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Experimental Performance Analysis of Macrobending Loss Characteristics in Polymer Optical Fiber

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ABSTRACT

An investigation of bending loss characteristics of a Polymer Optical Fiber is presented experimentally. Loss of optical power in an optical fiber due to bending has been investigated for a wavelength of 650 nm. Variations of bending loss with different lengths have been measured, with a number of radii of curvature. Bending Loss equations for short length POF is proposed, which shows the dependence of bending loss on the curvature radii. The equations can be an initial reference or aid in predicting the loss contributes by the polymer optical fiber.

1. Introduction

Fiber optic has been widely deployed as a communication system due to high performance contributes by key attributes of anti-interference, high sensitivity, remote sensing, multiplexing capabilities, compact size and low cost [1-4]. A fiber optic basic communication system consists of three components which are the optical transmitter, fiber optic cable, and optical receiver. Optical fibers (or optical fibres) are transparent fibers, usually made of glass or plastic, invented to carry huge amounts of data over long distances. Advances in the production of optical fibers made possible the recent development of innovative sensing systems for various applications including biosensor, civil structures, and medical appliances. The ability of optical fibers to measure parameters such as acoustic energy, temperature, strain, and vibration efficiently, is undeniable [5-9].

Polymer Optical Fiber or Plastic optical fiber (POF) is a low-cost multimode optical fiber, composed of acrylic (PMMA) as the core material and fluorinated or perfluorinated polymers as the cladding materials. POFs have been widely employed as an energy- effective solution for low-speed, short-distance applications in automotive networks, industrial networks, and home networks and

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appliances. At present, they are advantageously replacing copper cables in short-haul communications links due to easy to handle, flexible, and lightweight.

If the radius of curvature is large as compared to fiber diameter, macrobending can occur. Meanwhile, microbending loss happens when the curvature radius and the diameter of an optical fiber are of the same order of magnitude. Macrobending is related to twisting or wrapping the optical fiber. Light can be escaped from a fiber when it is twisted or bent. As the bends end up more tightly, more light leaks out of the cladding [10-11]. In POF, the light refraction index of the core is higher than the clad. As the result, the light entering the core will reflect at the core-cladding interface, so long as the angle of its incidence with the interface is smaller than a certain critical angle. The light will propagate inside the core-cladding arrangement throughout the length of the fiber by a phenomenon called the Total Internal Reflection (TIR) of light until it arrives at the end of the optical fiber [12-15].

When the light propagates in the optical fiber, various factors can lead to the reduction in the energy of the signal. Bending loss is one of the factors, resulted from the distortion of the fiber from the ideal straight-line configuration. In recent years, bending loss for various wavelengths, and bending parameters like the radii of curvature and wrapping turns have been reported [16-19]. In order to comprehend the behavior of such fiber optic, it is necessary to obtain the analytical dependence of the control factors versus fiber bend characteristics.

Macrobending can be modeled as a tilt in the refractive index profile based on the radii of curvature of the fiber bend as in equation 1 [20].

$$n_c(r,\theta) = n^2(r) + \frac{2n_1}{R} r cos\theta \quad (1)$$

where $n_c\,(r,\vartheta)$ is a modified local refractive index upon the fiber bend radii, R is the bend radii and ϑ is the tilt angle.The factors that contribute to bending loss are the radii of the bend, the number of bends and the wavelength of the signals [21-22].

In this work, we suggest a simple experimental setup with different radii of curvature and various lengths to study their effects on bending loss. The most significant outcome of this research is to show the relationship between macro bending loss and bending radius in polymer optical fiber. The analysis then leads to the bending loss equations for different bending radius in the range 1 cm to 3 cm.

2. Methodology

There are three main systems needed to make the system operates, which are the transmitter, fiber optic system, and receiver as shown in Figure 1. The transmitter is the main light energy used in this system produced by a laser diode at 650 nm wavelength. The laser diode also known as an injection laser or diode laser, is a semiconductor device that produces coherent radiation where the waves are all the same frequency and phase. Visual fault locator is used in this project as laser source which using a visible LED source to inject enough light into the fiber. Fiber optic cable allows the laser to be transmitted from the transmitter to the receiver. The result of the experiment will be measured by Optical Spectrum Analyzer (OSA) at the receiver. OSA will not only measure optical signal but power, wavelength and display the signal spectrum.

Fig. 1. Block Diagram of the Experimental Setup

Firstly, the initial measurement of straight POF was taken, follows by 1 cm, 2 cm and 3 cm bending. There are 3 readings taken for each length and the comparison has been conducted. An example of the measurement setup for bending loss calculation is shown as in Figure 2.

