World Applied Sciences Journal 23 (6): 845-853, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.23.06.3099

Experimental Study on Low Cost SI-POF Splitters and Effect of Plastic Filters Adhesion for Short Distance Data Communication Network

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Submitted: Oct 14, 2012; **Accepted:** Nov 25, 2012; **Published:** Jul 27, 2013

Abstract: An experimental demonstration of a polymer optical fiber (POF) based network has been conducted in wavelength division multiplexing (WDM) approach and some effects on placement of color filters in demultiplexing zone of the system. Three signals with different wavelengths can carry different information through one fiber. All the wavelengths will be multiplexed and have to be split at the receiver to regain the information. The main idea is to develop a demultiplexer by employing the principle of WDM. The transmitter will emit three different sources (λ = 470 nm, 520 nm and 665 nm) of light and be multiplexed into single white light. However, the light has to be separated at the receiver in order to recover back the information by using demultiplexer. Step index POF fused optical splitter has been used to realize the concept of multiplexer. A low cost demultiplexer is realized by using plastic films for the filter. The specialized designed color films are used to filter out any other wavelength that is not within the range. It will only allow one wavelength to get through the filter and thus conveyed the data carried at the receiver. Several readings using power meter are taken to record the losses and power outputs for efficiency and characterization process. LEDs are injected through the fiber and the demultiplexed signals at the end receiver are analyzed. The efficiency of the demultiplexer is about 70%. Fabrication of the demultiplexer using color filters and epoxy-resin is simple although it needs meticulous concentration for certain parts. The performance shows that the system can be used for home-networking and automotive application as one of the low-cost data communication media. It also provides high data rate and bandwidth.

Key words: Epoxy resin · Fused · LED · Multiplex · WDM

INTRODUCTION

An optical system can be used for communication, sensing or controlling other systems that carry information which is encoded on a beam of light. Polymer optical fibers (POFs) had already been seen as an effective alternative replacement for the traditional communication means over the using of the copper, coaxial cable or even glass fiber in short distance applications. One of the good reasons is that POFs are lighter than copper wires. This is very important for the big industry applications such as automotive and home networking-based business. Furthermore, it has nonexistent susceptibility of any kind of electromagnetic interference. POFs are proved to provide more bandwidths and better durability than copper. Higher bandwidths are of great advantage for media communications such as the Ethernet and video [1].

POFs have advantages over other standard communication media such as copper, glass fibers, coaxial cable and wireless technology. POF system is free of disruption, inexpensive, space-saving and has a greater bandwidth compared to wireless technology and free from electromagnetic interference to name a few. POFs are also suitable for data communication for distance up to 100 meters with high speed data transmission which is up to 400 Mbps for step index [2]. Hence, POF has become an excellent alternative for short distance data communication. POFs are also widely used in various applications especially in home-networking Ethernet

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and automotive media applications. One of the main requirements in POF is high bandwidth and solutions for this problem are in high demand [3-5].

POFs have been widely used in various applications mostly in the automotive and the home entertainment area. POF can be applied in many optical communication systems as automotive multi-media busses or in home Ethernet system. The demands of higher bandwidth are increasing very fast in these application aspects and high speed data rate is of great interest. One of the solutions here is to use wavelength division multiplexing (WDM) concept. WDM can carry several different wavelengths and information over one POF fiber. The wavelengths carried through the fibers are will be separated at the receiver to regain and redirect the information channels. The separators are specified as demultiplexers.

In WDM-POF system, numbers of transmitters with different lights color carrying single information. For example, red light with 665 nm wavelength modulated with Ethernet signal while blue, green and yellow lights carry image information, radio frequency (RF) and television signal, respectively [6]. Wavelength Division Multiplexer is the first passive device required in WDM-POF system and it functions to combines optical signals from multiple different single-wavelength end devices onto a single fiber. Conceptually, the same device can also perform the reverse process with the same WDM techniques, in which the data stream with multiple wavelengths decomposed into multiple single wavelength data streams, as the reverse process called de-multiplexing.

There are several designs that provide the system mentioned above in the market, however, most of the designed systems turn out to be really expensive [7]. POF is very effective for short range networking such as for the applications at home. It is easy to setup the connection and the cost is lower compared to copper. POF can also sustain a tighter bend radius, which makes it user-friendly and be able to withstand rigorous installation tasks such as pulling the fiber through walls and plenums [1]. Moreover, POF is more flexible than glass fiber since it can be passed with smaller radius of curvature and without any disruption because of its larger diameter [7]. Many services and applications need large amount of data to be carried out. Usually communications via optical fiber is limited by 2 Gbits/s [7]. Thus an alternative solution has to be combining several data together through an optical fiber hence increasing the bandwidth. Therefore, the method of several wavelengths carried over an optical fiber simultaneously is known as WDM technique as mentioned before.

