperature sensors are the only way to control temperatures in microwave chemistry.

2.4.5 GENERATOR AND TRANSFORMER

The claims of a modern society relating to electricity requirement approach the full capacity of the generating stations. To ensure industrial safety the temperature must be tightly controlled. High power generators are often filled with hydrogen to cool effectively. Besides the heavily contaminated electromagnetic environment, the risk for explosions is high. Only a fibre optical thermometer can be used for measurement in these areas.

2.4.6 WOOD DRYING

The renovation of wooden structures can control the core temperature of the wood on fibre-optic temperature probe beams in place. The thermal drying of wood components in the installed state between 80 and 95 °C is sufficient to affect the dry rot infestation to combat and prevent damage. The probes used for temperature measurement consist of a jacketed PTFE glass fibres with a GaAs crystals (gallium arsenide) tip and are completely non-metallic.

2.4.7 ELECTRIC MOTORS

In the industry, the machinery and equipment are increasing to the limits of their strength exhausted. An engine with a larger or smaller size can be used to gain or lose a job lead. On the consumer side as well on a high mileage engine value set. Fibre optic temperature measurements without external effects (magnetic fields, radio frequencies, microwaves) can work quickly and easily even in hazardous areas. They can be used easily to measure the stator winding temperature of an engine or the bearing temperature. The sensors help to detect temperature changes quickly to report the fact to initiate preventive measures.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This chapter consists of the steps taken to perform the experiment and all the materials that were used. A fiber optic sensor temperature sensor was employed in this study to measure the temperature change in a controlled environment.

3.1 MATERIALS

The materials used in this study include; a multimode optical fiber cable (59 meters), a patch panel and an OTDR.

3.1.1 PATCH PANEL

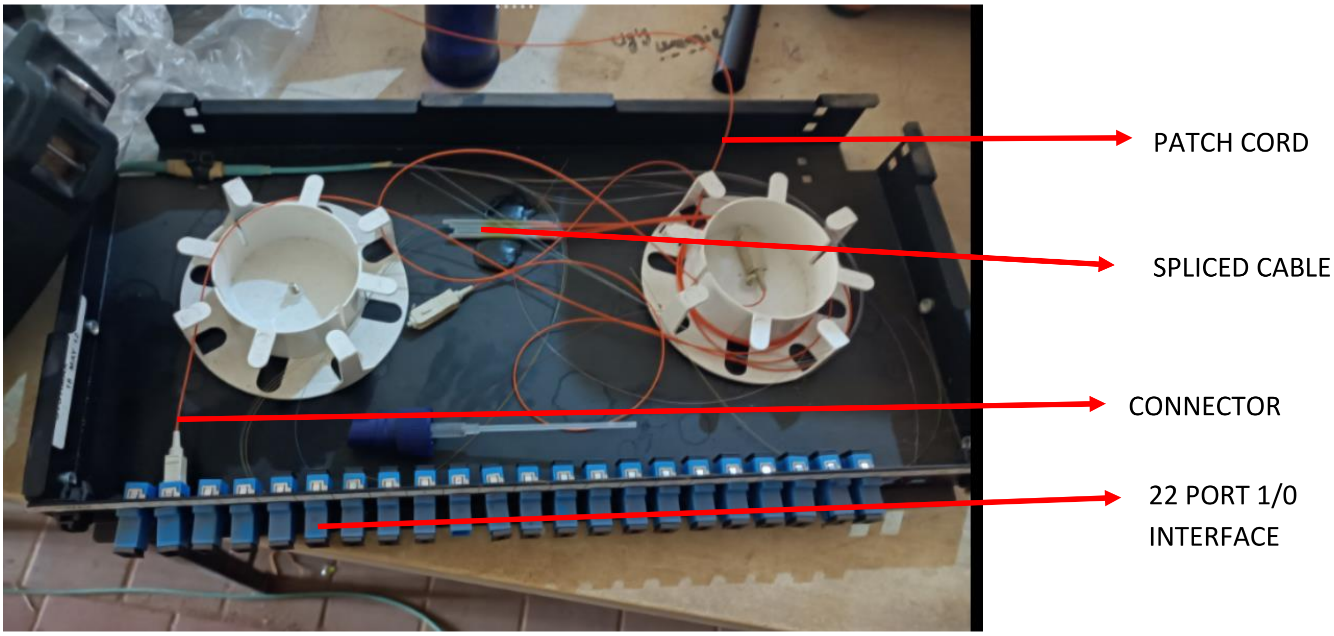


Figure 3.1: Patch panel

A fiber optic patch panel is commonly described as the interface panel that connects multiple optical fiber cables and optical equipment. Patch panels are rack-systems, and some are designed to be wall-mountable.

In physical terms, it is usually a metal enclosure that houses adapter panels, fiber splicing trays and space for excess fiber stotage . its basic construction consists of an array of ports where each port interfaces with another patch cable which is connected with opticalequiptment located elsewhere in the building. The adaptor panel provides an interface for both outside and inside ports to the enclosure.the inside ports are fixed as the cables are not meant to be disconnected at any point, whereas the outside ports are for fiber patching cables that can be plugged and unplugged as connections require.

The splicing trays are neatly embedded in the enclosure to provide fusion with fiber optic pigtails which in turn plud into the fixed insid4 adapter ports of the adapter panel.

