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A Review of the Reduction of Micro-bending Losses in Optical Fiber Cable Using Optisystem Approach

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ABSTRACT : *In as much as fiber optic cables are prominent for their numerous advantages as well as their application in modern telecommunication systems, micro-bends are a major anomaly occurring in fiber optic cable lines. The existence of these bends induce persistent optical power loss in the communication link and thus reduce the overall efficiency of the fiber link. 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 seek to review this problem and recommend possible solution using Optisystem Approach.*

Keywords: *Absorption, Cladding, Efficiency, Fiber ,Optisystem.*

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I. INTRODUCTION

Fiber is of course not a new development in telecommunication networks. It has been used for almost two decades in the provisioning of high-speed commercial data communication services. The need to produce optical fiber lines with very low attenuation and power loss margins has been a constant drive for telecommunications engineers and researchers hence the evolutionary progress of the fiber optic cabling technology is useful to this study. Earlier on in the 1990s, customer service providers found that replacing large bundles of copper by a few fiber strands could improve service reliability and lower design cost. BellSouth took the lead in deployment of access fiber in that period, and the move was justified completely on cost savings [1].

In the evolutionary progress of optical fibers, fibers with low enough attenuation for communication, about 0.8µm wavelength was successfully developed in 1970 by Corning Glass Works, while Gallium Arsenide (GaAs) semiconductors were developed that were compact and therefore suitable for transmitting light through fiber optic cables for long distance [2]. Progressively, In 1980, the second-generation fiber optic communication suitable for commercial consumption, using In Ga As (Indium Gallium Arsenide) semiconductor laser, operating at 1.3µm wavelength was designed and deployed to commercial services [3]

Although there was progress made on the design and application of optical fibers, the earlier systems were still hindered by significant power loss anomalies due to multi-mode fiber dispersion until late 1981 when the single mode fiber was revealed to greatly improve system performance. By 1987, fiber optic telecommunication system networks spanning 3,268km, linking 5 communities and operating at bit rates of 1.7Gb/s with repeater spacing of 50km were successfully commissioned in Canada [4].

Due to the advancements in laser technology, the third-generation fiber optic systems operating at 1.55µm wavelength, with attenuation losses below 0.2dB/km was developed. The effort of engineers to overcome the earlier difficulties by using Dispersion Shifted Fibers, tilting towards single mode optical fibers and limiting the laser spectrum to a single longitudinal mode were factors that made it possible for the third-generation systems to be efficiently employed. By the fourth generation, Optical amplification was used to reduce the need for repeaters and to increase data capacity so much that by 2001, bit rates of 10Tb/s were reached [5].

II. OPTICAL FIBER OPERATION

A wholesome idea about the operation of fiber is important to this study, as it informs researchers on the most prominent factors that induce losses in optical fiber networks and systems. The optical fiber is a practical application of total internal reflection. Thus, when incoming light pulses enter through one end of the optical fiber, it can be totally reflected along the inner surface linings of the fiber. This is possible because the refractive index of the cladding's coating is lesser than that of the core of the fiber. Finally, after a series of successive total internal reflections, the light comes out of the other end. This means that the optical transmitter has to emit rays of light at an angle of incidence greater than the critical angle, to ensure total internal reflection [6].

This same process is repeated again and again throughout the entire length of the cable. And since the angle of incidence and reflection are equal, the beams continue to be reflected and transmitted in a zigzag mode throughout the entire fiber. Thus, the energy of the light from the transmitting source is contained in the nucleus. [7]. However, not all the beams of light may enter the core of the fiber or may be transmitted through the core of the fiber. This is because the light hitting the core-cladding interface may not all have incidence angles greater than the critical angle, which will either make it impossible to enter the core or make the pulse loss energy into the coating due to refraction and that light pulse would not get to the end of the fiber [8].

