ABSTRACT

An experimental study of coupling efficiency of a circular multimode fiber coupler dependency of radiation from macro-bending is investigated. The study is done by experimental set-up using various radii of circular blocks customized with matching refractive index material. The aim is to provide a considerable explanation on the differences in splitting ratio, excess loss and insertion loss when different bending radii due to radii of circular blocks is applied to the couplers. Other factors that contribute to the characterization of the coupler include fiber diameters and forces exerted upon the two fibers that lapped together forming the coupler developed. The technique used is proven to develop a low-cost coupler using mechanical lapping technique.

KEYWORDS

Bending, multimode, polymer optical fiber, couplers, force.

1 INTRODUCTION

Multimode fiber (MMF) technology is vastly employed in short-distance communication applications such as LAN and interconnects. The utilization for MMF technology comes from the demand of higher bit rates and low-cost of materials compared to other medium such as copper. However, due to multimode drawback which it has limited bandwidth length due to modal dispersion, it mostly used for short distance applications only and for short distance communications purposes, the low attenuation gives the advantage of low cost employment compared to expensive glass fiber or bulky copper. Thus, demand of high-speed data transmission can be employed throughout the homes, intra-building offices and in automobiles [1].

It is well-known when a fiber is bent, it radiates power to the surrounding medium, i.e air, oil or other media. Depending on the bending radius, the amount of power radiates out of the fiber is parallel to the radius. Extreme bending could lead the propagation rays to lose into the air if the cladding is thinned or stripped. The proportion of the power in the fiber which is radiated out depends on the radius curvature or bending radius and the difference between the refractive indices of core and cladding. Radiation not only happens in single mode fiber (SMF) or slab waveguides only but same event happens with MMF [2].

Optical power losses due to bending are important in communication system due to the diminishing of link optical margin. Most of the propagation rays in bending fibers are leaky which they eventually lose power at successive reflections or repeated bending by refraction [3]. In theory, for a finite thinned cladding thickness, where the propagations rays that refracted at the core-cladding interface are lost. With the existence of cladding, it functions as waveguide and lights that travel along the waveguide are refracted and return back to the core after being guided in the
cladding. As a result of bending, the losses lead to incorrect estimation of measurement of some important parameters such as numerical aperture and bandwidth [3].

Other method that treats this leakage by cladding mode strippers, where the fiber cladding sections that were removed are treated by immersing it in a fluid of refractive index that is very close to that of the cladding index to reduce reflections and the propagation rays will escape the fiber and transfer to other fiber and the cladding will behave as if it were infinite [4].

Here in this study, we take advantage of the bared core of the fibers to develop coupler using lapping technique with other enforcement such as force and different bending angles to display various coupler/splitter characterizations depending on the customers’ needs [5]. Here the study includes the importance of fiber cladding thickness, force exertion and bending angles in developing a low-cost coupler using lapping technique as shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Multimode fiber coupler where the fibers will be lapped for coupling to happen

## 2 BENDING FOR MULTIMODE PROPAGATION IN STEP-INDEX WAVEGUIDE FOR DEVELOPING DIRECTIONAL COUPLER

A guided light ray in a bending fiber has evanescent field that propagates in the cladding. Bending loss occurs because the evanescent field would have to travel faster than the speed of light to keep up with the core field [6]. Most components based on bending are not really used extensively, thus, it is possible to manipulate the loss due to bending based on the phenomenon. A tapper can be fabricated by placing a receiving fiber at a certain angle in contact with the bent region of the main fiber. In this study, bending loss phenomenon is applied to develop a coupler. Figure 2. shows rays refracting and tunneling of a mode along core-cladding interface. At point 1 and 2, rays are refracting and they appear from the incident ray, one reflected and another one refracted where both are with certain power carrier [3]. The power splitter or taps split the optical power from a single input into two output fibers, and power combiners perform the opposite function [6].

![Figure 2](image2.png)

**Figure 2.** Phenomenon of fiber bending and radiation due to evanescent wave theorem

## 3 EXPERIMENT

In this study, acetone is used to etch or taper a certain length of the fiber as an initial procedure to fabricate the coupler which consists of two parallel fibers brought in close proximity at a certain length, which this method is known as lapping technique.

![Figure 3](image3.png)