3.1.2 OTDR

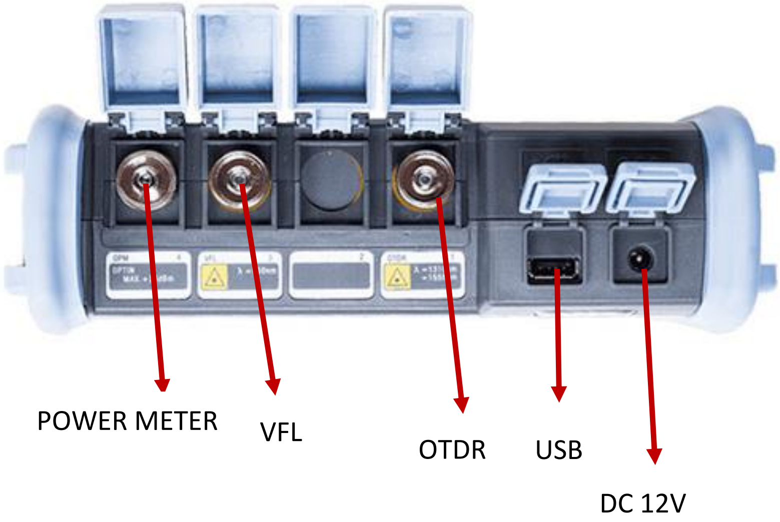


Figure 3.2: Top view of the OTDR

The top of the device comprises of the following ports; power meter, visual fault locator (VFL), OTDR, DC, and USB. The VFL is used to visually detect a defect within the cable. The OTDR has an in-built power meter, which is is used to transmit light pulse into the fiber cable, but some engineers prefer an external power meter to achieve same purpose. The DC 12V adapter is connected to the port to power the device and charge the battery. USB is used to copy measured traces from the internal memory and transferred to other devices.

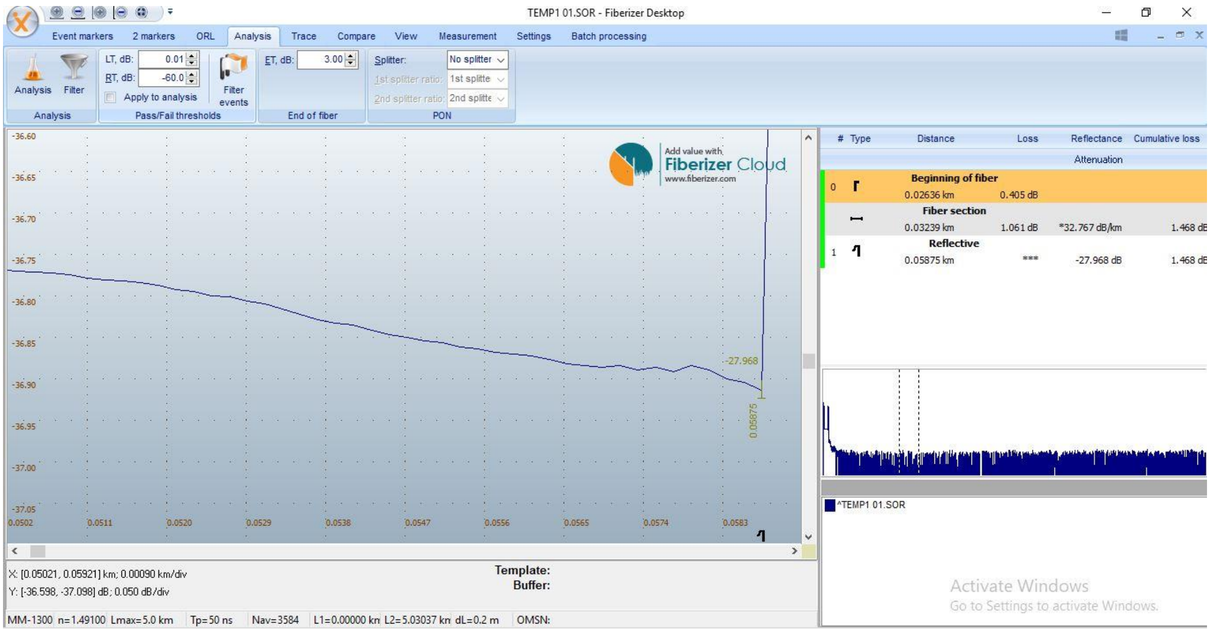
Figure 3.3: Front view of the OTDR

The OTDR comprises of power button, which is switched on when used and off when measurement is complete. The escape button returns the screen to provide display screen.

The navigation button controls the movement of the cursor, while the function button shows the various settings on the display screen. When the OTDR measurement is taken, the A-B button helps to navigate the trace. Its also used to calculate the attenuation of the trace from point A to point B

3.2 DATA ACQUISITION AND ANALYSIS

Data was acquired by placing one end of the fiber optic cable inside a refrigerator at freezing temperature and allowing it to freeze while the other end was connected to a patch panel which was connected to an OTDR to interpret the signals, the cable was then brought out of the freezer and allowed to warm up while still connected to the patch panel and OTDR, the signals were also taken and recorded. The results and interpretation of the data gotten and can be seen in chapter four.



