Loss Analysis in Optical Fiber Transmission

* Anusha Mushtaque, * Abi Waqas, * Zarlish Mushtaq, * Aftab A. Memon and ** B.S. Chowdhry

***Abstract*— Most of telecommunication traffic (voice and data) around the globe is carried over the optical fiber cable. The international traffic through various countries is carried over optical fiber cables laid under the sea. Similarly the long-haul traffic within the country is through optical fiber laid underground. Stress, strain, humidity, temperature, bending at acute angles affects the propagation of light energy in the optical fiber cable. All such factors increase the optical loss and attenuate the signal. The attenuation, especially in the long-haul communication increases the bit error rate and degrades the quality of service. In this paper, different optical losses are analyzed by setting up several experiments at a single mode optical fiber spool of 4 km. The optical fiber segment was subjected to various stress, temperatures and acute bending conditions. The resulting losses and degradation of the signal was measured using OTDR and Power meter.**

***Index Terms*—Fiber Optics Communication, Attenuation losses.**

I. INTRODUCTION

Optical fibers are strands of glassy materials or polymeric available in the form of cables, they are flexible, immune to electrical noise as well as the most extreme weather conditions, and not very sensitive to temperature variations. . In many Fiber laid networks, the fiber is hanged overhead if digging in the streets is not feasible [1][2]. In many buildings the optical fiber is raised to higher floors for connectivity whereas in urban areas, the optical fiber cable is laid under the roads which results in heavy stresses due to traffic over the roads. The pressure on cable can be observed when the duct is broken and cable is damaged. However in patch cords, stress and bending effects are observed seriously. The smaller size of pits in urban areas, forces the cable laying staff to roll the cable in acute angles/curve, resulting in spreading losses [3]. Optical Fiber cable is layed in ducts from cable roll in shape of "8" and no sharp bend is allowed. However in optical patch cords, bending and pressure issue occurs due to carelessness in laying. Accumulated sewerage and rain water in pits enters the cable jacket from the spliced joints. The humidity changes the refractive index of the cladding resulting in optical losses [4]. The cable raised in buildings outer walls are exposed to sun heat. Higher temperature changes the chemical composition of gel used in cable, increases the core temperature and excites the core/cladding interface charges.

Attenuation is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (Pi) to the optical output power (Po). It is measure in dB/ km. However, optical fiber cable may be subject to curvature/bent, temperature, pressure and many other attenuation losses during installation, servicing or maintenance [5][6].

Curvature/Bending generates a coupling between the guided mode and the ways radiative spectrum [7]. In the case where the radius of curvature is large enough, it can be assumed that the field distribution of the guided mode undergoes a slight deformation. Due to bending issues the propagation conditions alter and light rays which would propagate in a straight fiber are lost in the cladding [8].

Temperature also causes noteworthy changes in Fiber. Small amount of rain, wind or snow should not impact the speed of optical fiber cable [8]. Large storms, however, can be cause for concern [9][10]. Cold may also cause problems for electromechanical components of a connection, such as breakers or switches [11][12]. It does not affect optical fiber signal directly, however can cause electrical power issue in Optical fiber systems.

Pressure does not have exact effects on optical fiber cables, because there are always proper procedures when we underlay the fiber, from those most are successful those does not have any pressure effects but in few cases when it is not properly buried then it might have some losses [13][14].

II. METHODOLOGY

Detailed literature survey was done regarding losses in Fiber transmission. The performance of optical fiber at different impairments was analyzed and characterized along with different losses due to various conditions. Fiber spool of 4 km was taken to roof top for below mentioned experimental setup for measuring losses at various temperatures. Losses due to pressure and bending were measured and analyzed inside laboratory using Fiber Cable, source meter, light source, OTDR, power meter, etc.