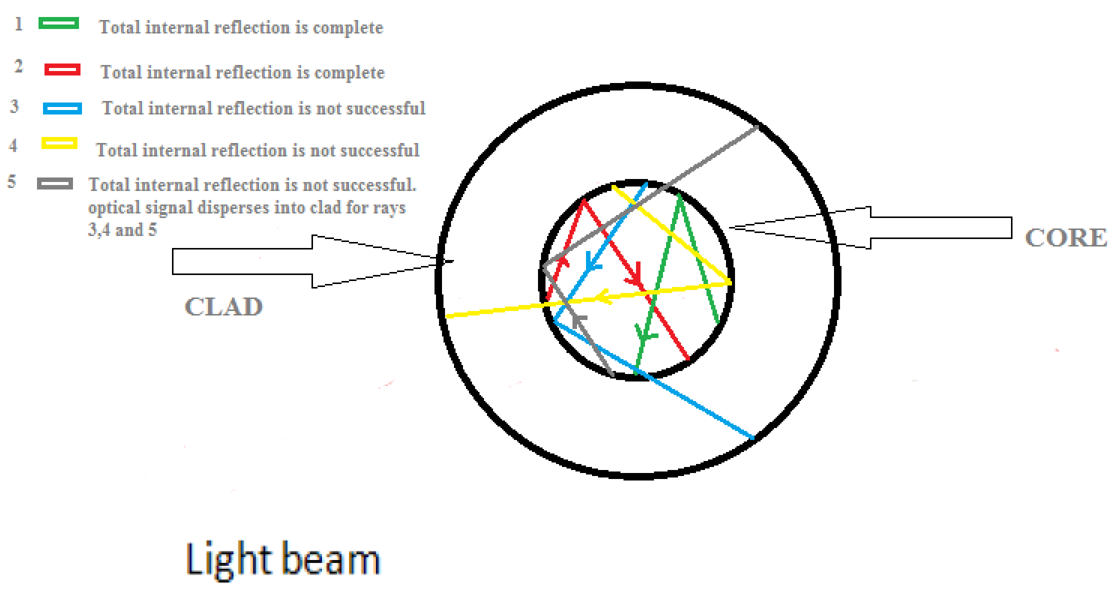

Fig. 1. Demonstration of Light Wave Propagation in Optical Fiber and the Expected Angles of the Rays

Looking from within the core outwardly into the clad, it will be noticeable that the first two rays have a complete total internal reflection, so the beams are reflected within the core. The first and second ray are expected to have incidence angle greater than the critical angle and will obey the law of total internal reflection for the remainder of its journey through the core of the fiber[9]. The third to fifth ray are expected to have incidence angles exactly equal to the critical angle, therefore total internal reflection occurs for the first time but dissipates energy at the boundaries.

2.1 Optical Fiber Composition

The Optical Fiber can be said to consist of three major layers, which are:

- ✓ **The Core:** This is the innermost part of the fiber. It is responsible for driving the optical signals from the transmitting device to the receiving device. It is made from high temperature pure quartz, plastic or silicon dioxide. If made with silicon dioxide, it is typically doped with phosphorous oxide (P_2O_5) or germanium oxide (GeO_2) to adjust its refractive index. It has a core diameter ranging between 10 to 300µm. The higher the diameter the greater the amount of light the cable can carry.
- ✓ **The Cladding:** It is the middle layer of the fiber. It surrounds and protects the core. The refractive index of the cladding must be lower than that of the core, so as to ensure total internal reflection throughout the fiber, and keep the light energy within the nucleus/core. It is made from high temperature quartz or plastic, with more thickness in order to absorb the potential impact or shock that the fiber can get and provide extra protection for the core against excessive cable bending
- ✓ **The Coating/ Buffer**: The coating is the outer part of the fiber. It acts as the shock absorber of the fiber and protects the core and the cladding from damage and external agents. It is made from plastic capable of resisting moisture, crushing force, rodent action, and other environmental hazards. The coating is

sometimes divided into 2 layers: The Buffer (Primary coating)and the Jacket (Secondary coating).The Buffer/Coating may have diameter of 125 to 250µm without secondary coating and 500 to 900µm with secondary coating [10]

2.2 Fiber Loss Mechanisms

Several models analyze and try to estimate the loss on fiber lines due to bending of fiber optic cables in two sub groups; material losses and fiber induced losses. Material losses include Rayleigh scattering, infrared absorption, ultraviolet and hydroxyl absorption [11].

Generally, fiber loss due to any anomaly is the ratio of the optical percentage power from a fiber of any given length L to the optical input power. The symbol is majorly expressed in dB/km.