LT, dB: 0.01
RT, dB: -60.0
☐ Apply to analysis
ET, dB: 3.00
Splitter: No splitter
1st splitter ratio: 1st splitte
2nd splitter ratio: 2nd splitte

#	Type	Distance	Loss	Reflectance Attenuation	Cumulative loss
0	Beginning of fiber	0.02636 km	0.405 dB		
	Fiber section	0.03239 km	1.061 dB	*32.767 dB/km	1.468 dB
1	Reflective	0.05875 km	***	-27.968 dB	1.468 dB

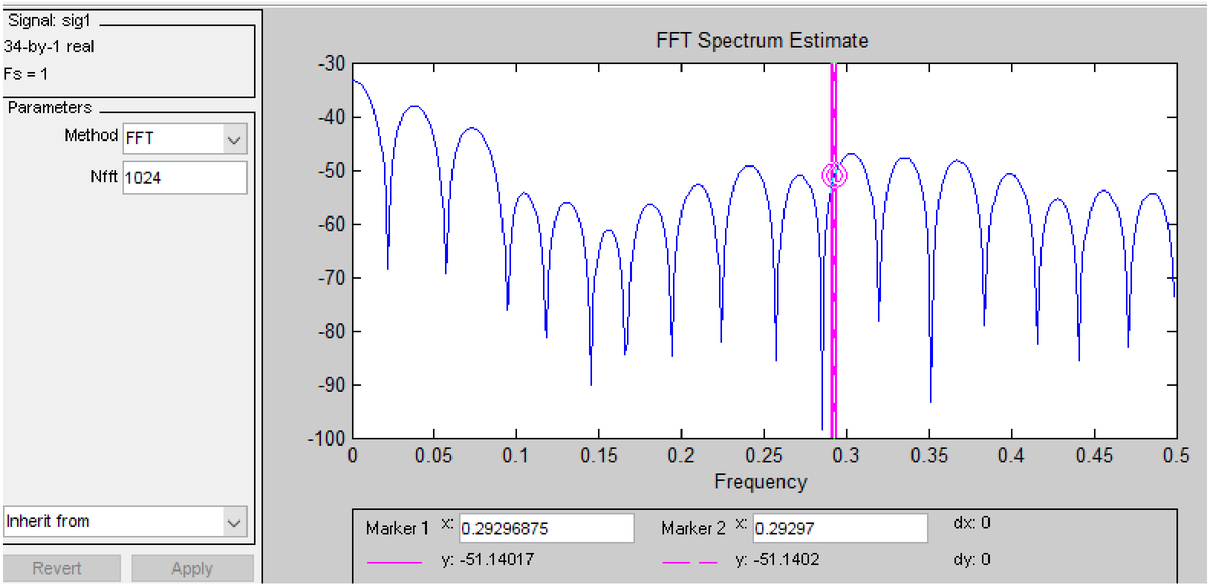
X: [0.05021, 0.05921] km; 0.00090 km/div
Y: [-36.598, -37.098] dB; 0.050 dB/div
Template:
Buffer:

MM-1300 n=1.49100 Lmax=5.0 km Tp=50 ns Nav=3584 L1=0.00000 km L2=5.03037 km dL=0.2 m OMSN:

Figure 3.4: Fiberizer Cloud Trace

Each trace indicates the various measurements. The trace can be navigated by moving the two point marker. This is used to determine the loss between point A and B on the trace. varying reflectance for different trace signal and backscatter level along the cable caused by change in temperature as shown in Figure 3.

The trace measurement shows the events on the cable caused by the change in temperature, which is analyzed to determine the various causes. Each sampled data obtained from the OTDR was recorded and analyzed separately. The measured signal obtained with the OTDR is further transformed from space domain to frequency domain using a Fast Fourier Transform (FFT) of the MATLAB (R2007B)



