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Reduction of Micro Bend Losses in Optical Fibers

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ABSTRACT

Over time, optical telecommunication network cables experience power loss due to micro inflammations on the core of optical fiber cable lines. These inflammations are usually very small and cannot be detected by physical inspection. However, they constitute a prominent source of optical power loss irrespective of size. This mechanically induced loss effect is investigated in the bid to reduce optical power loss by using an optical approach. The factors inducing the power loss are majorly the joining of fiber optic cable lines as well as the perturbations arising from the irregularity of soil surface in contact with the fiber lines implying lateral pressure on the fiber cable. The petermann model is used in the bid to reduce the losses. An optical approach based on the progressive marginal reduction of refractive index in progressive fiber lengths is employed to mitigate the micro-bending effect on the fiber cable line. The study is implemented using the optisystem telecommunication application tool to design and simulate three stages of four channel wave division multiplexed networks to illustrate the optical approach adopted to reduce the micro-bending loss effect. Results show progressive increment on the travelling speed of optical signals in fiber optic cables thereby bringing about a good reduction in optical loss effect that micro-bend nodes have on the optical signal. The total micro-bending loss due to joining reduced from 8.728dB/15km to 5.454dB/15km, while the highest micro bending loss due to external pressures on the fiber reduced from 33.076 to 26.67db.

Key words: Micro bend, Optical Cables, Optical Signals, Opti system, Speed

INTRODUCTION

Generally, optical fibers are employed as the most prominent cabling systems for actualizing improved or high bandwidth communication network designs over distances that are long and quite a number of factors are responsible for this. However, the particularly distinct advantage is the low attenuation that fibers offer in their use. Thus propagating signals through the fiber will experience very little power loss. To retain this distinct advantage that fibers have is a very critical issue once the cables have been deployed to use or are in service. This is because several effects can begin to comprise the fiber line in time thus increasing the fiber loss as the fiber is used in active data service over a number of years. One of the most prominent among these factors is the micro bending of fiber from a straight or normal axis. Usually, any bending increases the attenuation of the optical fibers and induces certain losses but micro bending can be more problematic since it cannot be detected by sight

A micro bend is a microscopic curvature, fracture or anomaly in the cladding and core (usually not seen with the eye) of an optical fiber cable line that induces small distortions which ultimately contribute to signal attenuation and foster power losses in the optical fiber network.Figure 1.0 depicts a typical micro bend scenario where non-uniform lateral pressures evolve into micro inflammations along the fiber line and thus bring about losses in the optical network which the fiber is deployed into.

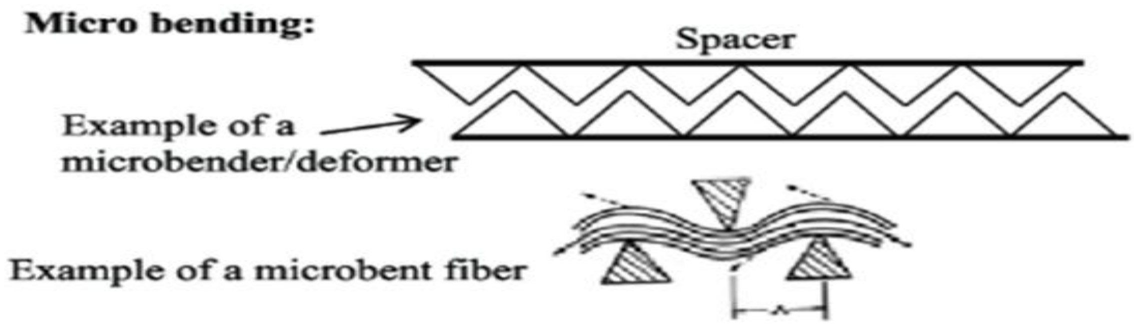


Fig. 1 Illustration of Micro-Bending in Optical Fibers**.**

Micro bending will pose threats on the entire cabling system by affecting the cable clad and core in optical fibers and also induce prominent breakdown of cables if not checkmated. These micro bends usually result from manufacturing processes as cracks or during installation processes as very small changes in curvature. They can reduce performance of the fiber line beyond repair. Asides manufacturing processes and installation processes as well, micro bending losses are also induced from dimensional changes in fiber cabling materials that cause undesirable material interactions [1]. These interactions can generate microscopic bends or very small curvatures thus creating micro bends and inducing power losses in the fiber cabling system. Therefore, the reduction of micro bend loss is very important for designing communication systems and optical telecommunication instruments.The manufacturing processes of fiber optic cables as well as the installation process are the main sources of micro bends [2]. The power losses induced by the micro bending anomaly can be problematic in designing a suitable power budget for building optical telecommunication networks since it will bring about performance degradation and eventually poorly performing cabling system. This paper seeks to reduce micro-bend losses by adopting the petermann model using Optisystem.

