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Bidirectional Optical Power Measurement for High Performance Polymer Optical Fiber-based Splitter for Home Networking

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Abstract: This research focuses on fabrication of 1 by 12 multimode polymethyl methacrylate based step-index polymer optical fiber (PMMA SI-POF). This home-made bundled-fiber splitters have been fabricated by a Distinctive technique. There several systems available on the market, which able to split or couple optical signals transmitted into some different channels, which are all afflicted with certain disadvantages. But all these solutions have one main disadvantage; they are all too expensive for most of the applications especially for home-networking. So the goal of the research is to develop an economical splitter for home-network application over PMMA-POF. Characterization of the splitter was reported. Red LED with 650 nm wavelength has been injected into the splitter with the aim to analyze power efficiency of the splitter. A coupling efficiency of 80% has been demonstrated. The device performance can be improved gradually through experience and practice. Main point here is the fabrication process is simple, easy and suitable to be used for household.

Key words: *Polymer Optical Fiber; POF; Polymethyl Methacryla te; PMMA; bundled fiber; optical splitter*

INTRODUCTION

In the past few years, number of applications based on optical fiber so rapidly developed as in the area of optical short-range communication. POFs have attracted much attention in past decades especially in home-network application because POFs have some unique characteristics, such as flexibility, easy to handle, relative low cost in coupling due to their large core diameter, heat-proof, immune for noise (external electromagnet disruption), suitable for data communication for long distance up to 100 meter, high speed data transmission (400 Mbps for SI's type and 1 Gbps for GI's type), wider broadband (exceed 4 GHz) and have losses below 25 db / km additional loss once it bent (Ab-Rahman *et al.,* 2008; Gogoi and Mladenovic 2002; Imoto *et al.,* 1987; Koonen *et al.,* 2003). As a result, increased demands on the architecture of the data connections as well as the transmission media are being made (Ab-Rahman *et al.,* 2008; Gogoi and Mladenovic 2002; Im *et al.,* 2002; Imoto *et al.,* 1987).

POF enables to use of inexpensive polymer connectors without any serious influences on the coupling loss (Ab-Rahman *et al.,* 2008). and reducing the modal noise in the multimode transmission for shorter distances. This is due to the high attenuation behavior of the polymethyl methacrylate (PMMA) POF fibers (100 dB/km in the visible wavelengths) compared to Silica fibers, a characteristic that could be a disadvantage but in our case for indoor applications could be an advantage from the flexibility and cost efficiency deployment point of view (Imoto *et al.,* 1987). Moreover, in order to improve the transmission characteristics of PMMA POF, Step Index profiles (SI-PMMA POF) is proposed (Kibler *et al.,* 2002).

The optical transmission layer has now been used for several years in the automotive area for and is widely spread. One of the most sophisticated systems named MOST (Media Oriented Systems Transport) standard specifies both optical and electrical technologies for the physical layer. It currently uses POF made of PMMA with core diameter of 1 mm as transmission medium, in combination with light-emitting diodes (LEDs) in the red wavelength range as transmitters and silicon photo diodes as receivers (Horak, 2007).

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Fibers with a core of polymethyl methacrylate and a fluorinated acrylate of a lower refractive index extruded thereon, are used both as light guides for lighting and for short range transmission systems with a length of less than 100m. Figure 1 shows the structure of a polymer fiber with protective cladding. PMMA fiber consists of an optical core with a diameter of 980 µm, which is coated with a 10 µm cladding material. The overall diameter of the optical PMMA fiber thus amounts to 1 mm ((Horak, 2007).