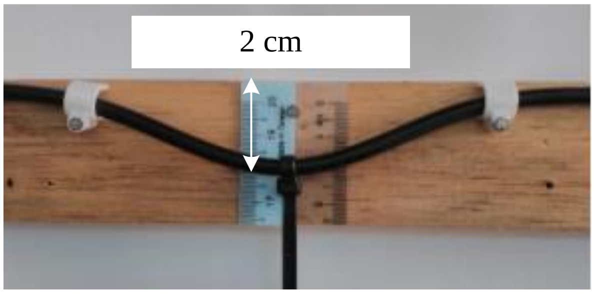

Fig. 2. Setup for 2-cm bending radii

3. Results and Discussion

Table 1 shows the measurement taken for 1.5-meter length fiber optic cable without bending observed from OSA. Five readings were taken and the average reading was determined. The average output power and average center wavelength power are -40.98 dBm and 660.01 nm, respectively.

Table 1
Power Received for 1.5-Meter POF

No.	dBm	Center Wavelength, nm
1	-39.50	659.24
2	-42.80	659.78
3	-40.20	660.13
4	-39.70	660.52
5	-42.70	660.40
Average	-40.98	660.01

Similar measurements were taken for 2.0-meter and 3.0-meter length fiber optic cable and the results were summarized as in Table 2 and 3, respectively. The average output power and center wavelength were then calculated and the resulted output for 2.0-meter fiber cable is -41.44 dBm and 661.26 nm, respectively. Meanwhile, for 3.0-meter cable the average reading was for received output is -42.40 dBm and average center wavelength is 660.68 nm. It can be concluded that as the length of the fiber increased, the received power at the receiver end will be decreased. This shows a good agreement with the fundamental theories where the larger loss will be experienced by a longer transmission medium. The relationship of fiber length and the received power for no bending or zero bending fiber cable is as depicted in Figure 3.

For wavelength analysis, the wavelength varies with the length, however, no exact pattern is observed for the wavelength shift. The wavelength at the receiver changes slightly at around 660 nm.

Table 2
Power Received for 2.0-Meter POF

No.	Output Power, dBm	Center Wavelength, nm
1	-41.30	660.44
2	-43.20	661.64
3	-40.00	661.53
4	-41.30	661.42
5	-41.40	661.27
Average	-41.44	661.26

Table 3
Power Received for 3.0-Meter POF

No.	dBm	Center Wavelength, nm
1	-41.40	660.52
2	-43.40	660.47
3	-43.00	660.79
4	-42.30	660.91
5	-42.90	660.71
Average	-42.60	660.68

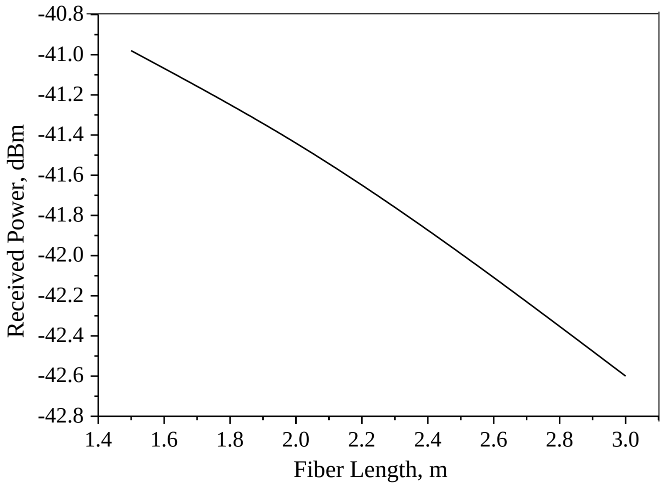

Fig. 3. Zero Bending Analysis for specified fiber length

In order to study the effect of fiber bending to the performance of fiber optic cable, the fiber is being bent with 1-cm, 2-cm and 3 - cm radii, R at the center of the fiber as portrays in Figure 4. Three readings each were taken and the average reading is depicted in Figure 5.