MATERIAL AND METHODS

Before live implementation, testing of the developed technique is required. Most of the time, testing and evaluating the protocols or theories proposed is not practically feasible through real experiments as it would be more complex, time consuming and even costly. So, to overcome this problem, “SIMULATORS and TESTBEDS are effective tools to test and analyze the performance of protocols and algorithms proposed [3].

The purpose of this study is to analyze and present an effective reduction approach to mitigate the losses induced in optical fiber telecommunication system as a result of micro bending using Opti systemand the Petermann model.The Opti system software is used to implement the two scenarios of micro-bending; varying sizes of optical cables which give rise to power loss along the joining that exist along the fiber line and physical irregularities on the surface in contact with the fiber.A four channel Wave Division Multiplexing fiber optic communication link is used as the premise to implement the study and a fiber Bragg grating optical component from the optisystem component library is used to induced strain on the fiber lines.

The Petermann equation shown below is used to effect the reduction of micro-bending losses [4].

$$\propto = \frac{13.644(\frac{0.4}{\sigma})^2}{Lw^2}\left[\frac{A^2(\frac{knw^2}{\sqrt{2}})^3 2((\frac{knw^2}{\sqrt{2}})^2+\sigma^2)^{\frac{3}{2}} + \sigma^2\,(\frac{knw^2}{\sqrt{2}})((\frac{knw^2}{\sqrt{2}})^2+\sigma^2)^{\frac{5}{2}}}{((\frac{knw^2}{\sqrt{2}})^2+\sigma^2)^{\frac{5}{2}}2((\frac{knw^2}{\sqrt{2}})^2+\sigma^2)^{\frac{3}{2}}}\right] exp\left[\frac{-A^2}{(\frac{knw^2}{\sqrt{2}})^2+\sigma^2}\right] \quad (1)$$

Where:

$\propto_{\delta}$=Change of the refraction index =5 x 10^{-6} to 8 x 10^{-6}

W= 4.8 (spot size from petermann experiment)

K= 0.78 (gauge factor)

A= 1050 x 10-6

This is used to estimate the loss margin, i.e. how many decibels per kilometer the simulated loss will reduce.

The Optisystem Simulation

The efficient and economical way to deploy live implementation is to perform adequate testing of the developed technique. But the environment to carry out the required test for wired/wireless network is not readily available especially for live experimental study which could be very challenging, costly and time wasting. Hence, the solution is to use “SIMULATORS, EMULATORS and TESTBEDS which is a helpful tool to adequately analyze and test the performance of algorithms and protocols [5].

The optisystem simulation is divided into three different stages. However, a four channel Wave Division Multiplexing network is used to implement all two stages of the different scenarios that contribute to the overall effect of micro-bending.

Simulation Stage One: Four ChannelWave Division Multiplexing Optical Communication Network.
The first stage is an ideal four channel WDM optical communication network. This stage of the simulation provides us with a reference for implementing the two scenarios stated in the work scope and also to compare results from the losses due to micro- bending over the fiber lines depicted by the second and third simulation stages.