A brief overview of these fiber loss models is very core to the overall success of this study as it forms a premise on which optimization can be made keeping in view the work scope.

$$\propto = \frac{10}{L}\log\left(\frac{P_{in}}{P_{out}}\right) \quad (1)$$

α = fiber loss
L= length
P_{in} = optical input power
P_{out} = optical output power

➢ **Rayleigh Scattering Fiber Loss Model**

Due to the "grain-like" form of appearance that atoms of glass fiber have light when transmitted through the fiber suffer scattering losses. This is known as Rayleigh scattering loss**-** the loss is also expressed in dB/km [12].

➢ **Infrared Absorption Fiber Loss Model**

The chemical bond that exists between the particles of which the fiber is composed also have a loss effect on the fiber cable. Due to the vibration frequency of these chemical bonds and the already existing electromagnetic field as a result of the optical signal travelling through the fiber, there is an interaction that sends energy from the E-M field in the fiber to the chemical bonds or between the atoms of the material with which the fiber is composed thus causing absorption in energy and resulting in power loss 13].

➢ **Ultraviolet Absorption Fiber Loss Model**

Valence electrons are usually found in the silica material from which fibers are manufactured. When light is transmitted through the fiber, the light ionizes these valence electrons into conduction [14].

➢ **The Petermann Model**

An increase in fiber losses results from micro bending because the fiber curvature causes repetitive coupling of energy between the guided modes and non-guided modes in the fiber. The existence of periodic "bell-shaped" micro inflammations along the fiber is a good scenario that is perfectly explained by a Gaussian curve

III. APPROACH TO MICRO-BENDING REDUCTION

Simulation is an imitation of the operation of a real-world process or system. 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 [15]. Furthermore, the emulation of the operation of a real live system or process is called simulation [16].

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 is shown in the figure below

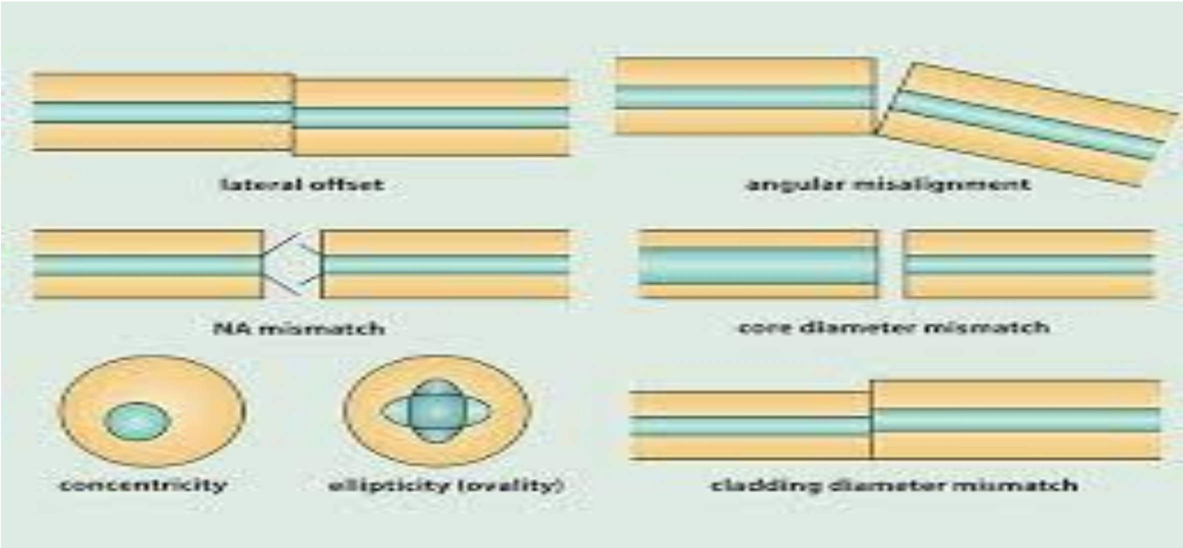

Fig. 2. Illustration of Different Scenarios Constituting Micro-Bending Existing at Fiber Joining Nodes

3.10 The Optisystem Simulation Environment

Optisystem is an advanced telecommunication application analytical tool or comprehensive software design development environment that enables users to simulate optical links in the transmission layer of modern optical networks. Several key functionalities which have influenced our choice of optisystem as an integrated development environment are presented.

3.10.1 Component Library

The Optisystem Component Library is a component compartment in the optisystem software that features hundreds of components that enable users to enter in parameters that can be measured from real devices. It integrates with test and measurement equipment from different vendors. Users can incorporate new components based on subsystems and user-defined libraries.