III. EXPERIMENTAL SETUP

Experiment # 1: Investigation of the attenuation losses. This setup comprised of fiber spool of length 4 km, power meter, source meter and a thermometer. To investigate the

* Department of Telecommunication Engineering, Mehran University of Engineering & Technology
** Department of Electronics Engineering, Mehran University of Engineering & Technology, Jamshoro. c.bhawani@ieee.org

attenuation losses due to impairments was implemented according to fig.1 below

Fig. 1. Experimental Setup

Experiment # 2: Fig. 2 represents the block diagram of experimental setup done for investigation of the attenuation losses due to curvature. This setup comprised of an optical transmitter, light source, fiber spool of length 4 km, power meter and an optical receiver. To investigate the attenuation losses due to curvature was implemented according to the scheme in fig..2 below

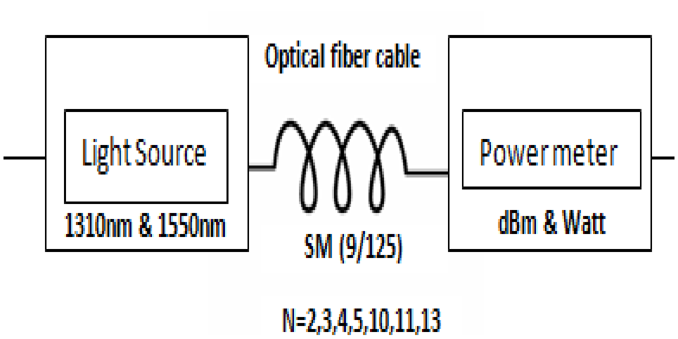

Fig. 2. Power measurements under different bending turns

Experiment # 3: Investigations of the attenuation losses due to pressure. This setup consists of an Optical Time Domain Reflectometer (OTDR) and a fiber spool of length 4 km. The attenuation losses due to the pressure effects were implemented according to the scheme in fig. 3

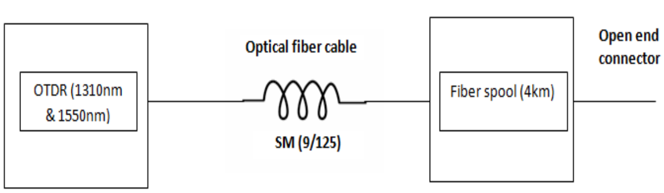

Fig. 3. Attenuation measurements on OTDR

Experiment # 4: Fig. 4 shows the investigations of the attenuation losses due to temperature variation. It portrays the block diagram of experimental setup done for measuring power at different surrounding temperatures. This setup comprised of Optical transmitter, light source, fiber spool of length 4 km, power meter and optical receiver. To investigate the temperature effects on attenuation losses and to ensure temperature stabilization on the fiber according to the scheme in fig. 4.

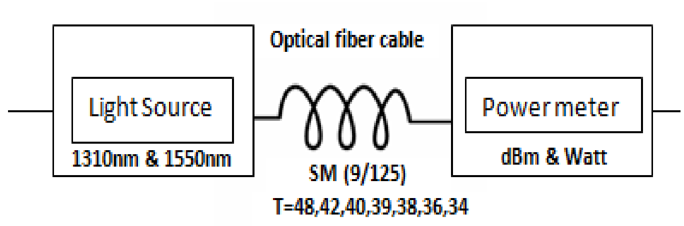

Fig. 4. Power measurements under different temperatures

IV. THEORETICAL EFFECTS OF TEMPERATURE, PRESSURE AND BENDING ON FIBER TRANSMISSION

A. *Effects of Bending on Optical Fiber Cable*

In the circumstance where the span of bend is enormous, it can be supposed that the pitch dissemination of the directed approach experiences a trivial distortion and extraneous. So the loss is interrelated at the junction of bend of the approach. At a curve the transmission circumstances modify and light emissions which would spread in a conventional fiber are vanished in the cladding. Macro bending occurs due to tight bends and micro bending occurs due to microscopic fiber deformation, commonly caused by poor cable design. Although optical fiber cable do not break easily, it is possible to bend the optical fiber cable too much that light that travels within the optical fiber will strike the wall at less than critical angle ,some fractions (but not all) of the light can escape at a bend. And the effect is visible; you can see light leaving the fiber near a sharp bend. The possibility and frequency depends on the person handling and installing the fiber [8].