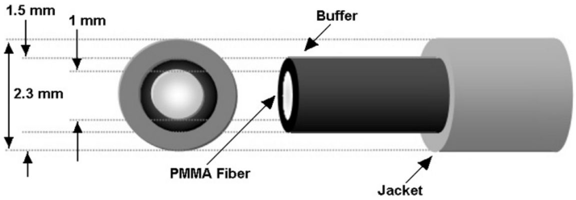


Fig. 1: Schematic diagram of the structure of a PMMA-based polymer fiber with buffer and cable coating

In this study, as a preliminary work, prototype characterization plays an important role to develop the design of end part of fused-taper-twisted POF splitter. In prototype characterization, experiments were conducted to determine optical output power, POFs attenuation characteristics and power losses on the network. 1 x 12 POF based optical splitter has successfully designed for a multi-purpose usage. But in this paper we highlighted on the fabrication and characterization of 1 x 12 POF optical splitter which can be used as a medium of data transmission especially in home network application (see Figure 2).

In this case, the proposed fabrication design finally comes out with a real fused-taper-twisted POF splitter (see Figure 3). The existing optical splitter made from waveguide based has been fabricated in full-equipped laboratory with the cost for each unit is approximately more than 1000 USD (1:12 ratio). As compare with hand-made-fabricated POF device which the cost is less than 10 USD. The customer themselves can fabricate the device with simple apparatus set up.

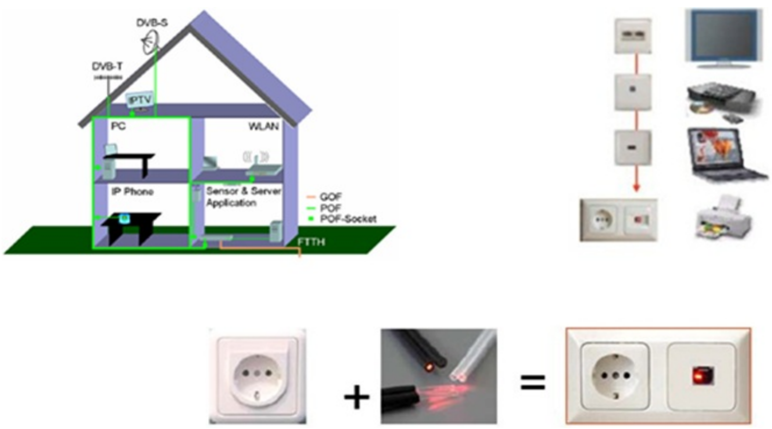


Fig. 2: POF increases the application for use in household, get rid of the bottleneck occurs between the Optical Network Unit and electronic appliances

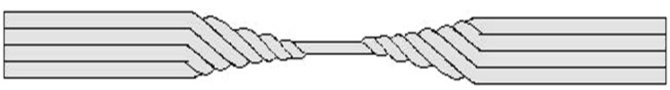


Fig. 3: Schematic of fused-taper-twisted POF-based splitter

Experimental (centered and all-caps font!)

***Material*:**

In development process of 1 x 12 splitter based on POF technology, multimode SI-POF type made of PMMA material with Øcore = 1 mm and NA: 0.50 fully utilized in this paper, as PMMA is one of the most commonly used optical materials, Due to its flexibility and cost efficiency deployment (Imoto *et al.,* 1987) PMMA-POF can easily be used near it operating temperature between -40ºC to +115ºC. it is well-known that attenuation spectrum of SI-PMMA fiber has three minimum point at 520 nm, 570 nm and 650 nm (red-LED wavelength). The attenuation minimum at 650 nm is 0.14 dB/m (Horak, R., 2007).

Prototype Development:

Prototype development gives a priority in fabrication method due to expectation to generate an optical splitter with the specifications which meet research's requirement. Development process for the proposed technology can be seen in Figure 4.

In this study, optical 1 x 12 splitter developed by the jointing of Optical 1 x 3 splitter and Optical 1 x 4 (both devices fabricated based on fused-taper-twisted POF). Other specification for the design, the 1 x 12 splitter reach data transmission distance up to 25 cm. therefore, a POF cables (11 to 13 cm length) is required to be linked with end part of 1 x 3 splitter (as an output) to input of 1 x 4 splitter. Basically, this optical 1 x 12 splitter design (see Figure 5) formed by all four optical 1 x 3 splitters arranged in series, and this series arrangement connected with optical 1 x 4 splitters parallel.