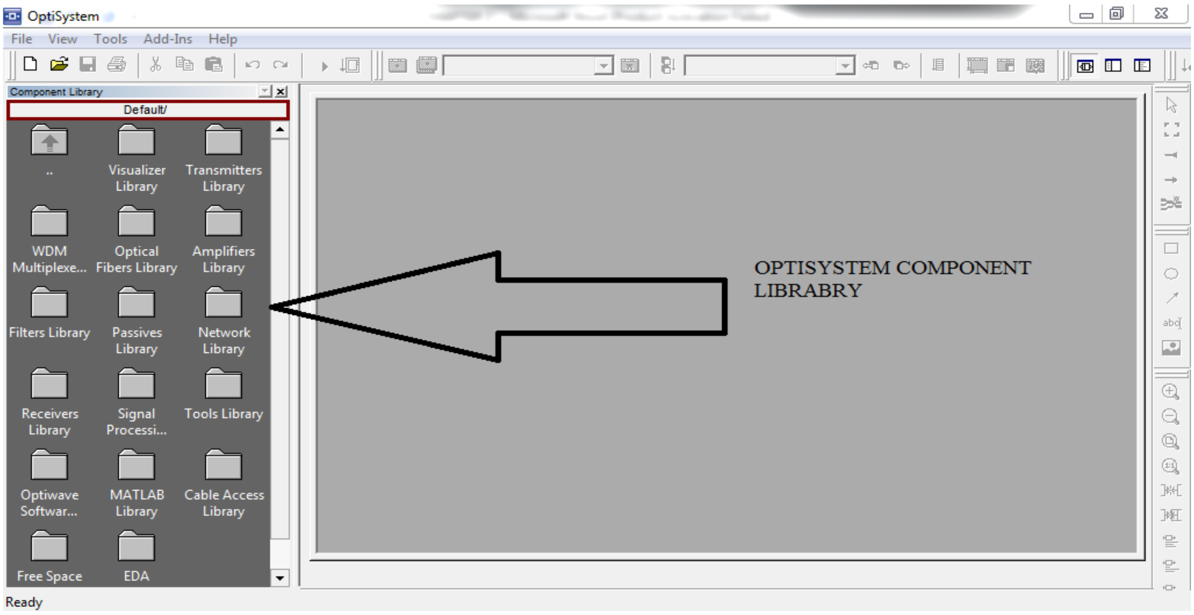

Fig. 3. Optisystem Component Library

3.10.2 Mixed Signal Representation

A useful premise on which the choice of optisystem is based on as concerning this work is the intelligence of mixed signal representation; binary, electrical and optical. Also optisystem possesses real-time signal converters from one form of these signals to another. These converters in Optisystem can handle mixed signal formats for optical and electrical signals. Optisystem signal converters calculate the signals using the appropriate algorithms related to the required to ensure simulation accuracy and efficiency.

3.10.3 Advanced Visualization Tools

Visualization tools are important in implementing the concept of micro-bend in optisystem environment since it is a loss based analysis. Visualizers are core to monitoring power losses as we progress across different sections of the simulation. Visualizers in optisystem range from frequency analyzers, optical and electrical power meters to BER analyzers and Eye diagram analyzers. Also included are WDM analysis tools listing signal power, gain, noise figure, and OSNR per channel. Optisystem provides all these functionalities. These features make it more feasible to realistically model the anomaly of micro-bending in optisystem