B. *Effect of Temperature on Optical Fiber Cable*

Small amount of rain, wind, or snow should not impact the speed of optical fiber cable. Large storms, however, can be cause for concern. High winds can knock out power lines, while extreme cold can cause ground heaves, which may break or tear existing copper lines. Cold may also cause problems for electromechanical components of a connection, Such as breakers or switches. The result could be a lost connection, intermittent service, or a much slower experience than normal. Freezing has been occurring for as long as cables have been put in tubes, but fiber optic cable is respectively to freezing in a way that traditional copper cables are not fiber optics standards may be bent by the tremendous forces that occur when water crystallizes into ice. These micro bends in the fiber optic standards can cause various degrees of signal degradation. Most fiber optic freeze-ups occur two to three feet within the hand wall of a bridge [8].

The all-weather cable can withstand low temperatures whereas the standard cable has a tendency to become brittle causing the fiber in the standard cable can break more readily. Both cables should be coiled to a diameter no less than 5 inches however, the all-weather cable is much more difficult to bend due to the thicker sheath. These cables are also waterproof however if water is allowed to run down the fiber optic cable to the instrument, the water will penetrate the unit and can cause damage [10].

C. *Effects of Pressure on Optical Fiber Cable*

The optical fiber is a prone to the surrounding environment like strain, pressure etc. pressure has a significant effect on areas where land is unavailable or planning consent is difficult to obtain within an acceptable timeframe. Effect of pressure increases more with waterways and other natural obstacles. Consequence arises due to land with outstanding natural or environmental heritage or vulnerable eco-systems [13]. Historically or culturally important sites/buildings, areas of significant or prestigious infrastructure development, land whose value must be maintained for future urban expansion or rural development [14]. In field, pressure on optical fiber may be due to damage of cables due to excavation work. However, patch cord could be in pressure due to poor laying.

V. RESULTS

A. *Bending Analysis*

Bend losses are a commonly occurring dilemma in fiber optics: optical fibers reveal supplementary transmission losses when they are bent. Usually, these losses increase very rapidly once a firm critical bend diameter is attained. Bend losses can take place as a result of tiny instability in the fiber, which can be caused by flawed fabrication circumstances.

Table I shows the calculated values of bending diameter and number of wrapping turns. Since, number of turns are inversely proportional to diameter, the increment in the diameter can cause decrement in the number of turns and vice versa.

$$\text{No of turns} \propto 1/\text{diameter} \tag{1}$$

TABLE I
\TRANSMISSION TABLE OF NO. OF TURNS AND DIAMETER

Number of turns	Diameter of Bending
2	25
3	6
4	5
5	4
10	3
11	2
13	1

Loss with number of turns and diameter of curvature has been measured in fig. 5. It clearly shows that wider the diameter lesser the number of turns and narrower the diameter more the number of turns, which causes greater attenuation.

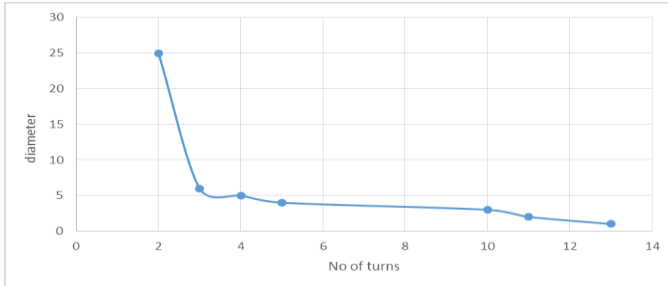

Fig. 5. Diameter vs. Number of turns

Loss of optical power in a single-mode optical fiber due to bending has been investigated for wavelengths of 1310 nm and 1550 nm. Table II below shows the calculated values using power meter and source meter twisting the optical fiber and its influence on power loss has also been investigated. Increase in number of wrapping turns can cause higher attenuation