**Figure 3.** Etching in process
Experimental setup was performed using customized platform and various radii of circular blocks made of acrylic shown in Figure 7. Groove was carved along the edges of each of the circular blocks that function to place the fiber. Before any of this experimental setup is being done, etching process take place where about 2 cm of middle fiber is etched using acetone for several hours, approximately from one hour to two hours as shown in Figure 3. The time taken for etching results in the thickness of the cladding left at the fiber that surrounds the core and thus defines the properties of the ray propagation when bending happens. Fibers used for this study has post-etching diameter of 0.95 mm for both fibers. As in Figure 4 and 5, we can see that the etching process does not impaired the structure of the fiber if etched for sufficient time. Figure 6 shows the broken fiber if brittleness occurred during the etching procedure. This happens when the fiber under etching is stressed due to bending and this leads to breaking of the fibers. The two post-etch fibers are taken paired and placed at the groovy of the acrylic circular blocks. The fibers are placed at the blocks according to the bending radius of the circular blocks and they are secured using the platform pivot so that the fibers are bent accordingly to the radius of the blocks. Then, both the fibers are brought closed together by pushing the blocks towards each other. Here, one of the blocks is fixed stationary while the other is flexible. A certain amount of force is given at the flexible blocks so as to allow the light propagation to transfer from the first fiber to the other effectively. The amount of force is measured using force gauge and the value is recorded accordingly. Thus, when signal of 650 nm wavelength is injected through input port, P1, the value of output power are recorded at P2, P3 and P4 which are the throughput port, coupled port and reflected port respectively. Five sets of couplers are measured for their output powers and characterized. Figure 8 shows the flowchart of the experiment procedure.
Figure 7. Platform of experiment with circular blocks of different radii

Etching process

Post-etching process: Po and IL are taken

Circular blocks of various radii are used as platform.

Red LED source is injected through one end of the fiber, P1

Po and IL is taken at the transmitted port, P2, coupled port, P3 and isolated port, P4. Force gauge is used to take pressure measurement.

Coupling ratio and Excess loss are calculated. Coupler is characterized.

Figure 8. Flowchart showing the fabrication process

4 RESULTS AND DISCUSSIONS

Characterizations on Coupler 1 which has bending radius pair of 25 mm-25 mm, Coupler 2 with bending radius of 30 mm-40 mm, Coupler 3 with bending radius of 35 mm-27 mm, Coupler 4 with bending radius of 30 mm-20 mm and Coupler 5 with bending radius of 52 mm-40 mm are constructed to each of the coupler with same post-etch diameter thickness of 0.95 mm for both fibers. The objective of using different bending radius for each coupler is to study the effect of the bending radius towards the radiation of the propagation rays by evanescent wave theorem. In theory, the smaller bending the bending radius, the larger the amount of rays radiated out of the fiber, thus the larger the losses. However, this study prevents the rays from radiated out into the air but by letting the rays to transfer to the other fiber, i.e. allow the coupling to occur between the two fibers when they are lapped together. Some amount of force is exerted to each of the coupler so that to minimize the gap between the two fibers and coupling length between the fibers is maximize in order to get optimum splitting ratios and least excess loss. Figure 9. until Figure 12. show the amount of force exerted unto the five sets circular blocks for about 30 seconds. Resulting from this, output powers coming through the throughput port, coupled port and reflected port is recorded and relationship of force exertion towards coupling length, splitting ratio, coupling ratio and excess loss is depicted in the Figure 14. to Figure 22. Figure 23. shows the dependency of excess loss to the bending radii.

Figure 9. Force exerted unto Coupler 1, with Rc1-Rc2 fiber pair with core-cladding diameter of 0.95 mm for both fibers and radius blocks of 25 mm-25 mm
Figure 10. Force exerted unto Coupler 2, with Rc1-Rc2 fiber pair with core-cladding diameter of 0.95 mm for both fibers and radius blocks of 30 mm-40 mm

Figure 11. Force exerted unto Coupler 3, with Rc1-Rc2 fiber pair with core-cladding diameter of 0.95 mm for both fibers and radius blocks of 35 mm-27 mm

Figure 12. Force exerted unto Coupler 4, with Rc1-Rc2 fiber pair with core-cladding diameter of 0.95 mm for both fibers and radius blocks of 30 mm-20 mm

Figure 13. Force exerted unto Coupler 5, with Rc1-Rc2 fiber pair with core-cladding diameter of 0.95 mm for both fibers and radius blocks of 52 mm-40 mm

Figure 14. Amount of force, F shows relation to coupling length, Lc for Coupler 1 to Coupler 5

From Figure 14, it can be seen that when the force is decreasing for Coupler 1 to Coupler 5, the coupling length, Lc also decreases. This shows that force exertion is an important factor in order to develop a coupler. It shows that force is needed to close the gap between the two fibers that are lapped to each other. Even though the fibers are brought closed into proximity when they are lapped without any force, the output power at the coupled port is very low and most of the higher modes of the propagating rays radiated out into the air and this leads to the ineffectiveness of the coupler developed.
Figure 15. Force exerted resulting in splitting ratios, SRc for Coupler 1 to Coupler 5

Figure 16. Coupling length resulting in splitting ratios, SRc for Coupler 1 to Coupler 5

Figure 17. Force exerted resulting in couplers coupling ratios for Coupler 1 to Coupler 5

