International Journal of Scientific & Engineering Research Volume 9, Issue 7, July-2018
ISSN 2229-5518

Measurement of Signal Losses in Optical Fibre Cables under Vibration using Optical Time–Domain Reflectometer (OTDR)

Igwele Minabai Maneke, Ogobiri Ebikabowei Godwin

ABSTRACT – In this study, the sensing capability of optical fibre have been explored using optical time domain reflectometer (OTDR) by generating vibrations on the optical fibre cable used in an existing network, where the vibrations sources were a combination of a flask shaker and gasoline generator. The flask shaker and gasoline generator were strategically placed at about 2m apart along the optical fibre path on a spliced joint of the network while both were powered on. The OTDR was connected to a switch at the server room through the fibre cable connecting the path being investigated for signal loss due to these vibrations at the same time the vibrations sources were powered on. The OTDR automatically generated a trace and a table containing the signal losses, the events across the optical fibre cable length where these losses occurred as a result of the vibrations and an overall end–to–end loss of 3.94dB and a reflective loss of -33.29dB was recorded. Furthermore, the distances at which the events occurred were plotted against the signal losses corresponding to these events with a line graph using Microsoft Office Excel, which showed that vibrations had a significant negative impact to the signal strength of the optical fibre network and so we concluded that the signal loss was directly proportional to the degree of vibrations as well as the distance covered by the network.

Index Terms – Optical Fibre, Optical Time–Domain Reflectometer, Vibrations, Measurement, Signal Loss, Sensor, Flask Shaker, Generator, Network, Trace, Event.

1 INTRODUCTION

In recent years, optical fibres have found prominent use in sensors as an added advantage to its major applications in communication networks[1]. Optical fibres also bridge security gaps, which is a serious concern to humans, notwithstanding their environment by means of its sensing capabilities and methods of application, especially in automated intelligence systems whereby an OTDR (Optical Time–Domain Reflectometer) can be connected between a computer server and a monitoring computer system just like the working principles of a CCTV (Closed Circuit Television). This study has been carried out to explore the sensing capability of optical fibres using OTDR to ascertain the impact of vibrations to signal losses across an existing network built on optical fibre cables, where a flask shaker and gasoline generator has been used as the sources of these vibrations.

In Nigeria, communication giants like Globacom, MTN, including tertiary institutions have only explored the use of optical fibres in internet connectivity and GSM communications and no relevant attention has been given to the effect of vibrations on these network signal's loss or drops which may arise from underground vibrations, movement of trucks, vehicles, and other possible sources of vibration hence, this study focuses on vibrations from a flask shaker and gasoline generator.

Most of the advantages of optical fibre are:

- They have high concentration of optical power and very little of that power spread with distance (low beam divergence), they carry huge amounts of information (high information bandwidth), they require small antennas compared to radio frequency communication systems, as a sensor, time delay can be determined using an OTDR (optical time – domain reflectometer).
- In respect to copper wire systems:
  - They have broad bandwidth, where a single optical fibre can carry over 3,000,000 full duplex voice calls or 90,000 TV channels, they are immune to electromagnetic interference, and also have low attenuation loss over long distances, which can be as low as 0.2 dB/km.

1.1 MATHEMATICAL CORRELATIONS ON OPTICAL FIBRES

1.1.1 LIGHT DISPERSION: The dispersion of light energy through a medium greatly depends on the refractive index of that medium hence, by applying Sellmeier's formula, we can determine the number of particles per unit volume vibrating with normal frequency as:

$$\mu^2 = 1 + \sum_p \frac{A_p \lambda^2}{\lambda^2 - \lambda_p^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where A_p is proportional to the number of particles vibrating with natural frequency λ_p and λ is the wavelength of incident radiation[2].

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1.1.2 CONFIGURATION OF OPTICAL FIBRE AND THEIR INDEX PROFILE

Optical fibres are configured according to their modes and profile index as in:
Multimode step index fibres (MMF), graded index (GRIN) fibres, and single mode step index fibre (SMF).