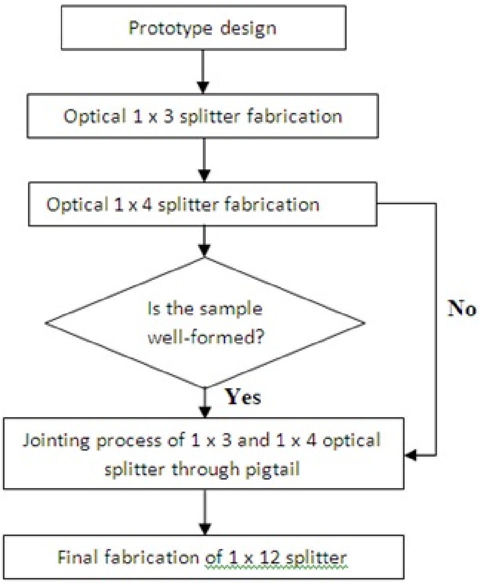


Fig. 4: Flowchart for prototype development process

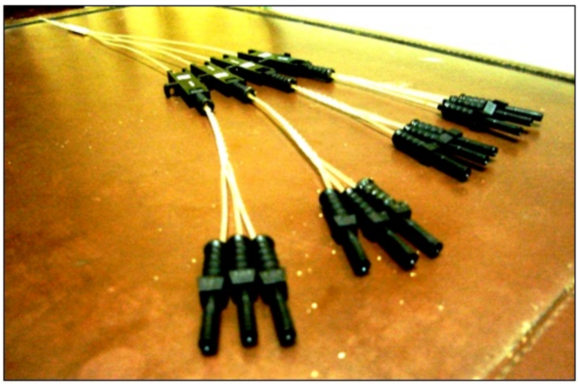


Fig. 5: Final product of 1 x 12 hand-made splitter as a media of data transmission application

Fabrication Method:

In order to fabricate the final product of optical 1 x 12 splitter, some stages has to be done, start from fiber fusion, bundle formation and finalized with POF jointing. Fusion method either for optical 1 x 3 or 1 x 4 splitter has just the same principle. Fabricated through fusion method by fuses and combine 3 or 4 POFs (in bundle form) and fabricate it ends part in a shape of fused-taper-twisted fibers (diameter 1 mm). POFs will be twisted and pulled down while it is fused in a heat of flame. Heating process was done indirectly, while POFs covered by metal tube. Thus, heat was provided for POFs through metal tube heating (see Figure 6). Right after twisted closely of POF's center part obtained, metal tube will heated up until center part starting melt. Than, gently pull the POFs in opposite direction, until the shape of that part taper-twisted properly.

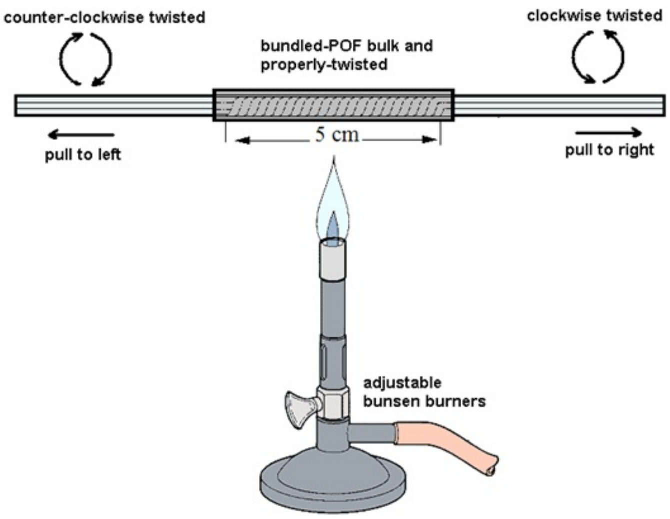


Fig. 6: Fabrication method of POF-based bundle fiber

However, many of bundled fiber successfully fabricated before, some deformed samples still found out, e.g. imperfect shape. A sample can be called ideal once its diameter uniformly fused-taper-twisted approaching 1 mm. To confirm that samples unable be used in characterization testing, these sample will be tested by red-LED injection. It is obtained that red-LED will not came out from the samples in a bad quality. Thus, the samples cannot be use in characterization testing (see Figure 7).

