International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 5 Issue 10, October - 2021, Pages: 42-49

Experimental Analysis of Bit Noise in Optical Fiber Communication

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Abstract— *In the communication era, technology is experiencing an unimaginable demand for low cost higher capacity networks. Recently, the progress in data processing due to the development of higher speed and higher density integrated circuits have exceeded the existing mode of data transmission. The usage of a large bundle of copper wires as a means for transferring information has become less desirable due to its size, metal conductor costs, weight and bandwidth limitations which have forced engineers and scientists to look for other ways of handling data. From the various possibilities developed, one of the most effective solutions to communication is fiber optics due to its importance and low cost. Most of the telecommunication traffic around the country is carried over the fiber optic cable. The long distance transmission within the region is through optical fiber laid underground. These are some parameters (Vibration, bending loss etc.) that affect the propagation of light in the fiber optic cable. All these factors increases the optical loss and attenuate the optical signal. The attenuation, especially in the long distance communication increases the bit error rate and degrades the quality of service. This research progress has analyzed various optical losses such as vibration, bending, pressure and temperature through different experimental data collections. The Optical Time - Domain Reflectometer (OTDR) has been used to acquire these signal losses on the optical fiber, and optical power meter was used for fiber optic test. This paper research has shown that from a real-time experiment, the implication of increased temperature of 50°C with loss of 10.77dB, vibrations from big and heavy trucks with overall end to end loss of 3.36dB and a bend about an object of 5cm in diameter with loss of 32.48dB contributes a digital bit loss of 85.62dB. This amount of loss is very significant as it contributes to the degradation of the quality of transmitted signal which in turn leads to poor quality of service delivered.*

Keywords— OTDR; fiber optic communication; attenuation; signal loss; optical power meter Vibration; bending; temperature.

1. INTRODUCTION

The technology of Optical fiber communication has had a rapid growth in order to achieve longer transmission distance and larger transmission capacity. Compared to metallic conductors, fiber optics has more advantages as in size, bandwidth, cost, weight, and resistance to electromagnetic interference (EMI), and nuclear radiation [2]. However, in several applications, these advantages are negligible unless the fiber optics implementation can also stipulate dependable data transmission capabilities for the expected system lifespan. There is need of a suitable prediction methodology which is capable of addressing different components and assemblies used in fiber optics due to the recent military/defense interest in using the system data links in its applications. Fiber optics are generally used in the optical fiber communications which allows data to be transmitted over a long distance, and at high bandwidth compared to other means of communications. The wavelength division multiplexing architecture based on optical transmission networks are dominating all fiber optics data transmission with the bit-rates over multiple Tbs^{-1} rates to handle the growing demand for internet protocol networks. There are various core transmission control protocol/internet protocol networking uses such as: de-multiplexing, add-drop multiplexing, wavelength conversions and routing, must be operational in order to epitomize internet protocol packet specifications in to optical layers.

Linear and non-linear features of the fiber optics at high bit-rates, critically limiting the data communication performance and then, required to establish best methods to strength the regeneration of data transmitted. In an optical fiber communication systems, the receiver end bit error rate (BER) may be influenced by the communication channel wireless multi-path fading, bit synchronization problem, interference, attenuation, noise, distortion,…etc. The bit error rate can be approximately considered as the measure of bit-error expectation that is the probability value of bit error-rate. The estimation is correct for a high number of bit errors and a long studied time interval [1]. Though, during data transmission in fiber optics communications, it faced several signal losses, which decrease the performance of the system.