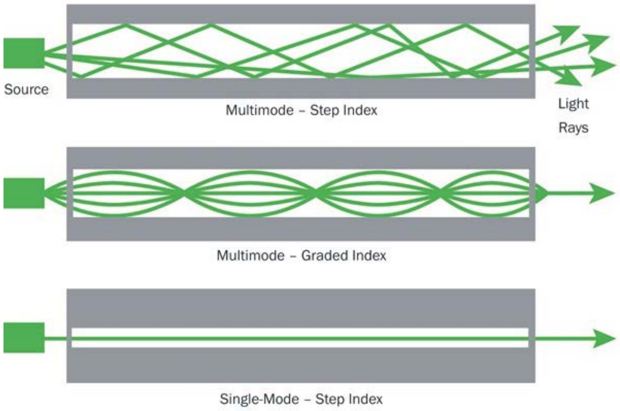

Fig. 1. Showing the mode configuration of optical fibres

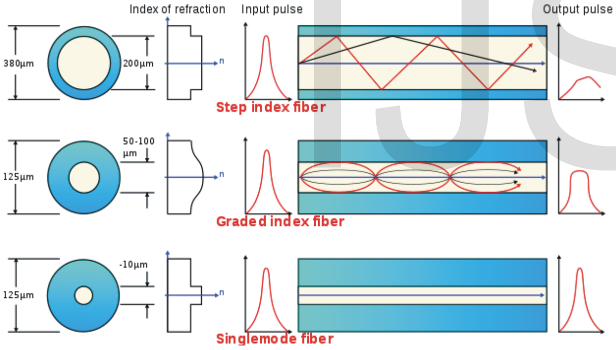

Fig. 2. Showing the mode configuration wave pattern of optical fibres

The modes can be visualized as the possible number of paths of light in an optical fibre. The number of modes that a fibre will support depends on the ratio $d/_{\lambda}$ where d is the diameter of the core and λ is the wavelength of the wave being transmitted. Furthermore, the total number of modes can be determined by adding the number of modes M_l for $l = 0, 1, \ldots, l_{max}$. To address this problem, we first determine the number q_β of modes with propagation constants greater than a given value β and for each l, the number of modes $M_l(\beta)$ with propagation constant greater than β is the number of multiples of 2π which yields:

$$M_l(\beta) = \frac{1}{\pi}\int_{r_l}^{R_l} k_r dr$$

$$= \frac{1}{\pi}\int_{r_l}^{R_l}\left[n^2(r)k_0^2 - \frac{l^2}{r^2} - \beta^2\right]^{1/2} dr \ldots\ldots\ldots\ldots\ldots (2)$$

Equation (2) is obtained by substituting for 2π from:

$$2\int_{r_l}^{R_l} k_r dr = 2\pi m; \ \ where\ m = 1, 2, \ldots, M_l$$

WhereR_l *and* r_l *are the radii of confinement corresponding to the propagation constant* β*. It is also clearly seen that* R_l *and* r_l *depends on* β *and the total number of modes with propagation constant greater than* β *is therefore:*

$$q_\beta = 4\sum_{l=0}^{l_{max}(\beta)} M_l(\beta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $l_{max}(\beta)$ *is the maximum value of* l *that yields a bound mode with propagation constants greater than* β*, this also implies that the peak value of the function* $n^2(r)k_0^2 - \frac{l^2}{r^2}$ *is greater than* β^2 *the grand total number of modes* M *is* q_β *and the factor 4 in "(3)" accounts for the two possible polarizations and the two polarities of the angle* $\emptyset$ *corresponding to positive or negative trajectories for each* (l, m)*. If the number of modes is sufficiently large, we can replace the summation above by an integral as:*

$$q_\beta = 4\int_0^{l_{max}(\beta)} M_l(\beta)dl \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

1.1.3 NORMALIZED FREQUENCY

This is the relation among fibre size, the refractive indices, and the wavelength. It is given by:

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where 'a' is the core radius, λ is the free space wavelength and the square root term is the numerical aperture, whereas V is the normalized frequency. The maximum number of modes M_N supported by a multimode step – index fibre is given by:

$M_N = {}^1/_2 V^2$ ………………………………….. (6a)

while that of a graded–index is:

$M_N = {}^1/_4 V^2$ ………………………………… (6b)

and for V<2.405, it means the fibre can only support one mode and is classified as Single Mode Fibre (SMF).