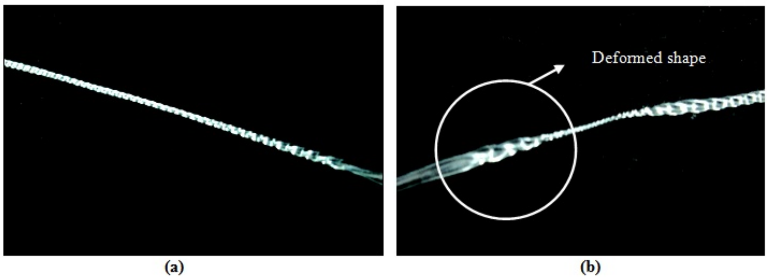


Fig. 7: Bundled fiber with (a) well-formed and (b) deformed body shape

To connect optical 1 x 3 and 1 x 4 splitter, research suggests using 1 mm POFs cable. Connection between 1 x 3 splitters and POFs cable joint by POFs connector (1 mm core diameter with jacket). POF connector contains two difference socket side, the one with a wide socket pit while other have a narrower. The end part of 1 x 3 taper-twisted POFs inserted into the socket with a wider slot and glued properly, so that the connection will be difficult to be pulled out. While the other slot side of connector inserted by POFs cable (see Figure 8).

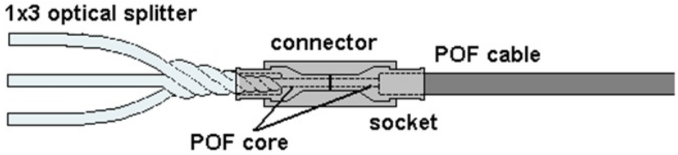


Fig. 8: Connection between optical 1 x 3 splitter with 1 mm POF cable.

After completely jointed the optical 1 x 3 splitter with one side of POFs cable, fabrication method continue by connecting the other side of POFs cable with optical 1 x 4 splitter with the same method explained before (see Figure 9).

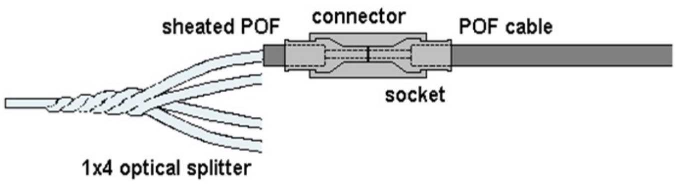


Fig. 9: Connection between 1 x 4 splitter with 1 mm POF cable

Prototype Characterization:

Each of developed splitter must be able to coupling every optical signal to generate one coupled optical signal with low power loss. Optical power meter has been used to measure the optical power from POFs. Before the switch opened, it is obtained that 0.02mW for it zero error exists on the meter. It is stated that 11mW optical power of red LED was injected as an optical input power for each POFs (see Figure 10 and Figure 11).

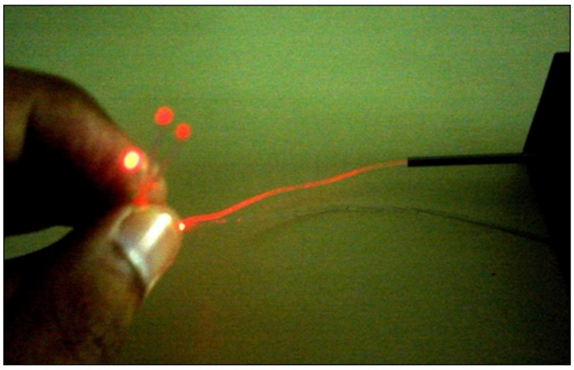


Fig. 10: Injection of 650nm wavelength of red-LED source into splitter

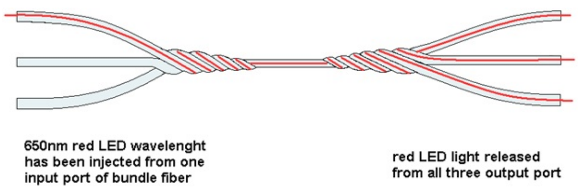


Fig. 11: sample of coupling method for the three optical coupled signals for 1 x 3 hand-made splitter