2. Light Intensity in a Fiber Optic Cable

In other to achieve a valid result, the light intensity propagation in a multi-mode fiber was derived from the well-known Helmholtz equation originating from Maxwell's equation to deduce the effect of forced vibration on the cable and hence the total light intensity after perturbation [7].

$$\nabla^2 \vec{E}(r) + K^2\vec{E}(r) = 0 \qquad 2.1$$

This is regarded as Helmholtz Equation

Light in fiber optics propagation in cylindrical coordinates, hence we have [8];

$$\frac{d^2E(r)}{dr^2} + \frac{1}{r}\frac{dE(r)}{dr} + \frac{1}{r^2}\frac{d^2E(r)}{d\theta^2} + \frac{d^2E(r)}{dZ^2} + K^2E(r) = 0 \qquad 2.2$$

The above equation can be rewritten as

$$\theta Z\frac{d^2R}{dr^2} + \frac{1}{r}\theta Z\frac{dR}{dr} + \frac{1}{r^2}RZ\frac{d^2E}{d\theta^2} + R\theta\frac{d^2E}{dZ^2} + K^2 = 0 \qquad 2.3$$

Dividing through by $R\theta Z$ and differentiating, we have

$$\frac{d^2R}{dr^2} + \frac{1}{r}\frac{dR}{dr} + (K^2 - \beta^2 - \frac{n^2}{r^2})R = 0 \qquad 2.4$$

Further calculations give the general form of the Bessel's equation, which has the solution;

$$\mathrm{R} = (r\mathrm{y}) + \mathrm{B}J\text{-}n(r\mathrm{y}) \qquad 2.5$$

As r tends to infinity, the second term of the Bessel's equation tends to infinity [7]. That is, $\mathrm{B}J\text{-}(r\mathrm{y})\rightarrow 0$, hence, we have

$$\mathrm{R} = (r\mathrm{y})sn\theta e{-}i\beta^{z} \qquad 2.6$$

Therefore, the electric and magnetic fields becomes

$$E = (u_m r)cosn_m\theta e{-}i\beta_m{}^{z} \qquad 2.7$$

$$B = (u_l r)cosn_l\theta e{-}i\beta_l{}^{z} \qquad 2.8$$

The light intensity is given by

$$\mathrm{I} = \frac{\varepsilon_o \mathrm{C}}{2}A_m(u_m r)Jn_l(u_l r)cosn_m\theta cosn_l\theta e{-}\beta_{ml}{}^{z} \qquad 2.9$$

As m and I take several values, we have

$$\mathrm{I} = \frac{\varepsilon_o \mathrm{C}}{2}\sum_{m=0}^{N}\sum_{l=0}^{N} \mathrm{A_m A}(u_m r)Jn_l(u_l r)cosn_m\theta cosn_l\theta e{-}\beta_{ml}{}^{z} \qquad 2.10$$

This is regarded as light intensity in fiber cable.

The light intensity of a single-mode (SM) or multi-mode (MM) fiber is dependent on the phase shift as the light intensity in a fiber cable is perturbed by an external factor (vehicular movement) [7]. SMF is mainly used for long haul, which implies that the phase shift is required to be minimal but for a MMF, it is obvious as shown in the equation (2.11).

$$\mathrm{I} = \frac{\varepsilon_o \mathrm{C}}{2}\sum_{m=0}^{N}\sum_{l=0}^{N} \mathrm{A_m A}(u_m r)Jn_l(u_l r)cosn_m\theta cosn_l\theta\ e^{[-i(\Delta\beta_{ml}{}^{z-\Delta\emptyset}{}_{ml})]} \qquad 2.11$$

where $e^{[-i(\Delta\beta_{ml}{}^{z})]}$ is change in propagation const. along the fiber as it experience perturbation

$^{[-(\Delta\emptyset_{ml})]}$ is change in phase in the multi-mode fiber

β is light propagating the fiber core in forward and backward direction. Therefore, detecting the changes of output light intensity, the light intensity inside a multi-mode fiber can be represented as [9];

$$\mathrm{I}_{(\mathrm{r},\emptyset)} = \frac{1}{2}Y\sum_{m=0}^{M}\sum_{N=0}^{N} \mathrm{A_m A_N}Jn_m(u_m r)Jn_l(u_l r).cos(n_m\emptyset)cos(n_l\emptyset)\ e^{[-i(\Delta\beta_{ml}{}^{z-\Delta\emptyset}{}_{ml})]} \qquad 2.12$$