1.1.4 ATTENUATION:

This is the ratio of optical input power from a fibre of length L to the output optical power. It is given by formula as:

$$\alpha = \frac{10}{L}log\left(\frac{P_i}{P_o}\right)(dB/km) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

There are also different attenuation mechanisms, which include absorption by material, scattering, and waveguide and microbend losses. (***NOTE:*** *there are different attenuation formulae for different comparisons*).

1.2 OPTICAL TIME–DOMAIN REFLECTOMETER

An optical time–domain reflectometer (OTDR) which are used to complement the sensors and vibrations abilities of optical fibres are now widely used for localizing fibre breaks and other types of anomalies occurring in the optical fibre. The system (OTDR) detects the presence and location of perturbations, which were affected by the intensity of the radiation (light) returned from the fibre, but do not respond to phase changes of the radiation (light) hence, the authors have designed a phase–sensitive OTDR to enhance coherent effects[3].

OTDRs are widely used in all phases of a fibre system's life, from construction to maintenance to fault locating and restoration. An OTDR is used to:

- Measure overall (end–to–end) loss for system acceptance and commissioning; and for incoming inspection and verification of specifications on fibre reels, measure splice loss; both fusion and mechanical splices; during installation, construction, and restoration operations, locate fibre breaks and defects indicate optimum optical alignment of fibres in splicing operations, and also detect the gradual or sudden degradation of fibre by making comparisons to previously documented fibre tests.

2 MATERIALS USED

The materials used for this research work are Flask shaker (Gallenkamp brand), Gasoline generator, and an OTDR (Anritsu MT9083AI Access Master).

3 METHODOLOGY

The vibrations generated for this study were carried out at the central administration junction of the university of Benin linking the main auditorium and physical sciences down to 500LT, while readings were being acquired using the OTDR[4] at the ICTU server room.

The readings were obtained from the combination of vibrations from the flask shaker and gasoline generator (the generator was actually used to power the flask shaker). The sources of vibrations (flask shaker and generator) were positioned at about 2m to the nearest splice joint, which is about 2m as well to the road side of the central administration junction. In essence, the vibrations sources were mounted directly on the optical fibre cable line at about 4m to the road side. The axial or regulator of the flask shaker was adjusted to the maximum to give a possible greater degree of vibration impact.

Fig. 3. Showing the flask shaker used at the field work

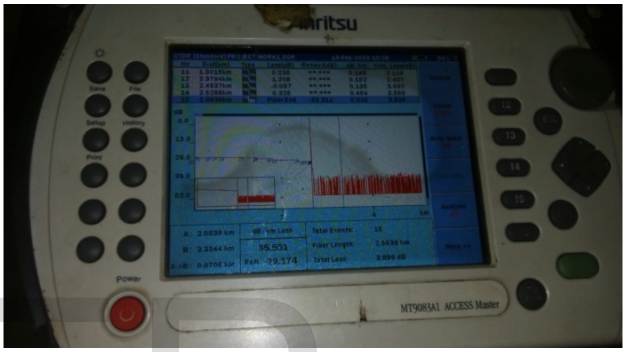

Fig. 4. Showing the screen view of the OTDR at the server room during reading acquisition

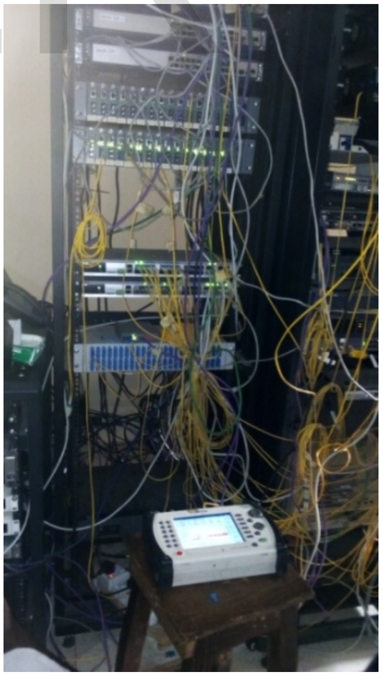

Fig. 5. Showing the connected OTDR with the patch panel or network switch at the server room while readings were being acquired