Signal: sig1
34-by-1 real
Fs = 1

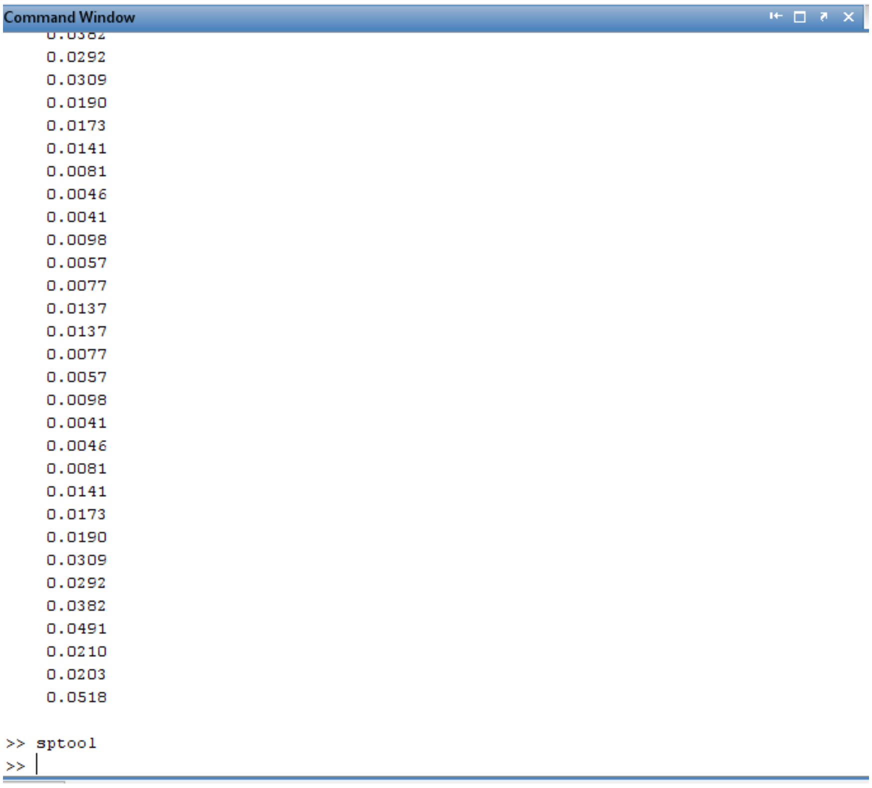
Parameters
Method FFT
Nfft 1024

Inherit from

Marker 1 X: 0.29296875 y: -51.14017
Marker 2 X: 0.29297 y: -51.1402
dx: 0
dy: 0

Figure 3.5: FFT Spectrum Estimate

It is impossible to determine the vibrating frequency of each temperature change as shown in Figure 3., hence the need to carry out a power spectral density of the signal. It is observed that the signal has a wide range of frequency spectrum and impossible to determine the vibrating frequency of the signal.



```
    0.0382
    0.0292
    0.0309
    0.0190
    0.0173
    0.0141
    0.0081
    0.0046
    0.0041
    0.0098
    0.0057
    0.0077
    0.0137
    0.0137
    0.0077
    0.0057
    0.0098
    0.0041
    0.0046
    0.0081
    0.0141
    0.0173
    0.0190
    0.0309
    0.0292
    0.0382
    0.0491
    0.0210
    0.0203
    0.0518

>> sptool
>> |
```

Figure 3.6 MATLAB window

The absolute value of the FFT data is gotten by excluding the first FFT value, because it is too large compared to the other values. The absolute value is then imported into sptool

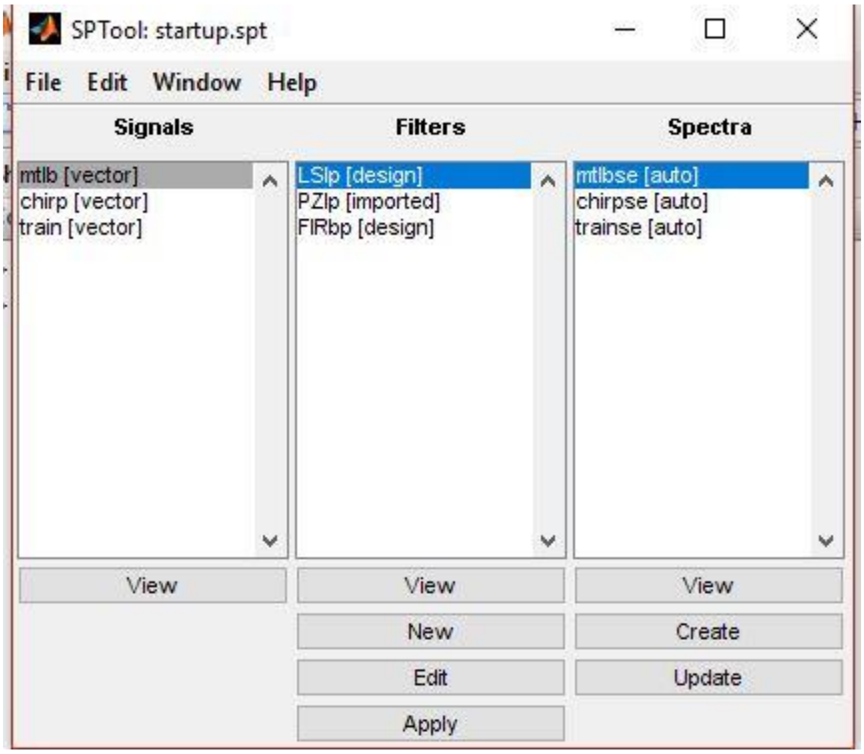


Figure 3.7: Sptool window

With noise embedded in the signal, a low band filter is used to eliminate the noise. In this work, a parametric model was used to calculate the spectral analysis. It was also observed that the choice of what order to use was also complex. The higher the order, the signal tends to display more peaks which represent noise. Conversely, at low order, the frequency peaks were characterized as a broad range of frequency.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 DISCUSSION OF RESULTS

The OTDR records the number of event on a fibre cable and uses the information to calculate the total loss of the signal. The experiment was carried out on the 18th of May, 2021 and the results thereof are described in Table 4.1 and 4.2 respectively.