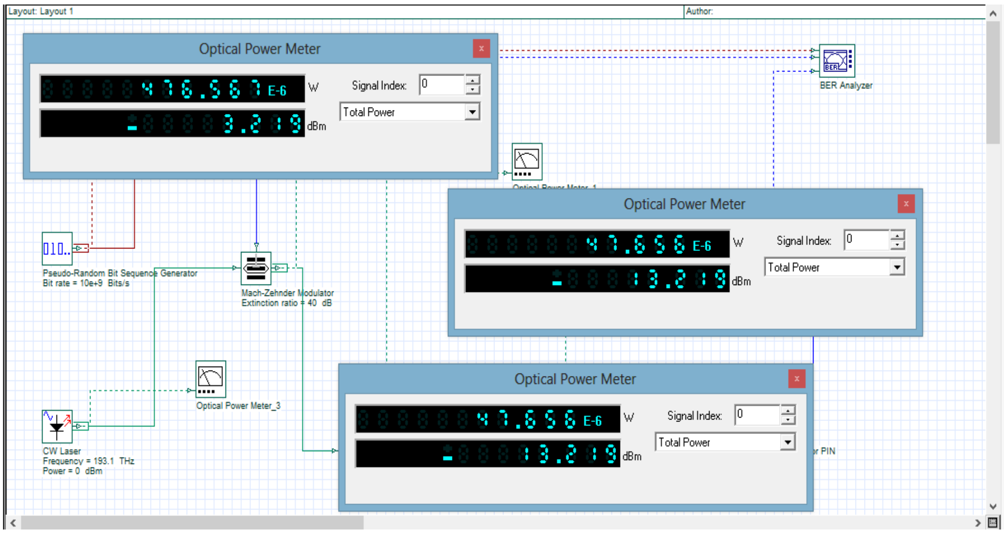

Fig. 4. Optical Power Visualization Component

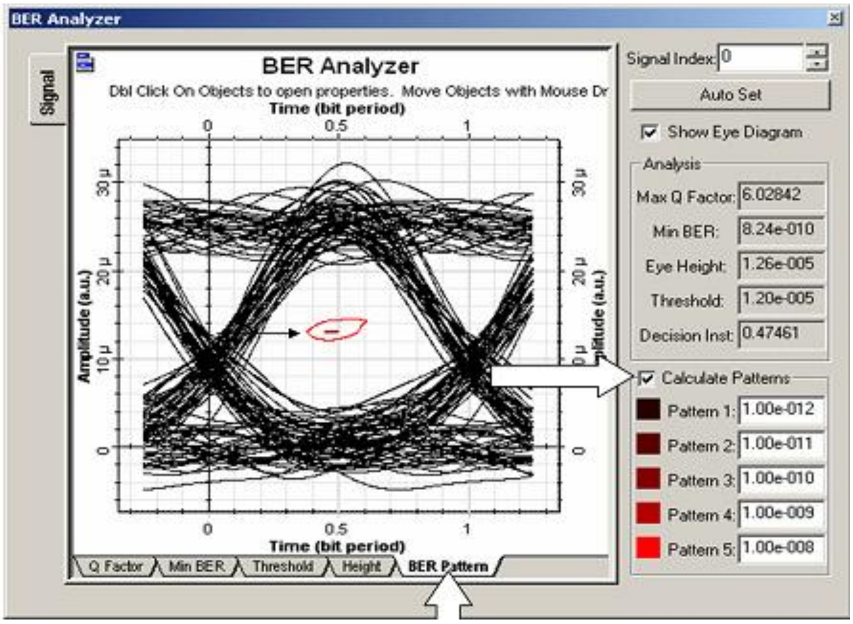

Fig. 5. BER Analysis Visualization Component

3.10.4 Data Monitors

Optisystem provides component ports to save the data and attach monitors after the simulation ends. This allows us to process data after the simulation without recalculating. Multiple visualizers can be attached to any data monitor.

IV. THE OPTISYSTEM SIMULATION

The optisystem simulation is divided into three different stages. However, a four channel WDM network is used to implement all two stages of the different scenarios that contribute to the overall effect of micro-bending. A fiber optic communication channel is incomplete without an optical transmitter. This is because, it is always necessary to have a light source for correct simulation of the channel and also because an optical transmitter will convert electric signal into optical pulses.

To successfully simulate the optical transmitter in Optisystem, the following component specification in the Optisystem library have to be review:

- **Pseudo Random Bit Sequence generator (PRBS)**
  PRBS is a component model in Optisystem that generates random bits of 1 and 0. PRBS generator signals are used in Optisystem as test pattern because it can be used as worst case pattern. I have considered it better to test the optical transmitter with the worst signal if we can receive the worst signal at the receiver. This is because if our optical transmitter is able to transmit a bad or noisy signal accurately to the receiver can definitely transfer a good signal without any problem, this is why I have used a PRBS generator from the Optisystem component library.