Bidirectional measurement for both ports of splitters, either from input or output side, need to be conduct to measure how efficient these PMMA-based POF operate. Refer to Figure 11, it can explain schematically the process of bidirectional optical power measurement for 3 x 3 optical splitters. With the same procedure, red LED fully utilized on this characterization process.

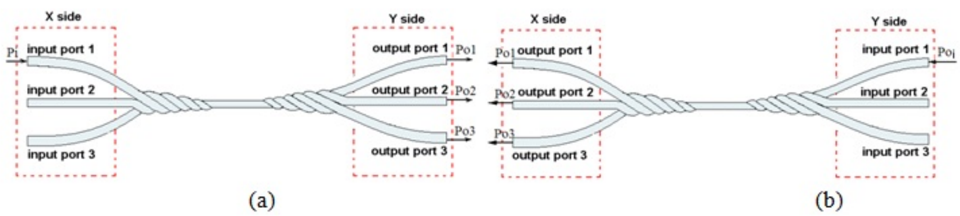


Fig. 12: Bidirectional optical power measurement test for 3x3 PMMA-based splitter from (a) X to Y side and (b) Y to X side.

RESULTS AND DISCUSSION

The best ten sample has been fabricated, and each of them have to be pass through a characterization stages, which lead to observation on level of efficiency for each sample. Red LED with 650 nm wavelength has bees injected into the fibers, once the light released through the fiber start from the input port to the output, surely caused a deviation on power of the light itself.

The analysis of the prototype characterization was carried out, especially for it efficiency percentage of each POFs. Hence the comparison for the all power efficiency of optical 1x12 splitter based on POFs has been observed, which the 1 end-POF act as an input and the other side which consist of 12 POFs stated as an output, the comparison between input and output has been calculated (see Figure 13).

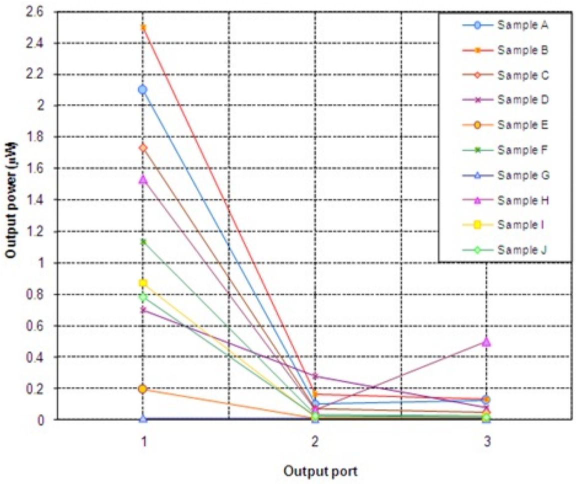


Fig. 13: Comparison of each POF output port which has been injected with 11mW from the input port (1POF), maximum efficiency of the splitter reach up to 80%.

Irregularities of controlled heat while heating process exposed on the POFs become one of the major problem, due to it lower melting point makes core structure of POF could be more sensitive on heating process. Once it is damaged, it is hard to let a light pass through the core, or even not pass at all. Refer to Figure 12, graph for the efficiency and power loss percentage of each sample can be obtained (see Figure 14).