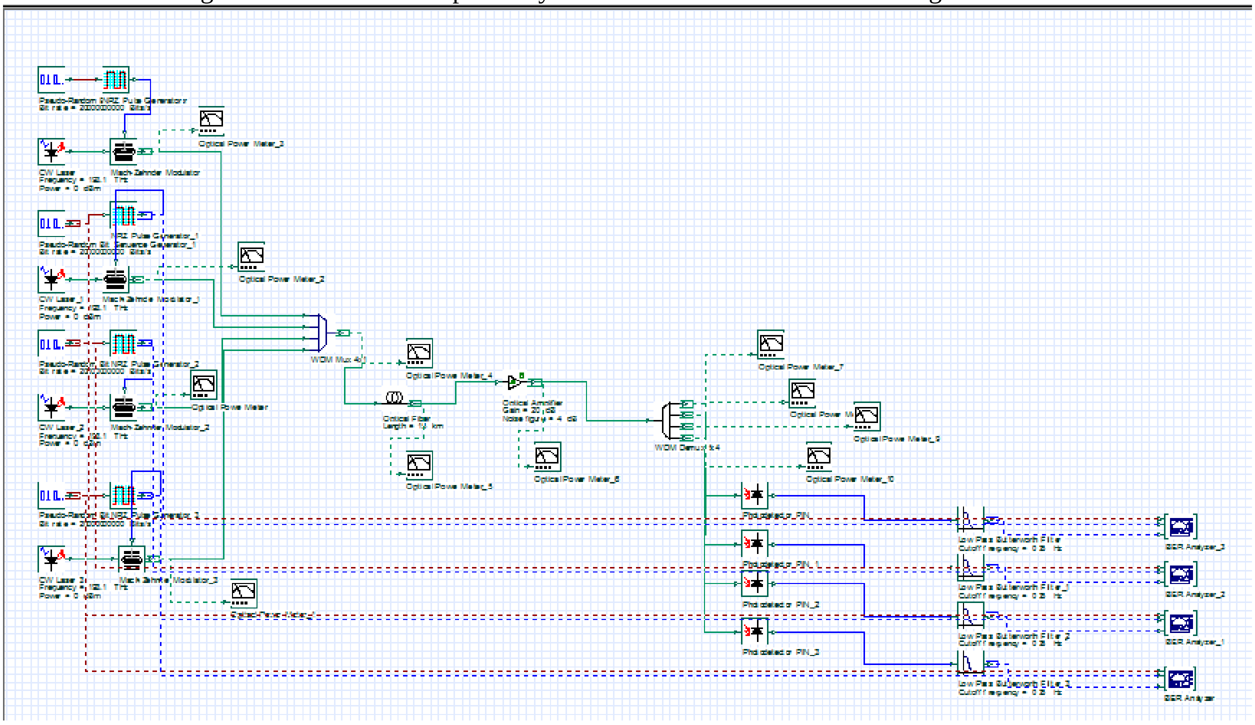


Fig. 2 Screen shot of a Four Channel WDM Optical Communication Network

Simulation Stage Two: Initiating Micro-Bending as a Result of Micro Inflammation at Fiber Joining Nodes in Optisystem.
The second stage of the optisystem simulation is designed as a premise for the micro bending simulation, depicting micro-bending losses as a result of the micro-inflammation due to joining existing at certain points of the fiber where there is a core mismatch or variation in core sizes.

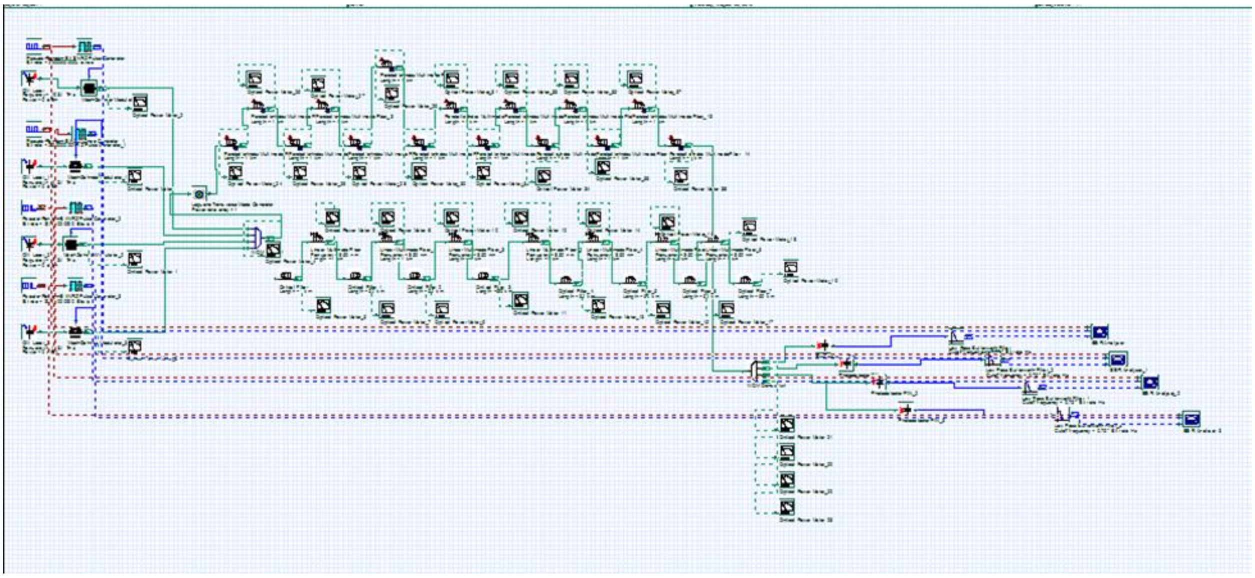


Fig. 3 Optisystem Implementation Showing Micro Bending Anomaly Over a Four Channel WDM as a Result of Micro Inflammation at Fiber Joining Nodes

In the Optisystem design for the second stage, micro inflammation in the fiber core is simulated by designing the four channel WDM network with fiber optic lines of different core sizes. Different intervals of 1km length of fiber optic lines are used as preset references to represents joining nodes with varying core sizes along the fiber line.In place of using one single fiber line of 15Km, 15 fiber optic lines of 1Km each are used to represent the entire fiber cabling system in the network. The fiber parameters from the component description in the component library are altered to change the fiber properties like length, size and attenuation. The joining points are also monitored with the use of optical power meters to check for optical power losses in dB/Km.