Figure 15 depicts the splitting ratio of Coupler 1 till Coupler 5 when different bending radius is applied to each of the coupler. For Coupler 1 with bending radius of 25 mm and 25 mm pair of circular blocks, the force exerted upon the coupler is 1.44 lbF which give splitting ratio of 0.68% for the coupling port. For Coupler 2 with bending radius of 30 mm and 40 mm, the force exerted upon the coupler is 1.46 lbF and gives the splitting ratio of 0.60%. Coupler 3 and 4 with bending radius of 35 mm -27 mm and 30 mm-20 mm have force exerted with the amount of 2.26 lbF and 1.30 lbF which gives splitting ratio of 0.81% and 1.08% respectively. Coupler 5 with bending radius of 52 mm-40 mm has force exerted with the amount of 1.28 lbF and has splitting ratio of 0.73% for the coupled port. The theory behind this is that the force exerted does affect the splitting ratio of the coupler. With normal pressure when the fibers are brought in closed together, the output power at coupled port is less than when force is given to the blocks and fibers. By giving some force, the gap between the fibers is smaller and more rays can be propagated into the second fiber. The bending radius is another factor that stimulates the transfer of energy from fiber one to the other. The splitting ratio of Coupler 1 with bending radius pair of 25 mm-25 mm is slightly higher than Coupler 2 with bending radius pair of 30 mm-40 mm. Coupler 4 appeals higher splitting ratio due to the smallest bending radius of fiber that coupled, i.e. 30 mm-20 mm. The smaller the bending radius, the bigger the amount of rays that radiated out of it. The rays couples and propagates into the second fiber. Figure 16 shows the correlation between coupling length and splitting ratio. It can be seen that as the coupling length decreases slightly, the splitting ratio increases.
Same explanation goes for coupling ratio as with splitting ratio as can be seen in Figure 17. Factors such as force exertion and bending radii encourage the light propagation to transfer from first fiber to the second one. Although not much of rays are transferred, this can be traced back to the gap that existed between the two fibers. However, we can see that Coupler 4 with bending radius pair of 30 mm-20 mm gives the largest coupling ratio due to the smallest bending radius of one of the circular blocks, 20 mm. Figure 18 shows the correlation between the coupling length and the coupling ratio.

Excess loss for each of the coupler as in Figure 19 shows that it is linearly inverse to the force exerted upon the circular blocks, thus, with splitting ratio and coupling ratio. The higher the force, the smaller the excess loss. The force exerted decreases the gap between the fiber hence, lower the excess loss. Figure 20 shows the correlation between coupling length and excess loss. As can be seen, as the coupling length increases, the excess loss decreases.

Figure 18. Coupling length resulting in coupling ration, CR for Coupler 1 to Coupler 5

Figure 19. Excess loss increases when force exerted decreases for Coupler 1 to Coupler 5

Figure 20. Coupling length resulting in excess loss, EL for Coupler 1 to Coupler 5

Figure 21. Insertion loss decreases when coupling force exertion decreases for Coupler 1 to Coupler 5
As shown in Figure 21, as the force decreases, the insertion loss decreases. This is due to the gap that existed between the two fibers that are lapped to each other. Not enough force is exerted upon them, thus, leads to the high losses. In Figure 22, the coupling length is the results of the force and here, as the coupling length decreases, the insertion loss decreases.

From Figure 23, we can see that excess loss is increasing as the coupler bending radii pair is increasing. Coupler 1 with bending radius of 25 mm-25 mm shows the lowest excess loss of 1.67 dB whilst Coupler 5 with bending radius of 52 mm-40 mm gives the largest excess loss of 2.12 dB. The reason is that the coupling length between the Coupler 1 is smaller and the force upon the Coupler 1 is enough to close the gap between the two fibers. While for Coupler 5, the coupling length is slightly longer and the force to close the gap is insufficient and therefore excess loss appeals bigger, i.e 2.12 dB.

5 CONCLUSIONS

This study shows the application and effect of bending radius towards characterization of coupler development using other technique other than fused coupler or planar waveguide. This technique of developing a coupler basically applying mechanical force and lapping method. Concepts such as bending radiation through evanescent wave theorem, coupled mode theory and the cladding thickness also stimulates the coupling between the two fibers. These parameters are the guidelines of developing the coupler intended. The study shows experimentally the influence of the cladding thickness and bending radius on bending losses in step-index multimode plastic optical fibers. When the bending radius is small, more light rays propagate between the two fibers. Since the cores are not fused together, there exists some air gap between the lapped fibers thus contributes to the losses and small splitting and coupling ratio at the coupled port. The etching affects the circular fibers where the cladding was stripped off not only at the lapping surface of the fiber but also at the region that is not lapped to the other fiber. This reason also contributes to the losses since the rays can radiate out of the fiber. Although the matching index material, acrylic groove is to prevent the rays from lost into the air, the groove size can’t contain the whole etched region and save it from radiating the rays into the air rather than coupling the rays into another fiber. Future improvement will include treating the impairment of the groove so that only the lapping region is bared. The bending radii contributes to bending losses and this concept is used to develop an optical coupler where the proportion of the power in the fiber which is radiated depends on both its radius of curvature and the difference between the refractive indices of core and cladding.

6 REFERENCES