- **Pulse generator (Continuous Wave laser)**
  A pulse generator component model named CW laser was used to design the optical transmitter alongside the PRBS. The auto connect facility in Optisystem provides the right connection prototype for user groups. Before sending the output signal from the optical transmitter output to the fiber optic communication channel or link,
- **Modulator**
  The Modulator component assigns the optical information bearing signal onto a carrier frequency for transmission. In modeling optical transmitters in optisystem, the modulator is always before the fiber transmission. The modulator component is designed with three ports, an input port, an output port and a modulation port. Both input and output ports are of optical references but the modulation port receives electrical signal and not optical signal.
  A complete overview of the optical transmitter in the simulation environment is shown below. The PRBS output is fed to the pulse generator. Data monitor facilities have also been added to the optical transmitter as shown below**.**

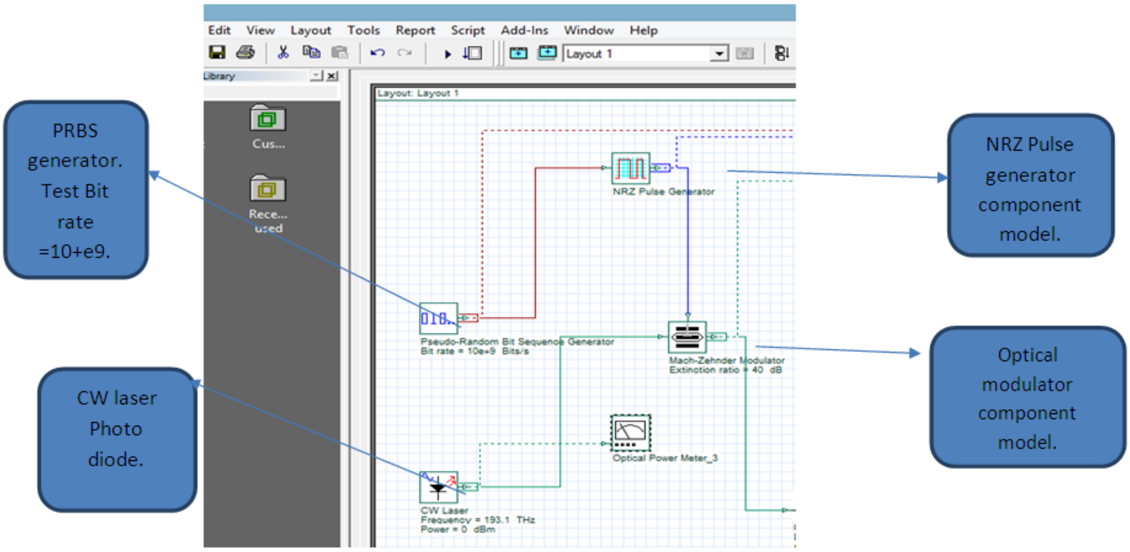

Fig. 6. Complete Overview of the Optical Transmitter in the Simulation Environment.

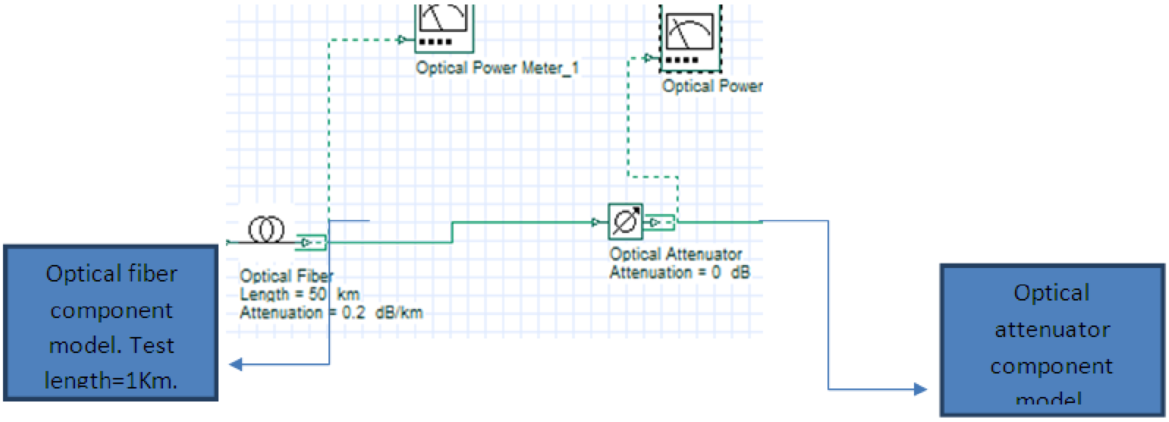

Fig. 7. Overview of a Segment of the Optical Fiber Line.

V. CONCLUSION

An 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.

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