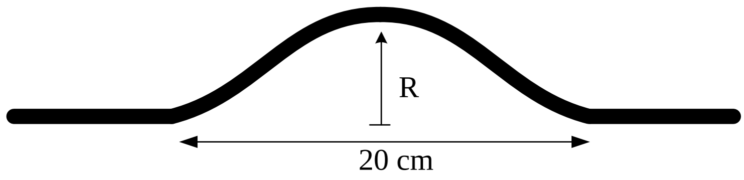

Fig. 4. Fiber optic bending radii

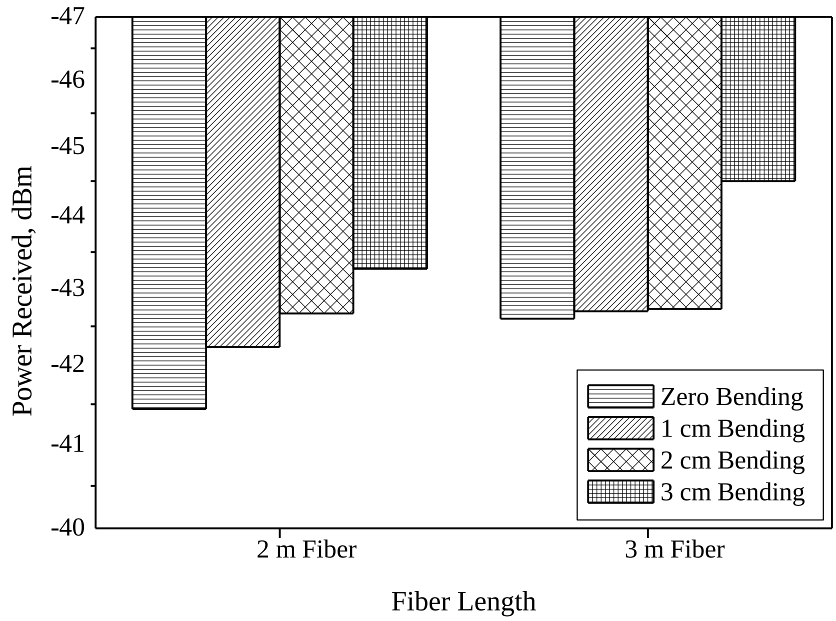

Fig. 5. Received power for different fiber length

From Figure 5, it can clearly be seen that by increasing the radii of the fiber bending, the received power become smaller. Both fibers adhere to the same trend. For example, for 3-m fiber cable, the discrepancy between the straight fiber and 3-cm fiber bending is 1.9 dBm. With the increase of the bending radii from 2-cm to 3-cm, the received power was reduced in 1.77dBm. From the results, it indicates that, the higher the bending radii, the lower the output power.

From the received power at the receiver end, loss contributes by bending can be determined by calculating the difference between the received power for certain bending radii with the straight or zero bending fiber. Figure 6 shows the loss in fiber optic measured for 1-cm to 3-cm bending radii. The mathematical modeling developed based on the resulted output are as shown in the equations below. These models can be employed to predict the loss due to curvature bending in POF.

For 2-m length fiber:

$$Loss, dBm = 0.887e\hat{}\{(Bending\ Radii, cm)/3.22)\} - 0.42 \tag{2}$$

For 3-m length fiber:

$$Loss, dBm = 0.0013e\text{^}\{(Bending\ Radii, cm)/0.41)\} \quad (3)$$

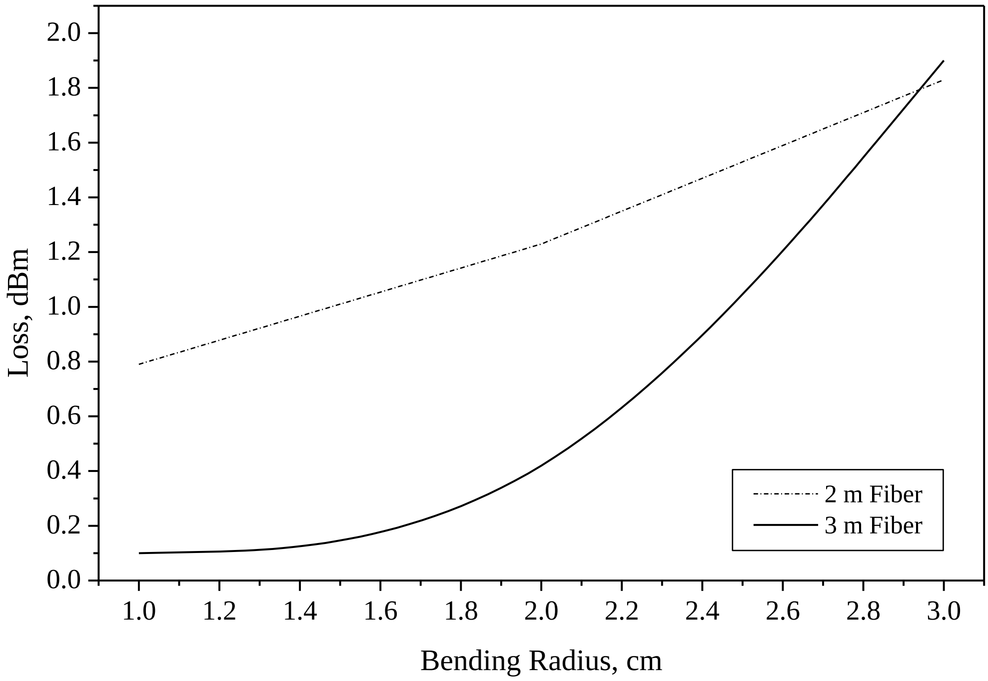

Fig. 6. Fiber Bending Loss

4. Conclusions

Bending losses in a multi-mode Polymer Optical Fiber were studied. Dependences of bending losses on bending radii and fiber length were investigated. The loss formula for optical fibers with constant radii of curvature was derived for 2-m and 3-m length of fiber. We have showed experimentally that with the radii less than 3.0- cm, the POF with shorter length exhibits more loss and at 3.0-cm both 2-m and 3-m fiber produces almost the same bending loss.

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