Simulation Stage Three: Initiating Micro-Bending as a Factor of Non- Uniform Pressure on Fiber Line in Optisystem

The third stage of the simulation depicts the contribution to micro-bending loss due to varying pressures on the core along an optical communication link. The simulation implements this aspect of micro-bending anomaly using fiber Bragg grating optical component from the optisystem component library

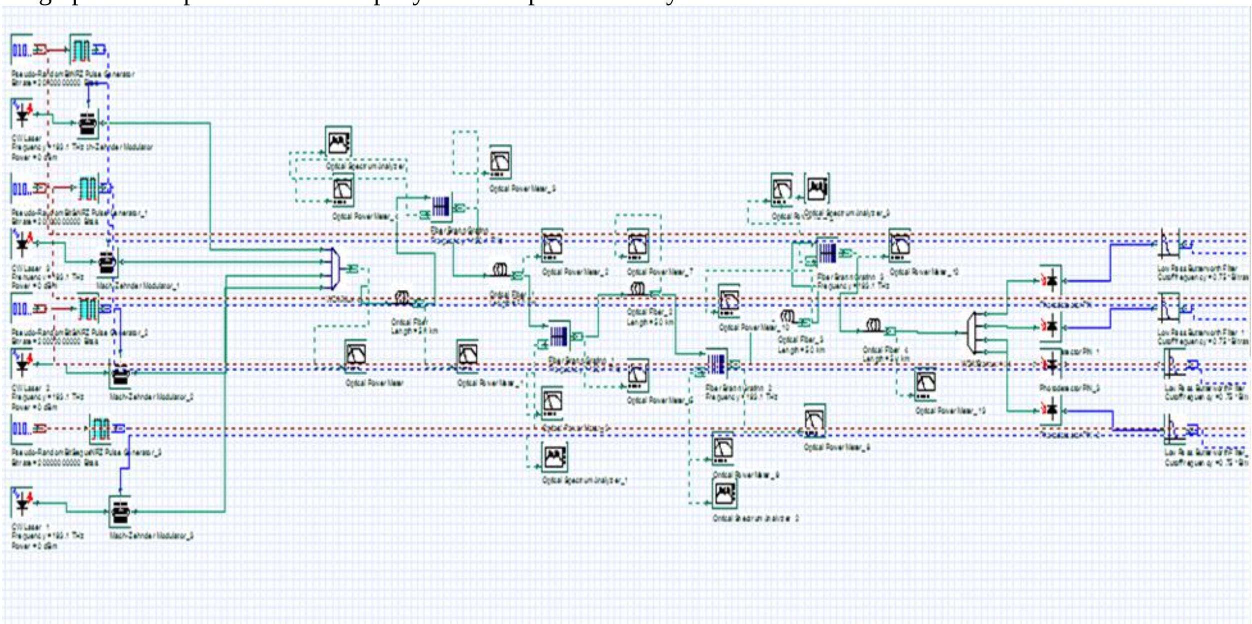


Fig. 4 Optisystem Simulation of the Micro-Bending as a Result of Varying Mechanical Pressures on Fiber Cable Surface.

Reduction of Micro-Bending Due to Joining and External Mechanical Pressure

In very practical scenarios, where it is speculated that joining cannot be avoided and the best approach to micro-bending loss reduction is to employ fiber cables with a core of lower refractive index in margins that still allows total internal reflection, succeeding (being joined with) a fiber with a higher refractive index core. This reduction in refractive index compensate for micro bending losses due to joining of fiber cables and micro-bending losses due to varying external lateral pressure.

Progressive Decrease in Fiber Refractive Index: An Approach to Reduce Micro Bending Loss

This approach considers the movement of optical signals from fiber A to fiber B as light waves travelling from one medium to another, factoring in the varying refractive index of both fibers that constitute the joining and ensuring that the fibers chosen for such designs have a progressive decrease in their refractive index.

When the optical signal travels through the joining from one fiber optic cable to a succeeding new length of fiber cable of lower refractive index value, the speed of the light wave travelling through the cable increases because the permittivity in the new fiber (of lower refractive index) is higher. This approach reduces the micro-bend losses by ensuring that the optical signal travels over the micro-bends (induced by the joining) with greater speed than the preceding length of fiber. This increment in speed is achieved by progressive decrease in the refractive index of succeeding fiber lengths. If the optical signal travels over the micro bends fast enough, the loss effect that the micro-bends imply on the optical signal is reduced to some extent. This solution method applies also to the loss reduction due to external pressure. However, in reducing micro-bend losses due to external lateral pressure, employing a fiber with higher clad thickness will complement the reduction in micro-bend. The solution approach given seeks to make use of "optical" parameters to reduce the micro-bend losses due to joining and external pressure on the fiber line.