When forcing function F(t) is applied, equation can be rewritten as;

$$\mathrm{I_i} = \mathrm{A_i}\ \{1+\mathrm{Bi}[cos\delta_{\mathrm{i}}]\text{-}[\mathrm{F(t)}\theta_{\mathrm{i}}\sin(\delta_{\mathrm{i}})]\} \qquad 2.13$$

Therefore, change in light intensity resulting from an applied forcing function is given as

$$\Delta\mathrm{I_T} = [\sum_{i=0}^{N} |\mathrm{C_i}\sin(\delta_{\mathrm{i}})|]|\frac{dF(T)}{dt}| \qquad 2.14$$

As light propagates through the fiber cable, the intensity is altered due to cable perturbation. The pressure exerted on the cable caused by vehicular movement creates an impression on the fiber core as light travels through it. The change in light intensity caused by the forcing function (uncontrolled vehicular movement) is derived in equation (2.14). This attenuation is measured using OTDR in the form of backscattered resulting from the vehicular movement, (t) is calculated using equation (2.1). It is possible by determining the backscatter level resulting from the forcing function. As light incident on the impression caused by vehicle tyre, the OTDR measures the Rayleigh backscatter along the fiber cable as described in equation (2.4). This implies that vibration can affect light intensity in fiber optics, and the excitation caused by vehicular movement is explicitly derived in equation (2.14).

3. METHODOLGY

The combination of quantitative and qualitative method has been acquired in this research paper since this research focused at investigating some parameters and their associated root causes of frequent fiber signal losses in the fiber optic system and its related effect in the telecommunication industries in Uganda. There are many ways to do experimental analysis on fiber loss, but not all of them are suitable for this research.

3.1.0 Hardware and Software Materials Used

3.1.1 Fiber Optic Cable

Fiber optic cables are pretty simple. They carry binary information through light waves, which is encoded into legible information by the time you see it on a screen. In order for the light-waves to travel over long distances, they need to be passed through material that allows the waves to continuously bounce off of the enclosure until it reaches its destination.

3.1.2 Optical Fiber Power Meter

Fiber optic power meters are instruments that measure the average power of a continuous light beam. They are used to test signal power in fiber optic networks. Fiber optic power meters consist of a solid state detector, signal conditioning circuitry, and a digital display. In short wavelength systems, the detector is made of silicon. In long wavelength systems, the detector is made of indium gallium arsenide (InGaAs). Most fiber optic power meters are calibrated in linear units such as milliwatts or microwatts. They may also provide measurements in decibels referenced to one milliwatt or microwatt of optical power. Typically, fiber optic power meters include a removable adapter for connections to other devices. By measuring average time instead of peak power, power meters remain sensitive to the duty cycle of digital pulse input streams

3.1.3 Bending Radii Stack

Bending Radii Stack (BR-ST): Optical fiber cable mounting grooves of radii 5 to 30 mm with screw locking arrangement for optical fiber cable

3.1.4 Visual Fault Locator

Pen Shape Visual Fault Locator is a compact but powerful fiber optical cable test tool, with an output power up to 1mW, which can be used to locate sharp bends & breaks in jacket or bare fiber within 5km. It can also be applied to identify the connectors in patch panels and identify the fibers during splicing operation. The choice of a continuous wave output mode for steady fault illumination or a flashing output mode makes for easier fault location.

3.1.5 Optical Time Domain Reflectometer (OTDR)

OTDR is the main instrument in the field of optical fiber testing technology, which is widely used in the maintenance and construction of optical fiber cable, and can be used to measure the length of the fiber, transmission attenuation of the optical fiber, joint attenuation and fault location. The OTDR has the advantages of short testing time, fast testing speed and high precision of testing

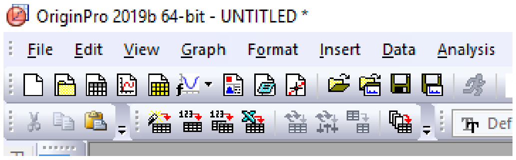
3.1.6 Hair Dryer

A hair dryer is an electromechanical device that blows ambient or hot air over damp hair to speed the evaporation of water to dry the hair. Hair dryers use the motor driven fan and the heating element to transform electric energy into convective heat.
The overall mechanism is simple:

- When the user plug in the hair dryer and turn the switch ON, current flows through the hair dryer.
- The circuit first supplies power to the heating element.
- The current then makes the small electric motor spin, which turns the fan.
- The air-flow generated by the fan is directed down the barrel of the hair dryer, over and through the heating element.
- As the air flows over and through the heated element, the generated heat warms the air by forced convection.
- The hot air streams out the end of the barrel.

In this research work, the hair dryer is used to generate heat to the fiber optic (FO)..

3.1.7 Origin Software



Origin is a proprietary computer program for interactive scientific graphing and data analysis. It is produced by OriginLab Corporation, and runs on Microsoft Windows. It has inspired several platform-independent open-source clones and alternatives like LabPlot and SciDAVis.

3.1.8 Data Acquisition and Analysis

Data was acquired in different parameters, the OTDR was configured depending on a single-mode optical fiber system and further specifications setup before being attached to run and trace. The approach through which this research paper was accomplished is basically to utilize OTDR in acquisition of data without and with vibration, Temperature, and bending loss. These data have been presented in origin software for which line graphs was plotted for the comparative relation of the optical fiber signal losses from the two categories. From the data set without vibration, Temperature, and bending losses, the data was acquired directly from the optical fiber launch cable base on the OTDR by linking it to the cable path running along the field of study on the launch fiber cable. During acquiring these data, assuming there is no any kind of environmental parameters (vibration, Temperature, and bending loss) affecting within the area. OTDR was able to generate the signal losses on the fiber optic cable of the network through this path. These parameters (vibration, Temperature, and bending loss), was positioned and powered ON at some distance on cable path for a period of about 15.5mins, the OTDR was used to the launch fiber cable path connecting the location on the field and second set of data displaying optical signal losses on the network

Determination of continuity to fiber end: By using an optical power meter to verify the light at the receiver end.
Measure fiber quality: In this research, the quality of fiber will be determined by the amount of loss it has per kilometers (km^{-1}). The smaller the $dBkm^{-1}$ value, the longer the system could be with the same loss budget, since the optical fiber attenuates the light less. The $dBkm^{-1}$ assessment will be done by checking for all loss and dividing the outcome (result) by the given length of an optical fiber.
Testing and detecting fault: The pulse traversing the fiber path gets scattered at various intervals and is reflected from connectors. A part of this light travels back towards the source, and along with the reflected light, this approach helps the OTDR in measuring faults. The OTDR displays data on loss measurement in the form of a graphic image which is called trace or signature, which is also used as a benchmark and compared with future traces for detecting faults. An OTDR underestimates splice losses by 3-10 dB

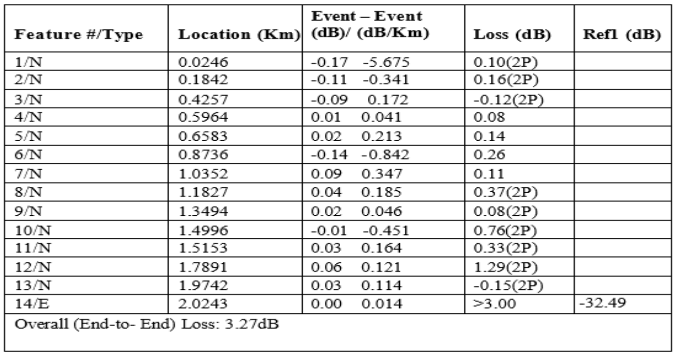
Bend Loss Detection: The detection of this loss consist of two separate wavelengths from Optical Time Domain Reectometer at 1310nm and 1550nm wavelengths. This was achieved with the help of OTDR to verify that the bending of fiber optic affects the optical signal