Distance		Temp1 01	Temp1 02	Temp1 03	Temp1 04	Temp1 05	Temp1 06	Temp1 07	Temp1 08	Temp1 09	Temp1 10	Temp1 11	Temp1 12	Temp1 13	Temp1 14	Temp1 15
		13:41	13:42	13:43	13:44	13:44	13:44	13:45	13:45	13:47	13:48	13:49	14:01	14:02	14:03	14:04
0.05211	**-36.657**	**-36.79**	**-36.848**	**-36.823**	**-36.834**	**-36.839**	**-36.831**	**-36.824**	**-36.831**	**-37.012**	**-37.002**	**-37**	**-36.766**	**-36.764**	**-36.816**	**-36.822**
0.05231	**-36.657**	**-36.793**	**-36.853**	**-36.826**	**-36.834**	**-36.841**	**-36.832**	**-36.825**	**-36.833**	**-37.014**	**-37.003**	**-37.003**	**-36.769**	**-36.764**	**-36.816**	**-36.826**
0.05251	**-36.658**	**-36.797**	**-36.859**	**-36.828**	**-36.836**	**-36.844**	**-36.835**	**-36.826**	**-36.836**	**-37.015**	**-37.005**	**-37.005**	**-36.771**	**-36.764**	**-36.816**	**-36.829**
0.05272	**-36.658**	**-36.8**	**-36.864**	**-36.83**	**-36.838**	**-36.846**	**-36.837**	**-36.829**	**-36.838**	**-37.018**	**-37.007**	**-37.008**	**-36.774**	**-36.764**	**-36.816**	**-36.831**
0.05292	**-36.658**	**-36.804**	**-36.869**	**-36.832**	**-36.841**	**-36.848**	**-36.839**	**-36.832**	**-36.84**	**-37.019**	**-37.009**	**-37.01**	**-36.777**	**-36.764**	**-36.816**	**-36.834**
0.05312	**-36.66**	**-36.808**	**-36.873**	**-36.834**	**-36.845**	**-36.851**	**-36.842**	**-36.834**	**-36.842**	**-37.02**	**-37.011**	**-37.012**	**-36.781**	**-36.764**	**-36.816**	**-36.837**
0.05332	**-36.661**	**-36.815**	**-36.879**	**-36.836**	**-36.847**	**-36.853**	**-36.843**	**-36.837**	**-36.846**	**-37.024**	**-37.014**	**-37.014**	**-36.783**	**-36.764**	**-36.816**	**-36.839**
	-															
0.05775	**-36.679**	**-36.89**	**-36.955**	**-36.872**	**-36.882**	**-36.888**	**-36.885**	**-36.882**	**-36.88**	**-37.066**	**-37.049**	**-37.056**	**-36.834**	**-36.764**	**-36.816**	**-36.887**
0.05795	**-36.678**	**-36.883**	**-36.955**	**-36.869**	**-36.881**	**-36.888**	**-36.881**	**-36.881**	**-36.884**	**-37.063**	**-37.05**	**-37.061**	**-36.84**	**-36.764**	**-36.816**	**-36.887**

0.05815	-36.673	-36.887	-36.956	-36.875	-36.88	-36.884	-36.881	-36.883	-36.881	-37.056	-37.05	-37.054	-36.839	-36.764	-36.816	-36.892
0.05835	-36.675	-36.898	-36.957	-36.875	-36.89	-36.888	-36.884	-36.882	-36.893	-37.07	-37.049	-37.054	-36.847	-36.764	-36.816	-36.894
0.05855	-36.687	-36.902	-36.957	-36.883	-36.886	-36.9	-36.893	-36.893	-36.895	-37.068	-37.06	-37.063	-36.85	-36.764	-36.816	-36.9
0.05875	-36.693	-36.912	-36.97	-36.884	-36.894	-36.891	-36.886	-36.905	-36.907	-37.077	-37.061	-37.07	-36.85	-36.764	-36.816	-36.905
0.05895	-36.658	-36.009	-36.033	-36.81	-36.814	-36.818	-36.806	-36.807	-36.814	-36.994	-36.989	-37.002	-36.789	-36.764	-36.816	-36.852

Table 4.1: OTDR TRACE RESULT

This table shows the raw figures gotten from the OTDR

Marker 1 x: 0.13769531
y: -19.872725
Marker 2 x: 0.2734375
y: -25.289283
dx: 0.135742
dy: -5.41655

Figure 4.1(a): Spectral View of Temp1 01 at 13:41 (b): Curve Fitting for Temp1 01 at 13:41

Figure 4.1(a) shows the power spectral density of the signals when converted from time domain to frequency domain. The OTDR recorded an attenuation of 0.405dB and the signal having 2 events with the spectra showing 2 peaks at 13:41pm. The peaks are as a result of the fiber cable cooling after it was put in the freezer