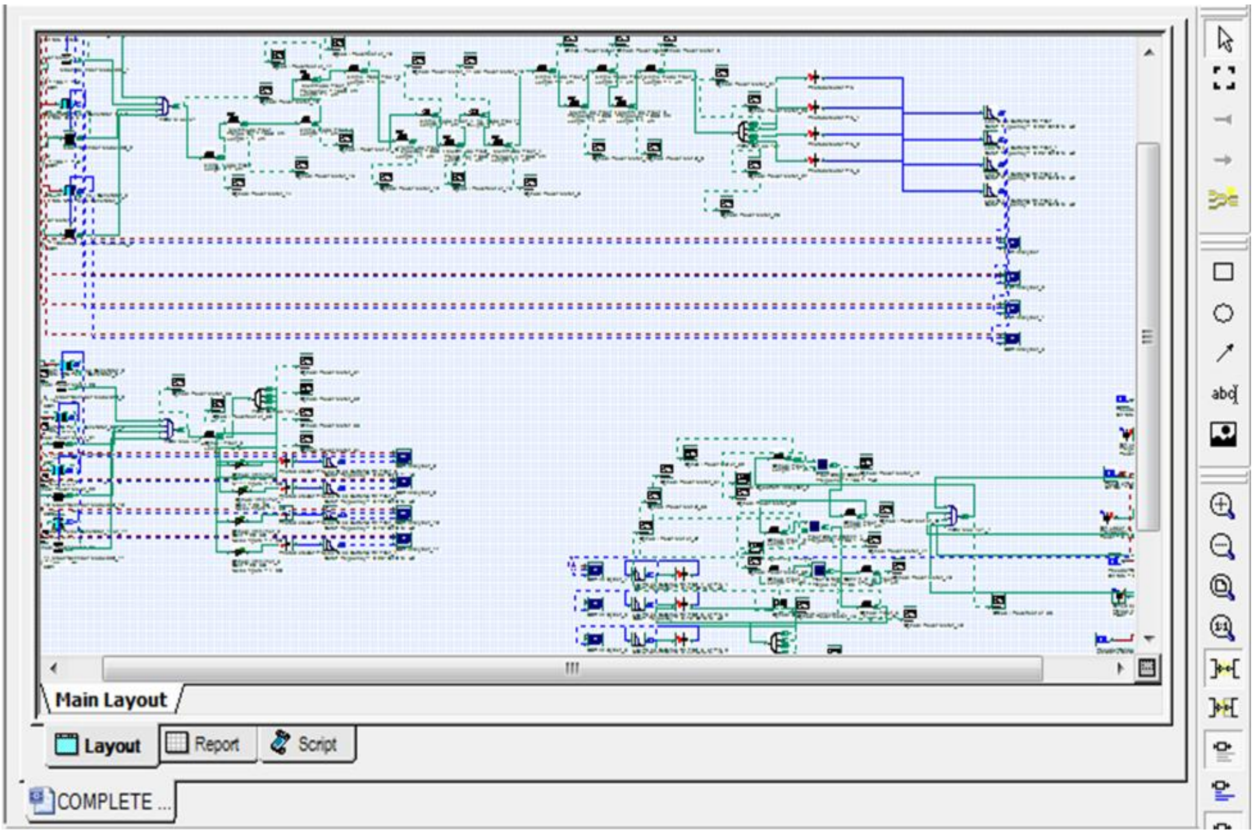


Fig. 5 Screen shot of all the Three Simulation Stages

RESULTS AND DISCUSSION

Results from power loss observations in four channel WDM system simulated as in first stage (the ideal case) was compared with the results from the second stage simulation, being the simulation stage where the micro-bending scenario is implemented in Optisystem simulation environment. The difference in loss values presented by the optical power meters in dB/Km equals the loss margin induced by reason of the micro-bending anomaly. The Optisystem power meter results shown by the ideal four channel WDM optical fiber telecommunications network simulated in this study is presented in table 1.

Table -1 Simulated Result of Four Channel WDM Optical Networks.

Cablelength (Km)	**Attenuation due to fiber length (dB/Km)**	**Powerloss before fiber transmission**	**Power loss due to 15km fiber transmission**	**Total Power loss over 15Km**
15Km	0.2db/Km	4.232db	3db	7.232db

The results show that the losses occurring over the 15Km length of fiber is majorly due to attenuation increase as a function of fiber length since there are no fibers joining simulated throughout the entire 15Km of fiber length.

From table 2, if we add the loss before fiber transmission (which is constant for all 4 channel WDM simulated stages presented in the study) given as 4.232db to the loss due to 15km fiber transmission given as 8.728dB , we have a total loss of 12.960db. Also, from Table 2, total micro-bend loss due to joining occurring across the 15Km length of fiber is 5.728/15Km of fiber length. This shows that the contribution to loss due to micro-bend over the 15Km of fiber length is 2.728dB above the attenuation due to length of the fiber.