TABLE II
TRANSMISSION TABLE OF NO. OF TURNS & ATTENUATION

Number of turns	Attenuation at 1310 nm	Attenuation at 1550 nm
2	6.55	5.68
3	8.92	6.12
4	34.92	33.74
5	35.68	30.67
10	37.89	34.14
11	38.53	35.23
13	40.32	36.20

Fig. 6 shows the comparison of bending loss at wavelengths of 1310 nm and 1550 nm. It was concluded that as the number of wrapping turns get higher, attenuation increases rapidly. The final result shows that the power loss at 1310 nm decreases and at 1550 power performance is better than that of 1310.

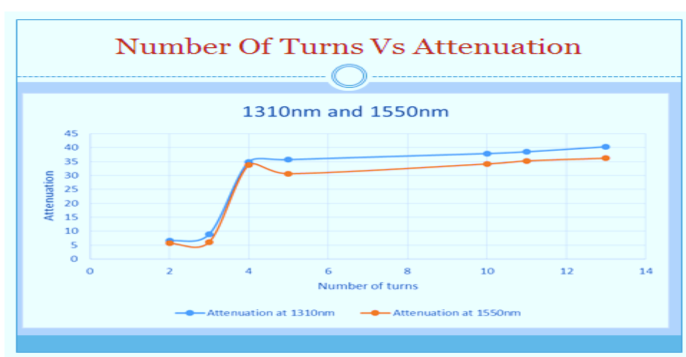

Fig. 6. Comparison of attenuation at different wavelength

B. Stress Analysis

Fiber cable is subject to additional losses as a result of stress. However, this is an additional source of uncertainty when making attenuation measurements. It is mandatory to minimize stress and/or stress changes on the fiber when making measurements. Optical fiber is susceptible to stress, mainly bending. When stressed by bending, light in the external part of the core is no longer conducted in the core of the fiber so some is vanished, tied from the core into the cladding, generating a higher loss in the stressed section of the fiber. If the fiber or cable is spooled, it will have higher loss when spooled tightly [8]. It may be advisable to unspool it and re spool with less tension.

Two methods are used to measure the attenuation losses due to stress. They are;

1. Least Square Approximation
2. Two Point Approximation

The table III shows the description of Least Square Approximation (LSA) when 75 kg stress exerted on the fiber on a fiber length of 2 km. The potential of fiber reduces rapidly in 1310 nm as stress increases which intensify the attenuation whereas the fiber at a wavelength of 1550 nm deteriorated from fewer losses.

TABLE III
OTDR READINGS LSA (WITH STRESS)

S.No	Wavelength (nm)	Distance (km)	Return loss (dB)	Total loss (dB)	Loss (dB/ km)	Attenuation (dB/ km)
1	1310	2.0529	39.4	0.88	0.48	0.985
2	1550	2.0529	36.5	0.55	0.30	0.615

Fig. 7 and fig. 8 shows the readings of LSA method at wavelength of 1310 nm and 1550 nm respectively, when stress of 75kg was applied to the fiber of length 2 km. It shows the variations in different parameters at above mentioned wavelengths, which concluded that 1310 nm indicates a greater reduction (losses) than 1550 nm.