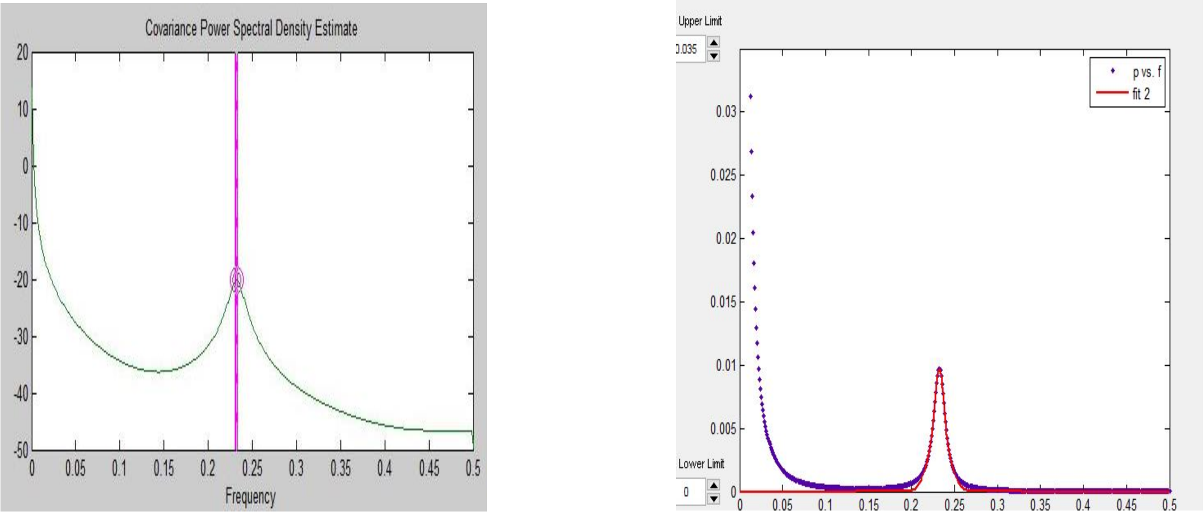


Figure 4.2(a): Spectral View of Temp1 02 13:42 (b): Curve Fitting for Temp1 02 at 13:42

The OTDR recorded an attenuation of 0.458dB and the signal having 1 event with the spectra showing 1 peak at 13:42pm as opposed to the 2 peaks in figure 4.1,this is as a result of further cooling on the fiber cable.

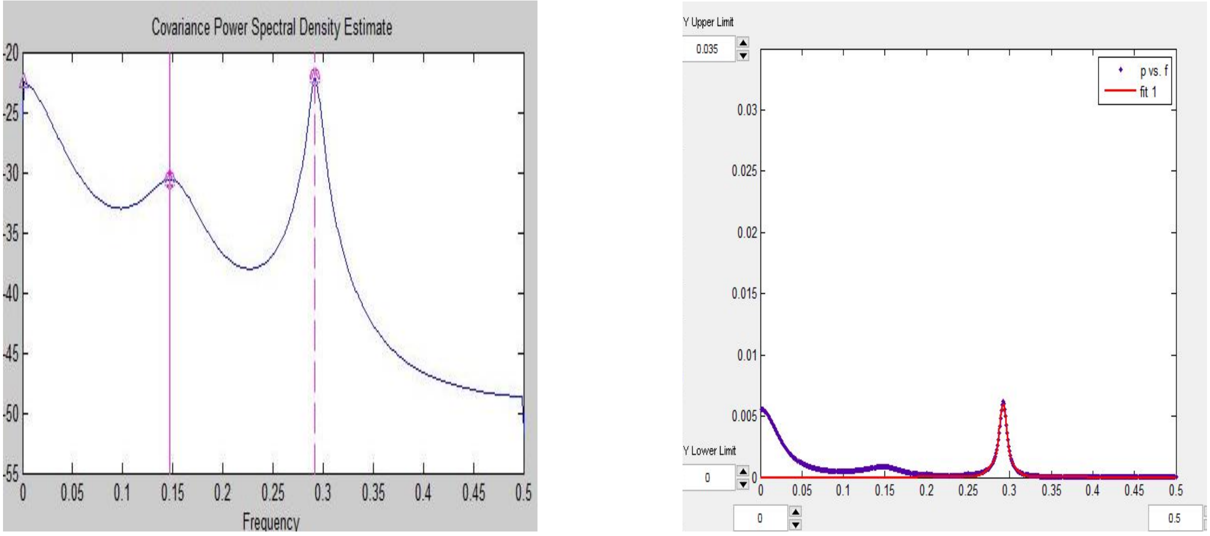


Figure 4.3(a): Spectral View of Temp1 03 at 13:43 (b): Curve Fitting for Temp1 03 at 13:43

The OTDR recorded an attenuation of 0.321dB and the signal having 1 event with the spectra showing 1 peak at 13:43 pm. This trace was taken a few seconds after Temp1 02 and as shown in figure 4.3(b), it has a smaller peak than figure 4.2 which further shows the effect of cooling on the fiber cable.

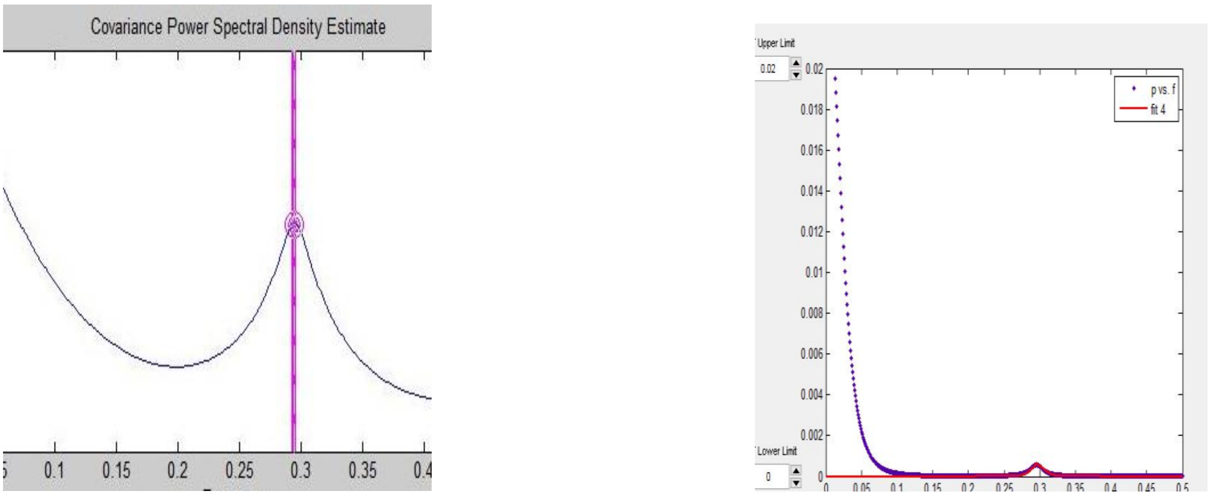


Figure 4.4(a): Spectral View of Temp1 04 at 13:44 (b): Curve Fitting for Temp1 04 at 13:44

The OTDR recorded an attenuation of 0.325dB and the signal having one event with the spectra showing one peak at 13:44. This trace has a smaller peak when compared to figure 4.3 as shown in figure 4.4(b). This further shows the effect of temperature on the fiber cable.