Figure 6 illustrates a non-uniform progression for the micro-bending loss due to joining along the fiber. This is due to non-uniform modes of fiber core along the fiber length as described in the optisystem simulation. These slight differences in core size offer a hike in the micro-bend loss for every new or succeeding fiber length. Thus, from figure 6, a higher micro-bend loss is observed for points where the difference in core size is higher.

Table -2 Simulated Results from Implementation of Micro-Bending Loss Due to Joining Over a 15Km Fiber.

Fiber length (Km)	Micro-bend loss due to joining (M_L) (dB/Km)	Attenuation due to fiber length (A_L) (dB/Km)	Loss/Km due to fiber length and joining(L_{f+j} = (M_L) + (A_L)	Standard deviation parameter ((μm) (σ=10 $\log_{10}P_o/P_e$)
1st Kilometer	0.201	0.2	0.400	20074
2nd Kilometer	0.468	0.2	0.668	46729
3rd Kilometer	0.443	0.2	0.643	44470
4th Kilometer	0.310	0.2	0.510	30834
5th Kilometer	0.135	0.2	0.335	14086
6th Kilometer	0.202	0.2	0.402	21112
7th Kilometer	0.130	0.2	0.330	13111
8th Kilometer	0.265	0.2	0.465	27404
9th Kilometer	0.472	0.2	0.672	47845
10th Kilometer	0.338	0.2	0.538	34471
11th Kilometer	0.200	0.2	0.400	19305
12th Kilometer	0.253	0.2	0.453	24933
13th Kilometer	0.284	0.2	0.484	28843
14th Kilometer	0.646	0.2	0.846	65785
15th Kilometer	1.381	0.2	1.581	137289
Total fiber length= 15km	**Total loss over 15km due to joining = 5.728dB/15km**	**Attenuation due to 15km fiber length= 3dB/15km**	**Total Loss due to fiber length and joining = 8.728dB/15km**	

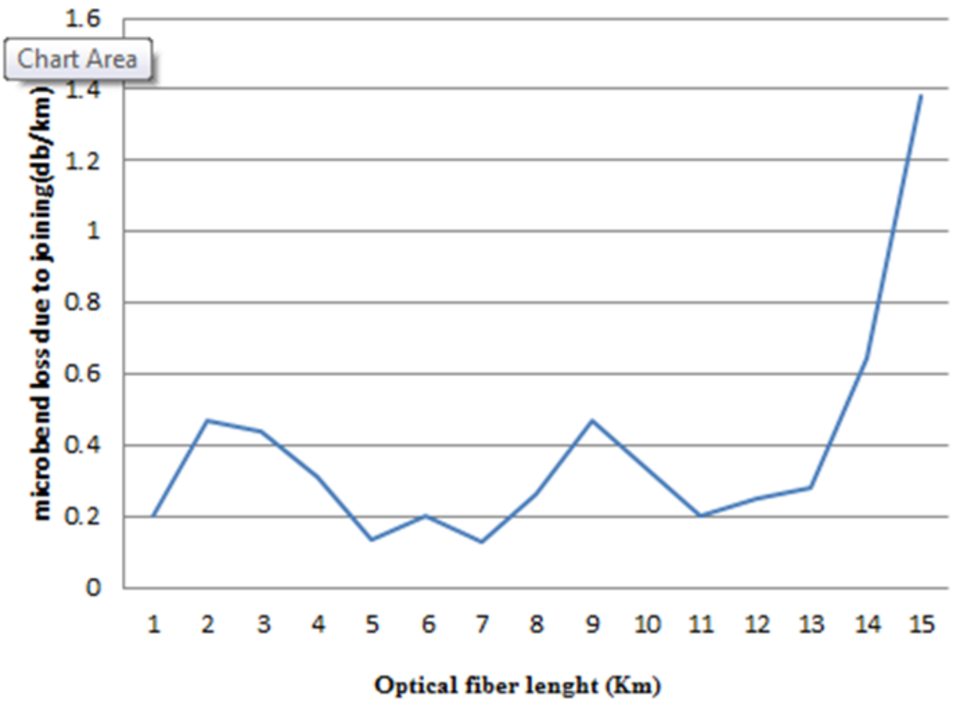


Fig. 6 Graph of Opti system Second Stage Simulation Showing Micro-Bending Loss Due to Joining

The loss margin obtained from the Peterman equation is subtracted from the simulated micro-bending loss to obtain the actual reduced micro-bend loss with specific reference to the simulated scenario. From table 3, experimentally derived values such as for A (µm), spot size (w) are obtained from the petermann experiment for micro-bend tests. The gaussian standard deviation parameter (σ) estimates the entire gaussian node (the gaussian width and the gaussian peak amplitude)**.**

Table -3 Simulated Results for Reduced Micro-Bending Loss Due to Joining Over 15Km of Fiber Length.