4 RESULTS AND DISCUSSIONS

4.1 Losses without Vibration Source

The result of fig. 3 below was acquired from the table 1, it is clearly shown that five events were recorded, which represents data set for fiber losses without vibration. The result indicated shows a progressive signal loss over a distance as light travels through the fiber optical cable. These losses are equivalent to the event points shown on the table 1. The recorded losses also indicate bending losses, splicing losses, reflectance loss on the cable. The negative losses shows that there were greater splice joint faults due to improper cable terminations, poor alignment, and avoidable bending losses that could arise from weak laying of the polyvinyl chloride (PVC) pipe carrying the fiber optical cable itself. within the first 500m, minor signal loss increment was recorded within a space interval of two events, which showed a significant four times increase from initial point event to about 250m point event. This loss difference was due to weak connection terminal, an end to end negative loss was recorded indicating a splice joint on the cable. At over 700m there was a progressive signal loss over distance due to bending losses. Between these distances (900m to 2Km) a continuous bending loss were recorded due to the difficulty in pipe laying and vibration sources from passing vehicles, shaker and possible natural underground movements, which were neglected while these data set was being recorded within the field of this study.

Table: 1 Data set for losses without vibration source



Feature #/Type	Location (Km)	Event – Event (dB)/ (dB/Km)	Loss (dB)	Refl (dB)
1/N	0.0246	-0.17 -5.675	0.10(2P)	
2/N	0.1842	-0.11 -0.341	0.16(2P)	
3/N	0.4257	-0.09 0.172	-0.12(2P)	
4/N	0.5964	0.01 0.041	0.08	
5/N	0.6583	0.02 0.213	0.14	
6/N	0.8736	-0.14 -0.842	0.26	
7/N	1.0352	0.09 0.347	0.11	
8/N	1.1827	0.04 0.185	0.37(2P)	
9/N	1.3494	0.02 0.046	0.08(2P)	
10/N	1.4996	-0.01 -0.451	0.76(2P)	
11/N	1.5153	0.03 0.164	0.33(2P)	
12/N	1.7891	0.06 0.121	1.29(2P)	
13/N	1.9742	0.03 0.114	-0.15(2P)	
14/E	2.0243	0.00 0.014	>3.00	-32.49
Overall (End-to- End) Loss: 3.27dB				

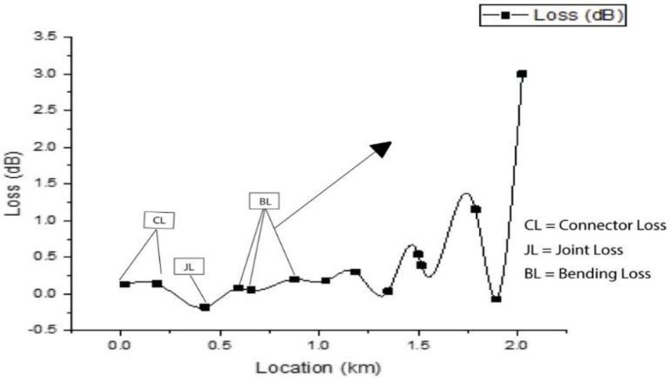
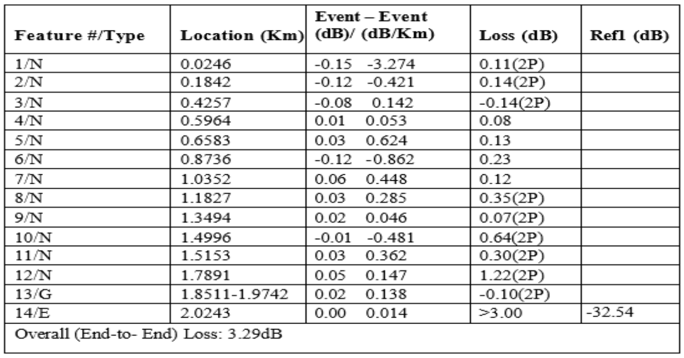


Fig. 3. *Line graph data set for losses without vibration source*

4.2 Losses with Vibration Source

The result of fig. 4 below was acquired from the table 2, the data set were obtained by subjecting the fiber optical cable to vibration from a combination of the shaker, and heavy duty truck. Comparing with the result of fig.3 above, it is clearly observed from fig. 4 that the line traces from the graphs followed a similar trend, but in these cases as in fig. 4, there were fewer events recorded, which implies fewer signal losses. Though the losses recorded from these results were fewer, it clearly shows that higher losses were acquired from these cases due to the generation of vibration from the various combinations of a shaker. A negative signal loss was hence recorded, which also coincided approximately to the spot where the shaker were strategically positioned on the fiber optic path.