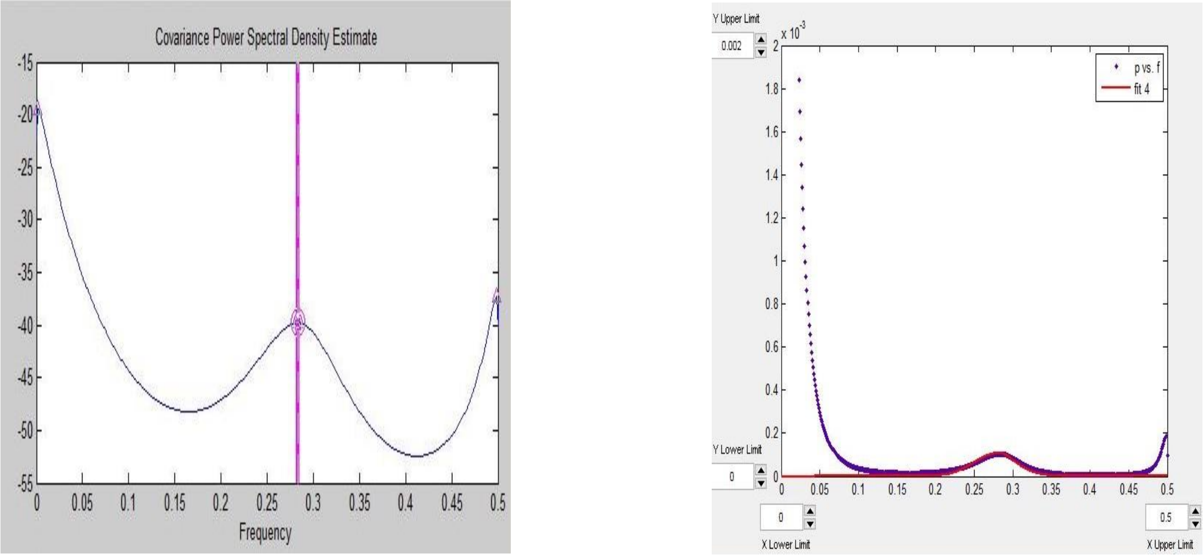
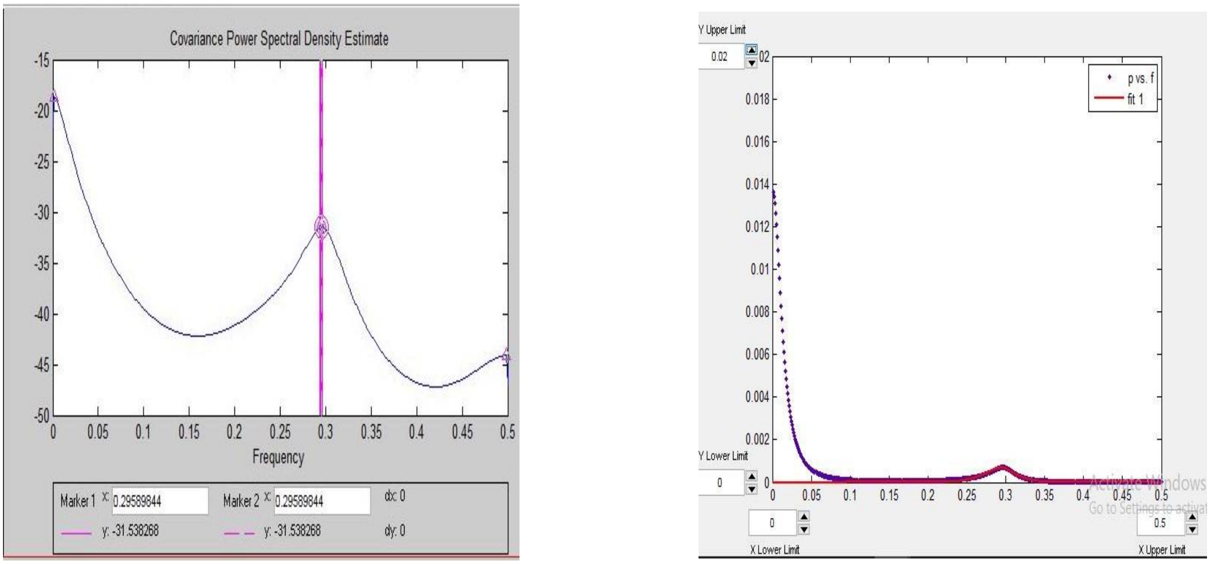


Figure 4.5(a): Spectral View of Temp1 05 at 13:44 (b): Curve Fitting for Temp1 05 at 13:44

The OTDR recorded an attenuation of 0.315dB and the signal having one event with spectra showing I peak at 13:44. This trace also has a broad peak due to the cooling of the fiber cable.