Fiber length (Km)	**Reduced Micro-bend loss (M_L) - (L_m) (dB/km)**	**Micro-bend loss due to joining (M_L) (dB/Km)**	**Micro-bend Loss margin from petermann equation (L_m) (dB/km)**	**Fiber Refractive index n**	**$B=\frac{knw^2}{\sqrt{2}}\mu m$ Ref wavelength =1550nm**	**Petermann experimentally observed quantity. A(μm)**	**Spot size or beam radius. w(μm)**
1	0.094	0.201	0.105262	1.4451	18.56	1050	4.87
2	0.463	0.468	0.004059	1.4051	18.05	1050	4.87
3	0.439	0.443	0.003053	1.3651	17.54	1050	4.87
4	0.303	0.310	0.006672	1.3251	17.02	1050	4.87
5	0.080	0.135	0.054348	1.2851	16.51	1050	4.87
6	0.189	0.202	0.012962	1.2451	15.99	1050	4.87
7	0.085	0.130	0.044932	1.2051	15.48	1050	4.87
8	0.260	0.265	0.004149	1.1651	14.97	1050	4.87
9	0.470	0.472	0.000672	1.1251	14.45	1050	4.87
10	0.336	0.338	0.001562	1.0851	13.94	1050	4.87
11	0.192	0.200	0.007793	1.0451	13.42	1050	4.87
12	0.249	0.253	0.003192	1.0051	12.98	1050	4.87
13	0.282	0.284	0.00183	0.9651	12.40	1050	4.87
14	0.640	0.646	0.000136	0.9251	11.88	1050	4.87
15	1.372	1.381	1.34E-05	0.8851	11.37	1050	4.87

Figure 7 illustrates the graphical result for the reduction of losses due to micro bending from the optisystem simulation.

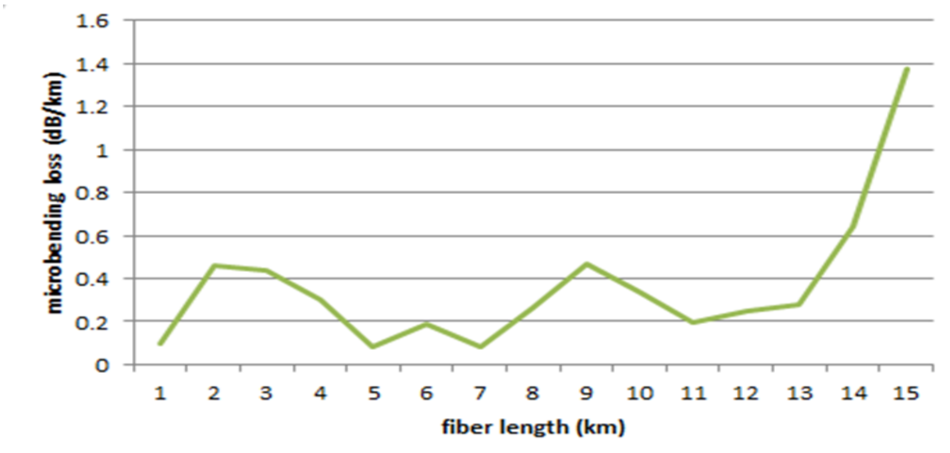
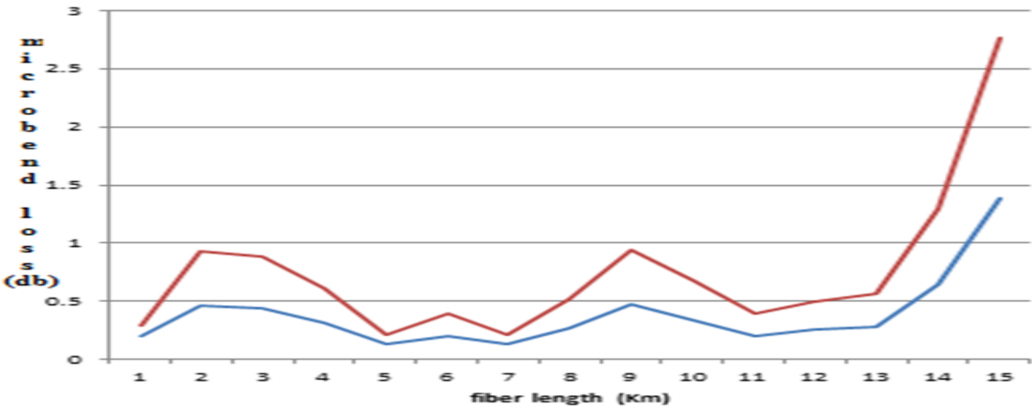


Fig. 7 Graphical Illustration of Reduced Micro-Bend Losses Over 15Km of Fiber Length.