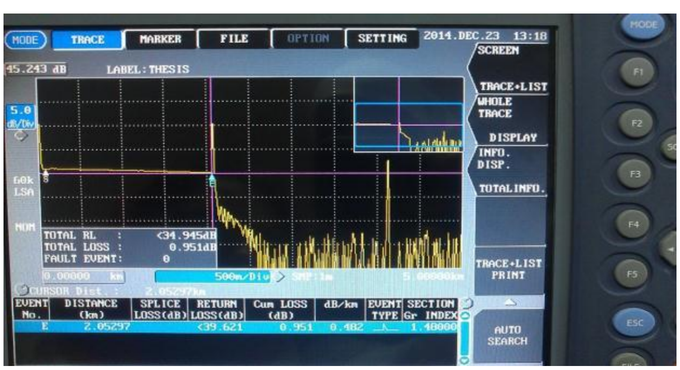

Fig. 7. OTDR analysis at LSA (with stress) 1310 nm

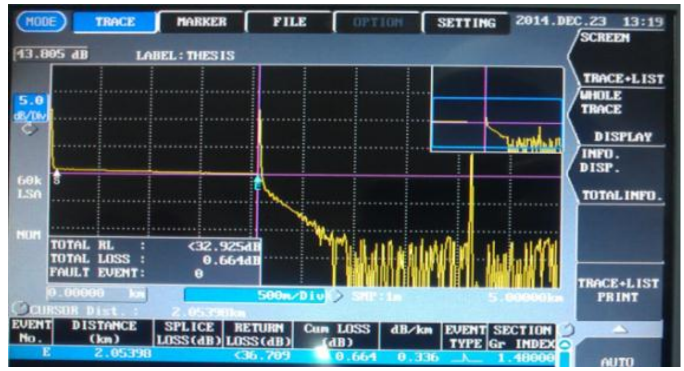

Fig. 8. OTDR analysis at LSA (with stress) 1550 nm

The table IV below shows the explanation of TPA when 75kg stress applied on the fiber length of 2 km. The potential of fiber diminishes speedily in 1310 nm as stress rises which causes the attenuation to increase whereas at 1550 nm the fiber suffers from fewer losses.

TABLE IV
OTDR READINGS TPA (WITH STRESS)

S. No	Wavelength (nm)	Distance (km)	Return loss (dB)	Total loss (dB)	Loss (dB/ km)	Attenuati on (dB/ km)
1	1310	2.0527	39.50	0.92	0.47	0.964
2	1550	2.0527	36.78	0.63	0.32	0.657

Fig. 9 and 10 shows the graph of the fiber performance at the wavelengths of 1310 nm and 1550 nm, when stress is applied to the fiber length of 2 km. It clearly shows that at 1310 nm attenuation is greater and fiber suffers from more losses whereas the performance of fiber is better at 1550 nm.

Fig. 9. OTDR analysis at TPA (with stress) 1310 nm

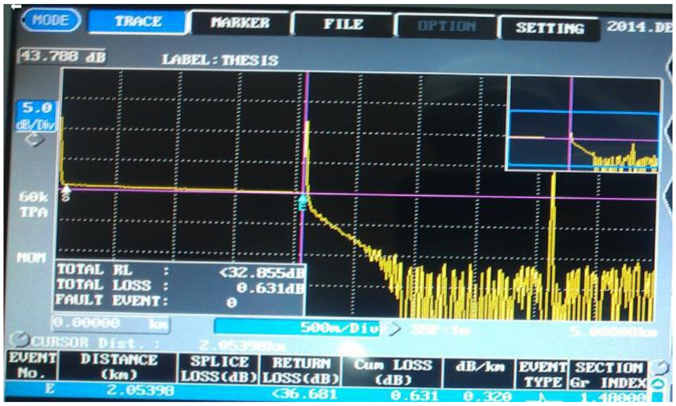

Fig. 10. OTDR analysis at TPA (with stress) 1550 nm

Table V below shows the comparison of attenuation readings measured by placing the fiber of 2 km length on different temperatures and at different wavelengths of 1310 nm and 1550 nm. The results conclude that higher temperature causes higher attenuation at wavelength of 1310 nm whereas at wavelength of 1550 nm the outcomes wrap ups the contents that higher temperature causes less attenuation.