Fig. 1: Application of 1 × 3 *handmade* fused tapered based splitter in splitting the red LED (λ = 665 nm) signal referred as an ethernet signals to be separated into three channels

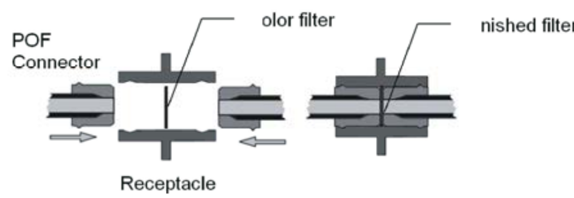

Fig. 2: Filters in Low Cost WDM-POF connector.

Every single monochromatic part of this propagating light carries information and as a result there is no limitation in bandwidth for optical fiber using WDM. To achieve this, two very important elements must be set up for the system to work. The first part is the multiplexer which is placed before the fiber to integrate every wavelength to a single waveguide. The second part is the demultiplexer which is placed after the fiber to regain each of the discrete wavelengths. This means the polychromatic light must be separated or split to its monochromatic parts to regain the information carried over the POF. There are three basic principles led to the system of WDM, which are arrayed waveguide gratings (AWG), fiber Bragg gratings (FBG) and thin film interference filters [7].

This paper will be focused on the using of color filters and combination with 1 × N fused tapered fiber (see Figure 1 And Figure 2), which N indicates number of output port from bundle fibers. Light is carried through the step index POF (SI-POF) with standard diameter of 1 mm. In general, POF splitter conceptually, POF splitter has similar function, operates to couple or combine several optical data pulse as a single coupled signal. Hence, the development of wavelength division multiplexer based on POF splitter is possible. Typically, the commercial POF splitter that manufactured commercially by some manufacturer priced expensively at approximately more than 250 USD in global market. There have been many techniques of fabricating POF splitter. These techniques include twisting and fusion, side polishing, chemical etching, cutting and gluing, thermal deformation, molding, biconical body and reflective body [8].

For this study, fusion technique is practically applied to fabricate POF splitter. Essentially, the term of *fusion* defines the act or procedure of liquefying or melting by the application of heat [8]. In order to develop the economical POF splitter, this study is undertaken to modify the typical fusion technique, whereby the technique is fully implemented by handwork. The heating elements and immune-to-heat tube (from the previous fusion technique) are changed in terms of availability and the appropriate twisting and pulling strengths are tuned specifically for the modified fusion technique [9, 10]. In this study, the characterization of the handmade splitter is carried out in order to determine the performance of device. Besides, study on how far the WDM-POF system can go and how far filters influences the output power of the system also reported.

Experimental: Adapting the fused tapering technique for conventional multimode fiber, we successfully established fabrication process for 1 × *N* POF fused taper splitters. The 1 × *N* handmade splitter is an optical device, which ended by *N* number of POF output terminals, while the other side ended by one POF port. Like other typical splitter, it is also possible to work bidirectional, whereby it works from the *N* ports into 1 port (for coupling signal purpose), or *vice versa* (for splitting signals purpose). As an example, optical 1 × 4 splitter developed by the jointing of four *polymethylmethacrylate* (PMMA) POF [2]. Other specification for the design, the input POF is designed and fabricated to be fused tapered shape.

Standard multimode SI-POF is used with its core diameter of 980 μm, cladding thickness of 10 μm and the refractive index is 1.49. To obtain the results, demultiplexer is realized using handmade color films attached using *epoxy resin* to the edge of the connectors. The components are chosen because they are low cost and are easily found in the market.

Almost same with POF material, the color filters are comprised of two types of plastic. More than 65% of the line is made from *co-extruded polycarbonate* plastic. The remainder of the line is *deep dyed polyester* [11, 12]. Filters create color by subtracting certain wavelengths of color. Thus, a red filter absorbs blue and green, allowing only the red wavelengths to pass. The process is subtractive not additive, so the light source must emit a full spectrum. The *swatch book* provides detailed information on the spectral energy curve of each filter. The curve describes the wavelengths of color transmitted through each filter. For example, *Supergel 342* transmits approximately 40% of the violet and blue energy of the spectrum and 75% of the orange and red energy. It absorbs all energy in the yellow and green range [11, 12].

In this study, certain colors of red, blue and green filters are analyzed and chosen to get the optimal results for the experiment. The way the filter colors are chosen are by reading the spectral energy distribution (SED) curves. The filters that transmit high levels at 700 nm may also transmit high levels in the infrared range above 700 nm. For example, the visible red light has a wavelength of about 665 nm. The filter color of red is chosen by which film that provides the highest transmission percentage and with minimal loss. Same goes with choosing color filter green and blue. In this experiment, eleven different colors are chosen for each red, green and blue filter. The aim is to observe which one of the choices gives the best result, that shows optimal transmission and minimal losses.