Table: 2 Data set for losses with vibration source



Feature #/Type	Location (Km)	Event – Event (dB)/ (dB/Km)	Loss (dB)	Refl (dB)
1/N	0.0246	-0.15 -3.274	0.11(2P)	
2/N	0.1842	-0.12 -0.421	0.14(2P)	
3/N	0.4257	-0.08 0.142	-0.14(2P)	
4/N	0.5964	0.01 0.053	0.08	
5/N	0.6583	0.03 0.624	0.13	
6/N	0.8736	-0.12 -0.862	0.23	
7/N	1.0352	0.06 0.448	0.12	
8/N	1.1827	0.03 0.285	0.35(2P)	
9/N	1.3494	0.02 0.046	0.07(2P)	
10/N	1.4996	-0.01 -0.481	0.64(2P)	
11/N	1.5153	0.03 0.362	0.30(2P)	
12/N	1.7891	0.05 0.147	1.22(2P)	
13/G	1.8511-1.9742	0.02 0.138	-0.10(2P)	
14/E	2.0243	0.00 0.014	>3.00	-32.54
Overall (End-to- End) Loss: 3.29dB				

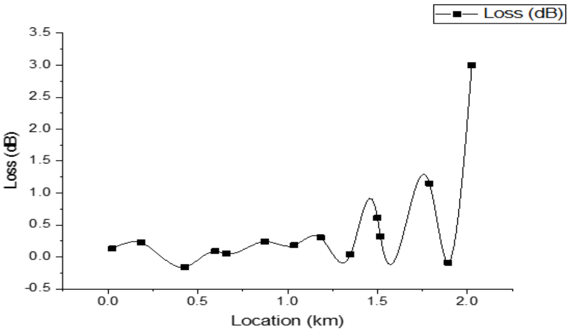


Fig. 4. *Line graph data set for losses with vibration*

4.3 The Fiber optic losses with vibration (Heavy truck)

The result of Fig. 5 below was acquired from the table 3, the data set was obtained by subjecting the fiber optical cable to vibration from heavy truck. Comparing with the result of Fig. 4 above, it was well observed from Fig. 5 that the line traces from the graphs followed a different trend. And it clearly shows that higher losses were acquired from the last events due to the greater generation of vibration from the heavy truck. Table 3 shows a big difference from table 1 and table 2, this is because the truck generate more vibration than boda-boda and small and mini-vehicles.

Table: 3 The Fiber optic losses with vibration (Heavy truck)

SN	Location (Km)	Event – Event (dB)/ (dB/Km)	Loss (dB)	Refl (dB)
1	0.0246	-0.15 -3.274	0.13	
2	0.1842	-0.12 -0.421	0.39	
3	0.4257	-0.08 0.142	-0.18	
4	0.5964	0.01 0.053	0.08	
5	0.6583	0.03 0.624	0.51	
6	0.8736	-0.12 -0.862	0.20	
7	1.0352	0.06 0.448	0.18	
8	1.1827	0.03 0.285	0.06	
9	1.3494	0.02 0.046	0.42	
10	1.4996	-0.01 -0.481	0.24	
11	1.5153	0.03 0.362	0.39	
12	1.7891	0.05 0.147	1.15	
13	1.8511-1.9742	0.02 0.138	-0.12	
14	2.0243	0.00 0.014	>3.00	-32.67
Overall (End-to- End) Loss: 3.36dB				