The OTDR was used to acquire all the readings of signal losses generated from the vibrations arising from the flask shaker and gasoline generator combined. Before taking the readings or traces with the OTDR at the patch or server room, the OTDR ports were cleaned and sterilized with an alcohol as well as the fibre cable connectors to ensure dust free surfaces that may inhibit proper connection. After cleaning, the fibre cable connecting the line or route of the network (i.e. the central administration junction) was then connected to the OTDR and router or switch, the OTDR was then configured to the desired specification (in this case, only single mode was available) and finally, the OTDR was engaged to record and run a trace diagram.

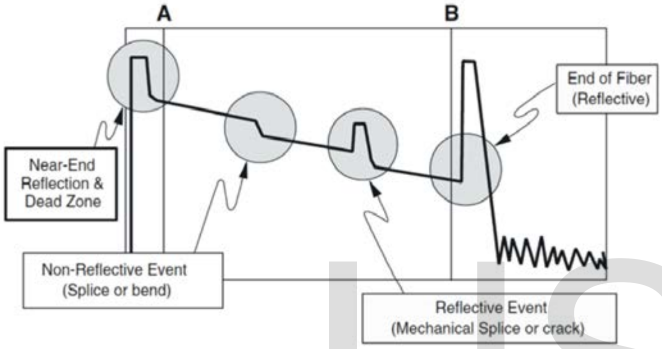

Fig. 6. Showing elements of an OTDR trace from Anritsu OTDR manual

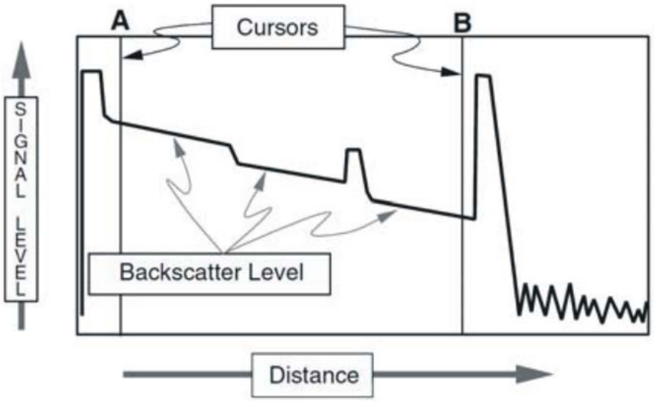

Fig. 7. Showing components of an OTDR trace display from Anritsu OTDR manual

4 RESULTS

Table 1 below shows the readings obtained from the OTDR through the vibrations of the flask shaker and the gasoline generator. Figure 8 shows the direct OTDR trace from the readings obtained in table 1.

Table 1
The OTDR Readings from vibrations of the Flask Shaker and the Gasoline Generator

Feature/ Type	Location (Km)	Event-Event (dB)/ (dB/Km)	Loss (dB)	Ref1 (dB)
1/N	0.0276	-0.12-4.181	0.03	
2/N	0.1941	-0.10-0.603	0.21	
3/N	0.4761	0.03 0.092	-0.12	
4/N	0.7620	0.10 0.347	0.20	
5/N	1.1722	0.08 0.198	0.22	
6/N	1.4839	0.12 0.387	0.49	
7/N	1.8102	0.02 0.055	0.96	
8/N	1.9031	0.01 0.124	0.23	
9/N	2.3792	0.09 0.199	1.18	
10/G	2.4943	0.07 0.605	0.19	
11/E	2.6637	0.04 0.230	>3.00	-33.29