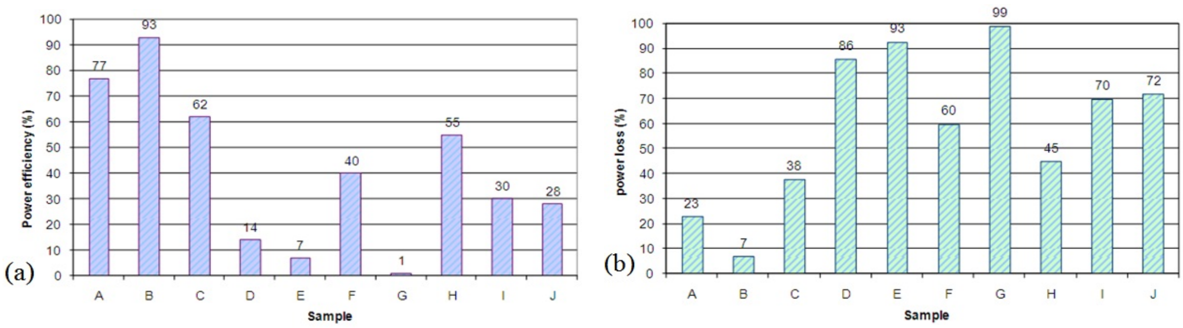
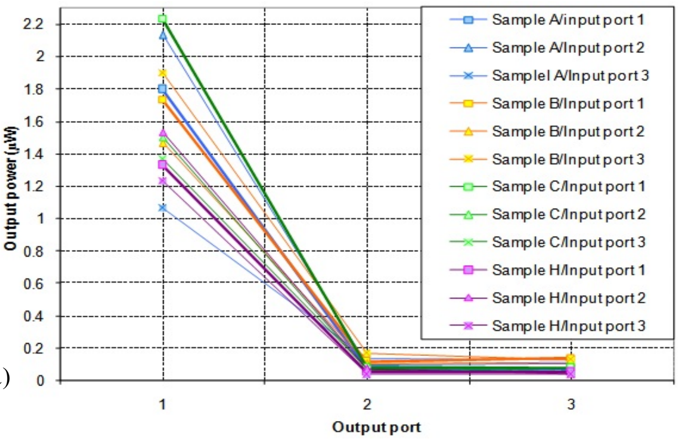


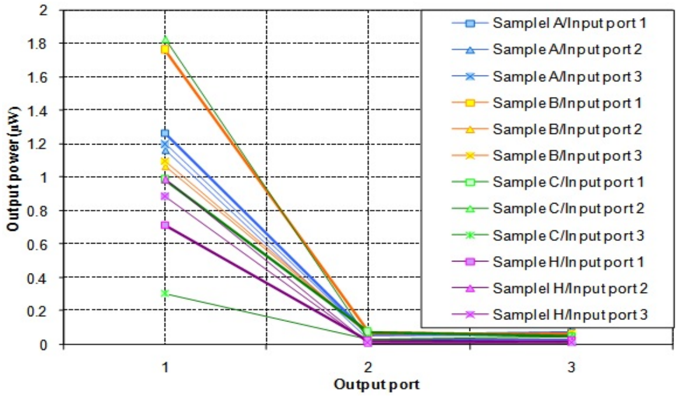
Fig. 14: Observation for average power (a) efficiency and (b) loss for all samples.

Refer to the result obtained as shown in Figure 10, research still go on by choosing the best four samples to measure the level of power efficiency bidirectionally of 3x3 optical splitter. The purpose of this measurement is to verify whether the coupling method run well on the optical device. Hence measurement and comparison for both port of 3x3 splitter need to be conduct as shown in Figure 12.

For this measurement stage, the best four samples which have been chosen are sample A, B, C and H which is have the highest level of power efficiency, and will be injected with 3μW input power measured by digital optical meter. Characterization process conducted twice, and started with measure the light flow from the one input (X side) into the three output port (Y side) using power meter, and otherwise. Result for the two measurement test can be observed in Figure 14.