Figure 7 displays the micro-bending loss reduction by presenting a graphical outcome using the petermann model to estimate the loss reduction margin that the progressive decremented change in refractive index will offer and further subtracting the loss reduction margin from the simulated losses.

Figure 8 below shows comparisons between the actual (simulated) and reduced losses results. There is successful reduction of the losses but to a small reduction extent as the study employs an optical approach.



Simulated Micro-Bend Loss

Reduce Micro-Bend Loss

Fig. 8 Graphical Comparison of Simulated Losses and Reduced Losses

The approach employed in reducing the micro-bend losses is associated with marginal trading on the refractive index of the optical fibers and the increasing speed effect of the optical signal as a result of this reduced index fibers. This marginal trading concept permits (to an extent) a small change in refractive index so as to obtain a higher effect on the speed of travelling optical signals in every new fiber length. Figure 9 shows the loss reduction margin.

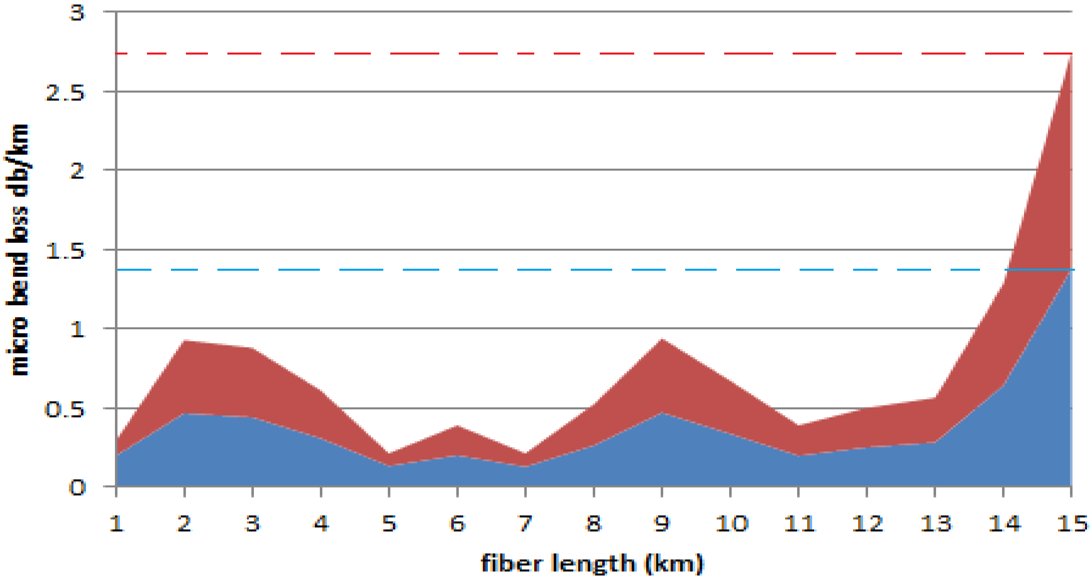


Fig. 9 Graphical Illustration of Extent of Micro-Bending Loss Reduction

The study revolved around employing optical means to reduce micro-bend in optical fibers. The approach adopted offered a reduction of the micro bending loss induced by reason of joining varying core sizes of fiber cables.

An attempt towards the reduction of fiber refractive index to further reduce the losses, thereby increasing the loss margin will begin to induce a new challenge where the refractive index of the fiber clad begins to be higher than the core. This in-turn brings about a huge power loss in the fiber. Thus, the margin of fiber reduction presented is fixed at a value of 0.04.

CONCLUSION

The reduction of micro-bending loss is mostly approached from a mechanical or external point of view which involves increasing thickness and toughness of fiber coating and clad to withstand external pressure from soil surfaces in contact with the fiber cables. This study considers the reduction of micro-bend losses in fiber optic cable systems from an internal or optical point of view. This study discusses the workability of using optical parameters to reduce bend loss and checks the extent to which this approach is effective. This study is an added mile stone to the possibility of approaching the reduction of micro-bend losses from an optical or internal perspective. This study has highlighted core areas worthy of concern.The optical approach towards the reduction of micro-bend losses in fiber cables has been presented in this work. Amongst several scenarios that foster the existence of micro-bends and give rise to optical power losses, the approach presented in this work has considered the most prominent scenarios for the existence of micro-bends in fiber optics which include; joining of fiber cables and external lateral pressure on optical fibers Four channel WDM optical network was used as a premise for the work done in this study.An optical based experimental approach to micro-bending loss reduction using trade-off as an analytical technique is recommended for future works.

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