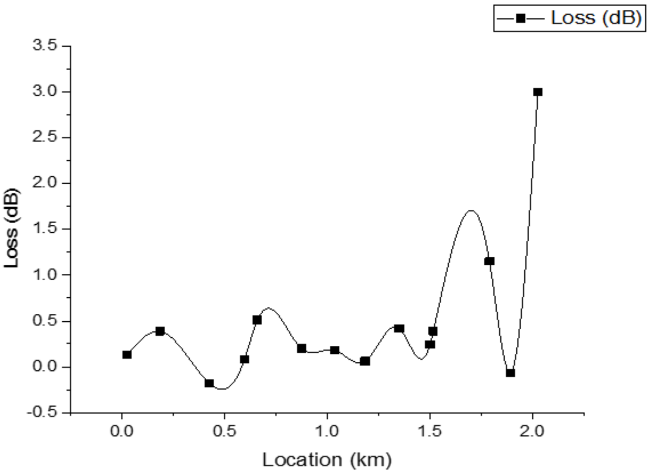


Fig. 5. *Line graph data set for losses with vibration (Heavy truck)*

4.4 The fiber optic losses with and without vibration

The result of Fig. 6 below was acquired from the table 4, the data set were obtained from fiber optic without vibration and by subjecting the fiber optical cable to vibration from a combination of the boda-bodas, vehicles and heavy truck. Comparing with the result in the above figures, it was clearly observed from Fig. 6 that all the line traces from various events obtained in one graph. From the Fig. 6, the losses in the above table 1, 2 and 3 results measured were selected out and they were compared against their normal distances of noted events. By doing so, this research has been able to find out the ultimate relationship between the results. Therefore, this confirms that the generated vibration actually had impact on the optical signal losses and these losses rise over distance as presented in Fig. 6 below from the table 4 data set

Table: 4 The Fiber optic losses with and without

SN	Location (Km)	Loss 1 (dB)	Loss 2 (dB)	Loss 3 (dB)
1	0.0246	0.10	0.13	0.13
2	0.1842	0.16	0.22	0.39
3	0.4257	-0.12	-0.16	-0.18
4	0.5964	0.08	0.09	0.08
5	0.6583	0.14	0.05	0.51
6	0.8736	0.26	0.24	0.20
7	1.0352	0.11	0.18	0.18
8	1.1827	0.37	0.30	0.06
9	1.3494	0.08	0.04	0.42
10	1.4996	0.76	0.61	0.24
11	1.5153	0.33	0.32	0.39
12	1.7891	1.29	1.15	1.15
13	1.9742	-0.15	-0.09	-0.12
14	2.0243	>3.00	>3.00	>3.00

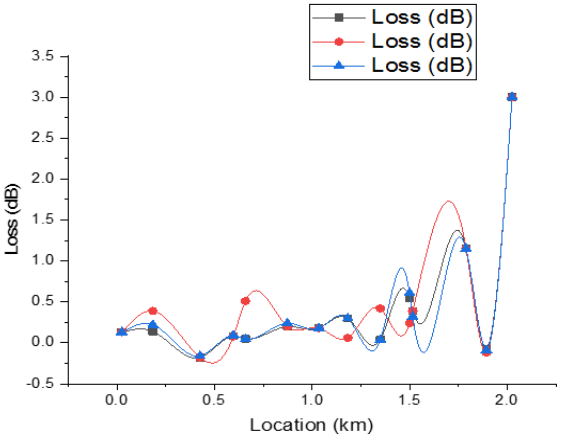


Fig. 6. *Line graph data set for losses with and without*

4.5 Bending Losses

Loss of optical power in a single-mode optical fiber due to bending has been measured for wavelengths of 1310 nm and 1550 nm. Table 5 below shows the calculated values and its influence on power loss has also been investigated. The increase in number of wrapping turns can cause higher attenuation. Fig. 7 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