(a)

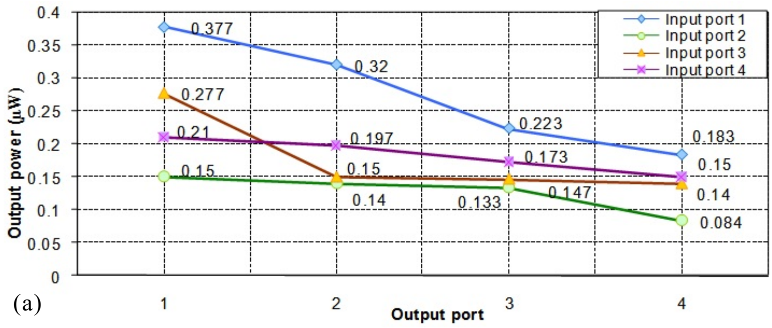


(b)

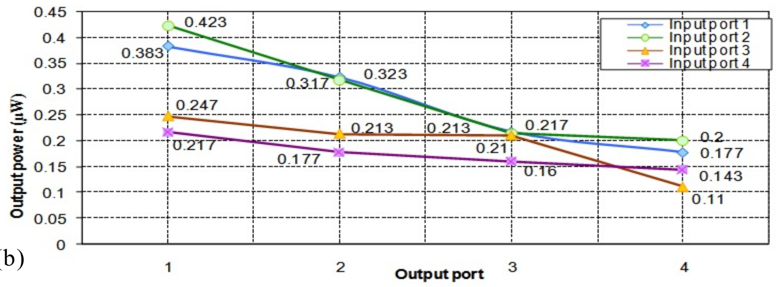
Fig. 15: observation for bidirectionally power output test from (a) X to Y and (b) Y to X.

Here can be seen that, both curve have the same pattern, but averagely shifted around 20%. One factor could possibly influenced is that small defect on a core of samples caused a different path of light which lead to a shifted result on both port. Asymmetrical shape of PMMA-based POF able to influenced power value from input to output port in term of bidirectional measurement conducted into samples (Ab-Rahman *et al.,* 2008a.b.c).

In order to measure whether both side of splitter has a significant deviation, from the view of power efficiency, bidirectional measurement test also conducted to 4 x 4 optical splitter. Procedure for the measurement can refer to schematic diagram from Figure 11 with a few different, it is from the number of the port, which for this stage the number of input and output port are four. Observation for this test can be shown in Figure 15.



(a)



(b)

Fig. 16: Bidirectionally measurements for 4 x 4 optical splitter from (a) X to Y and (b) Y to X.

From the above graph, it shows that both curves whether from X-Y measurement or otherwise did not indicate a significant different value, except for sample number 2. The deviation reach approximately 20% from overall efficiency. Similar to 3 x 3 splitters, body of polymer, which exposed by fusion process, result in asymmetrical shape of POF itself as it is observed from different port.

Conclusion:

The properties of different core and cladding materials of polymer fibers for different applications have been examined since the late 60s. fibers with the core of Polymethyl Methacrylate (PMMA) and fluorinated acrylate of the lower refractive index extruded thereon, are used both as lights guides for lighting and for short-haul data transmission systems with a length of less than 100m. the use of standard PMMA fibers is permissible up to temperature of 85°C. next to deterioration possibly due to aging, the attenuation of an optical fiber during operation is mainly influenced by additional losses such as Bending (Horak, R., 2007).

Light-emitting diodes having an emission wavelength of 650 nm (red-LED) are attractive transmitter units for cost-efficient PMMA networks of less than 100 MHz bandwidth. That is why red-LED was chosen to be fully utilized on the research.

A fused-taper-twisted technique has been used to fabricate 1x12 optical splitter with based on PMMA-POF technology. Multimode PMMA-SI-POF type with Øcore = 1 mm and NA: 0.50 fully utilized as a base material of the splitter. Some procedures, such as fabrication and characterization stages have been carried out before completely develop the splitters. Red LED with a 650 nm wavelength has been injected into the splitter for the purpose of characterization testing to analyze the level of power efficiency of the splitter. Final analysis shows that efficiency of splitter output able to reach up to 80%.

The device performance can be improved gradually through experience and practice. Main point here is, the fabrication process is simple, easy and suitable to be used for household. Further study about interfacing POF-based system for home network application are advised to be conducted, all the way to improve the efficiency of POFs power transmissionc.

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