Overall (End-to-End)
Loss: 3.94dB

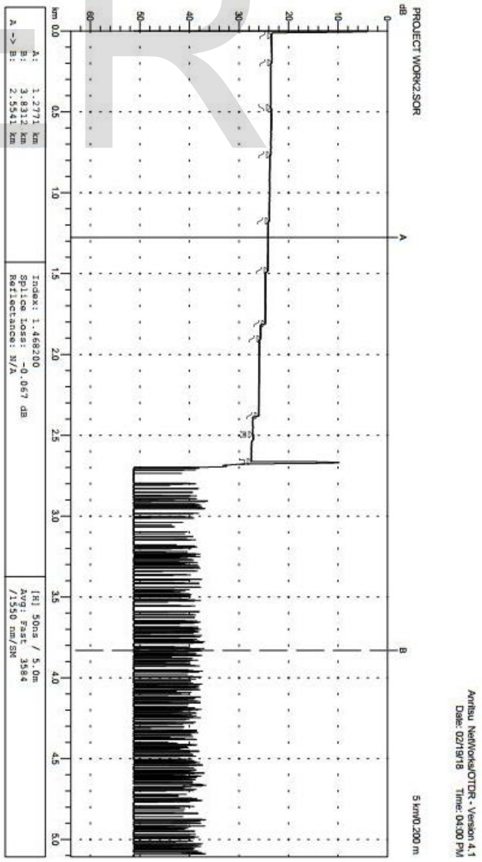

Fig. 8. Showing OTDR Trace from the vibrations of flask shaker and gasoline generator

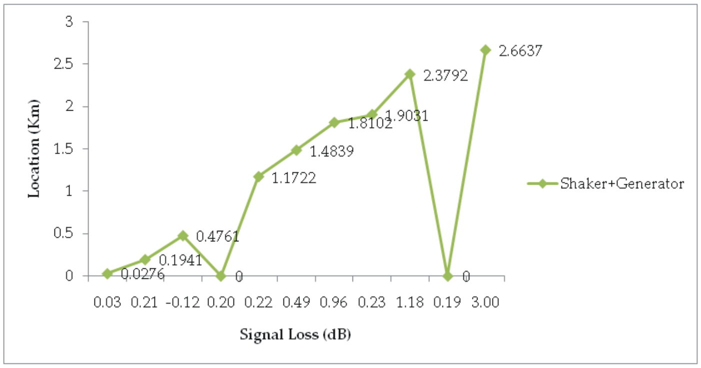

Fig. 9. Showing line graph of location (Km) against signal loss (dB) from Microsoft Office Excel

5 DISCUSSION

Table 1 shows the OTDR readings from vibrations of the flask shaker and gasoline generator where events or losses have been recorded, the losses at those particular event as well as the overall end–to–end loss of 3.94dB and the reflectance loss of -33.29dB, while figure 8 shows the OTDR trace from vibrations of the flask shaker and gasoline generator, which summarizes the signal loss information, the length of the fibre cable measured, the total wavelength of the travelling signal (1550nm), the cumulative loss of over 3.00dB, the reflected losses, splice loss, among other parameters displayed on the trace legend.

In the figure 8, the nodes shows the points where events were recorded which are up to 11 events in the study carried out. On these same events, signal losses have been recorded accordingly. The slopes between each successive event are the backscatter levels of light signal through the optical fibre. More so, the sharp drops or bevels tapering down from the trace indicates non – reflective events, splice joint or cable bends, whereas the bumped bevels are the reflective event, mechanical splice or crack on the fibre, which in this study it only showed one reflective event (-33.29dB).

The sharp peak from the trace indicates end of fibre reflection and beyond this point is total noise. The number of events, which were 11 events in total, indicates that the vibrations generated significant losses on the network.

Figure 9 above shows the Microsoft Excel correlation of location (Km) against signal losses (dB). From the same figure, it is evident that signal losses increases over the progressive distance as a result of the vibrations generated as indicated by the peaks of the graph. Also, the intermediaries in signal drop over distance indicates that there were effective splicing at those events and proper laying of pipes through which the optical fibre cable is laid, hence the degree of vibrations only helped to normalize the signal drops at those events.

6 CONCLUSION

A signal loss of 3.94dB and a reflective loss of -33.29dB as recorded in this study were not limited to the exposure of the fibre cable to vibrations alone, but may also imply that there were splicing faults hence, vibrations on or within an optical fibre network have greatly affected the signal loss of the network and optical fibres can also be used as sensors. More so, this study have shown that OTDR plays a major role in complementing the sensing ability of optical fibres as it helps to acquire the necessary signal losses arising from the generated vibrations of the flask shaker and the gasoline generator.

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