TABLE V
READINGS SHOWING COMPARISON AT 1310 NM & 1550 NM AT 2 KM DISTANCE

Temperature	Attenuation at 1310 nm	Attenuation at 1550 nm
34	5.52	2.85
36	6.58	3.45
38	6.79	4.05
39	7.71	4.21
40	7.94	5.45
42	9.48	7.84
48	11.7	9.15

C. *Temperature Analysis*

The fluctuation in the temperature can cause the losses in the fiber performance. Temperature plays a main role in calculation the attenuation losses. As temperature gets higher the performance of the fiber descends and causes losses in the fiber.

Fig. 11 below shows the comparison of attenuation at wavelengths of 1310 nm and 1550 nm at a fiber length of 2 km. It is concluded that as the temperature rises, attenuation rapidly increases. The final result concluded from the above graph is that the attenuation effects as temperature rises are greater in 1310 nm as than that of 1550 nm.

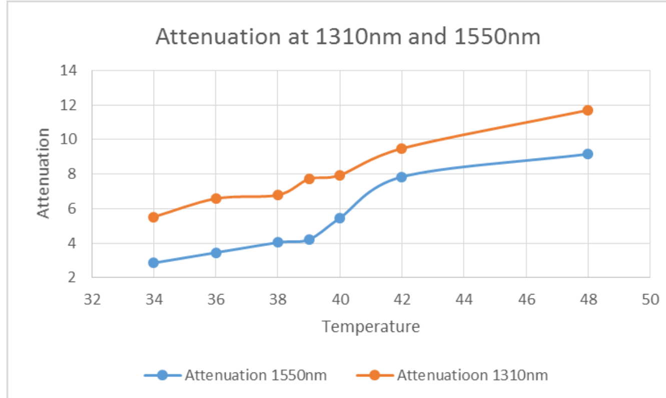

Fig. 11. Comparison graph of Temperature vs. Attenuation at 2 km

Table VI below shows the comparison of attenuation analysis calculated by placing the fiber of 4 km piece on diverse temperatures and at different wavelengths. The effects conclude that rise in temperature can cause more loss at 1310 nm wavelength as than that of 1550 nm.

TABLE VI
READINGS SHOWING COMPARISON AT 1310 NM & 1550 NM AT 4 KM DISTANCE

Temperature	Attenuation at 1310 nm	Attenuation at 1550 nm
34	9.91	5.741
36	10.59	6.457
38	11.64	8.022
39	13.22	9.927
40	15.45	10.12
42	18.58	15.14
48	20.83	18.71

Fig. 12 shows the comparison of attenuation at wavelengths of 1310 nm and 1550 nm at a fiber length of 4 km. It was concluded that as the temperature rises, attenuation increases greater in 1310 as than that of 1550 nm.

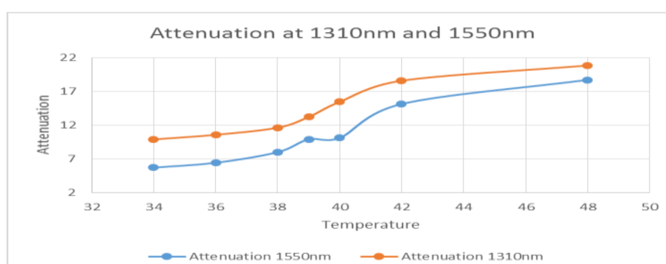

Fig. 12. Comparison graph of Temperature Vs. Attenuation at 4 km

VI. CONCLUSION

Variation of bending loss in a single-mode fiber against bending diameter (1<d<25), up to 52 turns has been investigated resulting that smaller diameter causes greater loss and vice versa. Temperature effects in a single-mode fiber up to 48° C temperatures has been inspected and found that the rise in temperature can cause significant change in the behavior of fiber. The experiments done by applying pressure of 75kg concluded that the loss increased with increase in pressure. This work may provide various benefits to industry/end users, such as to optical fiber companies for either manufacturing or laying optical fiber, telecom companies using optical fiber medium for information transport, corporate sector using optical fiber as last mile connectivity of its information/data network and Entertainment network based on optical fiber cable.