Table: 5 Data set for bending losses

SN	Number of turns	Attenuation at 1310 nm	Attenuation at 1550 nm
1	1	3.34	2.46
2	2	6.27	5.52
3	3	9.56	7.45
4	4	29.44	26.83
5	5	33.29	32.48
6	6	35.74	34.12
7	8	36.43	35.27
8	10	38.01	37.19
9	12	40.26	38.99
10	14	41.95	40.23

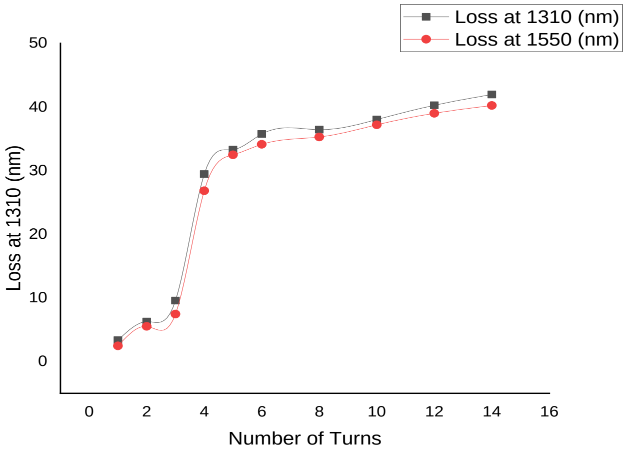


Fig. 7. *Line graph data set for bending losses (1310nm and 1550nm)*

4.6 Temperature

Table 6 below shows the comparison of attenuation readings measured by placing the fiber of 2km 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. Fig. 8 below shows the comparison of attenuation at wavelengths of 1310 nm and 1550 nm at a fiber length of 2km. 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 increases are greater in 1310 nm as than that of 1550 nm

Table: 6 Data set for temperature

SN	Temperature	Attenuation at 1310 nm	Attenuation at 1550 nm
1	30	5.26	3.542
2	33	6.32	4.132
3	35	7.71	6.218
4	38	10.41	7.714
5	41	12.15	9.316
6	44	14.38	11.921
7	47	16.60	13.25
8	50	19.43	15.64
9	52	21.33	17.45
10	54	24.62	20.14
11	55	25.53	21.34

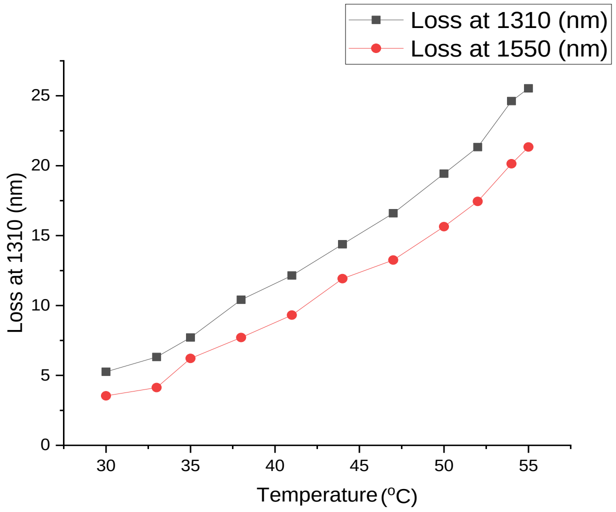


Fig. 8. *Line graph data set for temperature (1310nm and 1550nm)*

5 CONCLUSION

It has been investigated that it is possible to detect temperature, bend loss, and vibrations and measure their parameters using the Optical Time - Domain Reflectometer (OTDR). Variation of bending loss in a single mode fiber with number of turns has been investigated resulting that more number of turns causes greater signal loss in an optical network. From this paper research, we have observed that reducing the number of turns help to decrease the level of bend loss in an optical fiber communication system. Temperature effects in a single-mode fiber, up to 55°C temperatures has been investigated and found that the increase in temperature can cause significant change in the behavior of an optical fiber. Vibrations also have a negative effect on optical fiber networks as shown in the above results. We also observed that improper burying of fiber, poor termination of fiber, poor splice joint and coupling cause a greater optical signal loss in the fiber communication system.

6 REFERENCES

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