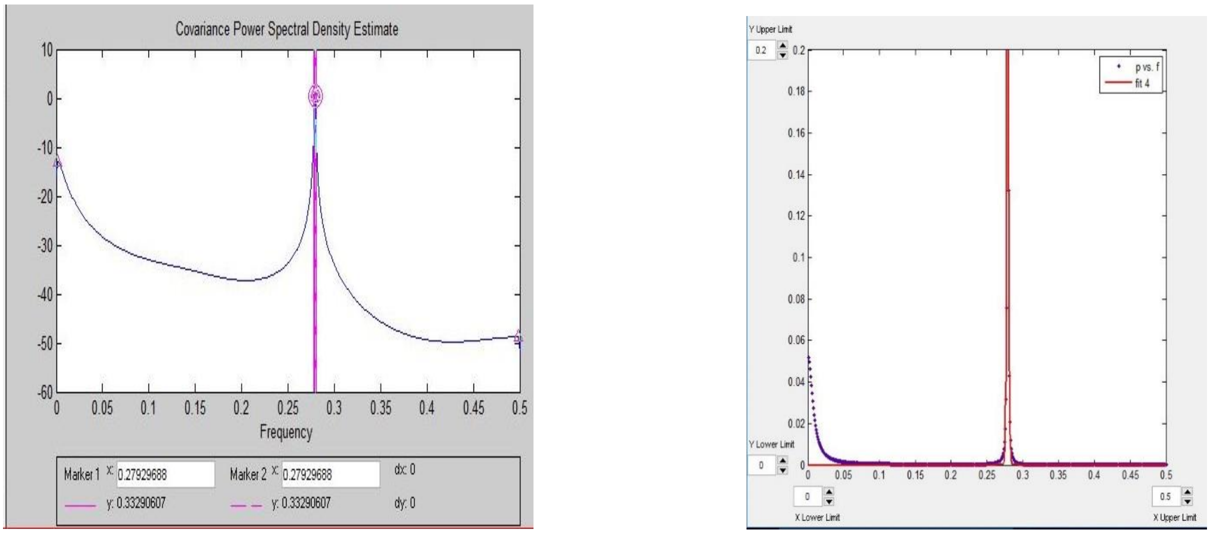


Marker 1 X: 0.29589844 y: -31.538268
Marker 2 X: 0.29589844 y: -31.538268
dx: 0
dy: 0

Y Upper Limit: 0.02
Y Lower Limit: 0
X Lower Limit: 0
X Upper Limit: 0.5

Figure 4.6(a): Spectral View of Temp1 06 at 13:44 (b): Curve Fitting for Temp1 06 at 13:44

The OTDR recorded an attenuation of 0.329dB from this trace, it has one event and a broad peak similar to that of figure 4.5 which further shows the effect of temperature.



Marker 1 X: 0.27929688 y: 0.33290607
Marker 2 X: 0.27929688 y: 0.33290607
dx: 0
dy: 0

Y Upper Limit: 0.2
Y Lower Limit: 0
X Lower Limit: 0
X Upper Limit: 0.5

Figure 4.7(a): Spectral View of Temp1 07 at 13:45 (b): Curve Fitting for Temp1 07 at 13:45

The OTDR recorded an attenuation of 0.338dB from this trace. Compared to figure 4.6, this trace has a very low peak with broken lines and almost looks as though there is no activity on the fiber cable. This is due to the cable almost being completely frozen.

Table 4.2: FWHM

	CURVE 1				CURVE 2			
-Trace	C1	C2	Peak	RMS	C1	C2	Peak	RMS
01	0.007438	0.01761	0.012	4.393e-005	0.0202	0.007248	0.0014	0.0001485
02	0.00617	0.01628	0.01	2.871e-005				
03	0.005786	0.01901	0.008	8.367e-005				
04	0.004272	0.01514	0.001	6.545e-005				
05	0.01425	0.03999	0.1	9.666e-006				
06	0.01578	0.03417	0.001	3.006e-005				
07	0.0006735	0.002715	0.13	0.001984				
08	0.01381	0.03261	0.002	4.41e-005				
09	0.00905	0.0294	0.001	6.23e-006				
010	0.001592	0.005689	0.045	0.0003536				
011	0.004533	0.01316	0.005	8.23e-005				
012	0.08349	0.04502	0.4	2.525e-005	0.007348	0.0319	0.3	1.515e-005
013	0.007967	0.02605	0.002	4.195e-005				

014	0.006101	0.01549	0.003	5.465e-005				
015	0.007992	0.01579	0.002	3.794e-005				

The FWHM table shows all the details for the various curve fittings in the above figures.

CHAPTER FIVE

CONCLUSION

5.0. In conclusion, it has been proven that Optical fiber sensors can be used for Vibration classification temperature measurement. This study has shown that this technique can be used for temperature sensing.

5.1 FINDINGS

From the results of this research, the following findings were made:

1. Double Gaussian gives the best fitting in determine the Full Weight at Half Maximum (FWHM) for differential signal in this work.
2. It was discovered that the methods used by (Awodu,2019) and (Okuonghae, 2020) respectively for measuring uncontrolled and controlled vehicular traffic can also employed in temperature sensing

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