VII. FUTURE WORK

There are number of future recommendations that could make this research more versatile. This research has been done on 4 km fiber length, which can also be replaced by fiber length in many kilometers. The determination of stress effects in an optical fiber was carried out with two point approximation (TPA) and least square approximation (LSA) methods, those methods need to be further confirmed through repeated research. In future, several other methods like two point loss and combination loss methods can be used to determine the stress sensitivity of an optical fiber. Connector cleaning method can be used which can help to reduce the losses or increase the performance of the fiber.

REFERENCES

[1]. Jeff Hecht, “The story of fiber optics”, Published by Oxford University Press, Inc., Issue 1 (2014), ISBN 0-19-510818-3; 0-19-516255-2

[2]. Taylor Bilyeu& Dr. La Rosa “Optical Fibers: History, Structure and the Weakly Guided Solution”, Journal of physics 464 Portland State University (May 30, 2008)

[3]. Ankit Gambhir, “Merits and Demerits of Optical Fiber Communication”, International Journal of Research in Engineering & Applied Sciences 99 http://www.euroasiapub.org, IJREAS Volume 3, Issue 3(March 2013) ISSN: 2249-3905

[4]. J. R. Clowes, et al., Effects of High Temperature and Pressure on Silica Optical Fiber Sensors, IEEE Photonics Technology Letters, 10:3, 403-405, 2008.

[5]. Gwaro J.O*, Maweu O.M, and Kirui M.S.K,” Attenuation Losses Due to Changes in Curvature, Temperature, and Pressure in Optical Fiber Cables’’, Indonesian Journal of Physics, Volume 21 Issue 4(October 2010).

[6]. K.A.H. van Leeuwen and H.T.Nijnuis “Measurement of higher-order mode attenuation in single-mode fibers: effective cutoff wavelength” Optics letters, volume 9, Issue 6, pp.252-254.

[7]. A Zendehnam, M Mirzaei, A Farashiani and L horabadi Farahani, “Investigation of bending loss in a single-mode optical fiber”, Vol. 74, No. 4, journal of April 2010 physics pp. 591{603}

[8]. John A. Jay, “Overview of micro and macro bending of optical fiber”, WP1212 (December 2010)

[9]. B. Hadj,” Effect of seasonal temperature fluctuations on performances of 160Gbps transmissions with adjustable chromatic dispersion compensation”, Journal of high speed networks, 17, 51-57, 2007.

[10].W. J. Chang, H. L. Lee and Y. C. Yang, Hydrostatic pressure and thermal loading induced optical effects in double-coated optical fibers, J. Appl. Phys., 88, 616-620, 2000.

[11]. K.A.H. van Leeuwen and H.T.Nijnuis “Measurement of higher-order mode attenuation in single-mode fibers: effective cutoff wavelength” Optics letters, volume 9, Issue 6, pp.252-254.

[12]. E. S. Faramarz, and T. Golnoosh, Effects of temperature rise and hydrostatic Pressure on Microbending loss and refractive index change in double-coated optical Fiber, Progress in Quantum Electronics, 30, 317-331, 2006.

[13]. J. B. Wojtek, W. D. Andrzej and R. W. Tomasz, Influence of high hydrostatic pressure on beat length in highly birefringent single-mode bow tie fibers, Applied Optics, 29, 2000.

[14]. Lhatein and RoslyAdb Rahman, “Investigation on the sensitivity of optical fiber sensors, for pressure sensing, based on the OTDR technique”, Global journal of computer science and technology interdisciplinary, Volume 13, Issue 4, Version 1.0(2013) ISSN: 0975-4172