The fabrication of the demultiplexer is made by connecting the multimode POF with a connector at one end of the fiber. A small piece of color films are cut up and ready to be attached to the socket. The glue used in this fabrication is *epoxy resin* as mentioned before that consists of resin and hardener. When both of the resin and the hardener are mixed up, it produces a strong adhesive that holds the components to be attached together rigidly. After polishing up the end of the fiber that is connected to the socket, the small piece of color film is then attached to the edge of the socket using resin. Then, after putting the film onto the resin to be attached to the socket, the component then is hold together tightly for about two minutes to assure that no gap between them exists and also to assure the strong bond. This part has to be done gently since the *epoxy resin* has to be avoided covering the fiber's surface as much as possible so that any power losses can be prevented when the measurement is taken. However, since the edge of the socket is quite thin and sharp, the spread of the *epoxy resin* to the fiber surface cannot be 100% avoided.

After securing the adhesive, the POF attached with the film is kept at a secure place so it won't be disturbed and left to dry up. Usually it takes about one day for the resin to set fully. After the epoxy dried up, the film that attached to the end of the connector is cut in circle according to the shape of the socket's end. After the fabrication is done, readings and measurements are taken

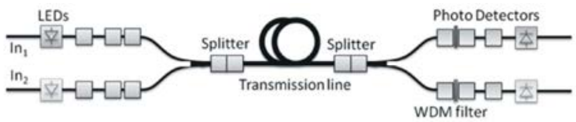

Fig. 3: WDM-POF system design using 1 × 2 handmade splitter and filters

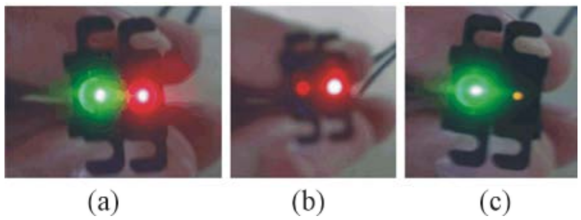

Fig. 4: 1 × 2 demultiplexer is used to split the signal to different frequency (color). The multiplexed signal is separated according to the application (data and video signal) respectively

for insertion loss and power output for each of the POF. The instrument used for taking the readings is the power meter. In this experiment, a lot of samples were fabricated to get the optimal results and to see which of the color filters that shows the most transmission and gives least losses. The length of the POFs is fixed at 3 meters long.

An experimental test bed for 1 × 3 WDM-POF network has been set up in order to measured the efficiency of the handmade splitter-filter combination for the whole system. Each of the red filters is injected by red, green and blue LED transmitters and readings were taken accordingly. Same is done for the blue and green filters. It is observed that when measurement is taken using power meter, readings should be visible on the meter, if not, then the samples cannot be used for characterization testing.

To measure and obtain the readings, first, the POF with film has to be connected with another short fiber using connector. Then the other end of the short fiber will be assembled to the power meter socket. The reference of the power meter for the red LED is set to be -10.7 dBm as is for blue and green LED. Before the readings could be taken, the other end of the POF (the one without the film) is connected to the transmitter. After all is set up, the LED is then injected through the fiber and measurement for insertion loss and power output is taken accordingly for each sample.

A certain information or data are carried by the transmitters where each transmitter carries signals of different wavelengths specified by the LED. The specialized designed color films are used to filter out any other wavelength that is not within the range. It will only allow one wavelength to get through the film and thus conveyed the data carried at the receiver. Filtering and signal coupling process can be easily explained in Figure 3 and Figure 4 for the experiment of 1 × 2 POF-WDM system through a combination of red and green filter.

RESULTS AND DISCUSSION

From the design of 1 × N splitter, the fused taper-twisted part, where every four POFs were fused or combined becoming as so-called single POF, play major role in coupling four individual optical signals. The fused tapered POFs should be fabricated as well as all fibers in bundle arrangement fused completely. Otherwise, the POF splitter would probably fail to transmit the signal lead to failure on coupling the numbers of single signal [6, 10, 13].

The error could be occurred on it either while fabrication process or characterization test stages imposed on them. Irregularities of controlled heat while fusion process 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 damaged, it is hard to let a light pass through the core, or even not pass at all. It is so important to stop twisting and pulling POF while the POF was getting hard in order to prevent micro-scaled crack on core. That is why we use the metal tube while we conduct the indirect heating to fiber, in order to reduce effects of damage of the device.

Indirect heating was used to minimize the undesirable deformation in the fused fiber bundle. This allows us easier fabrication and accurate control of the fused-tapered fiber. Furthermore, the continuous processing capability leads us to the reduction in fabrication time and improved yield. This method is expected to drastically reduce coupler fabrication costs [14]. In order to investigate precisely the exact value of power intensity for each POF outputs of fused bundle, bidirectional optical loss measurement has been carried out whereby injecting red LED through each of POF inputs on both sides of fused bundle separately. The average optical loss for fused POF bundle has been yet calculated for both directions (leftward and rightward) and then analytically compared. The analytical observation can be viewed as depicted in Figure 5.

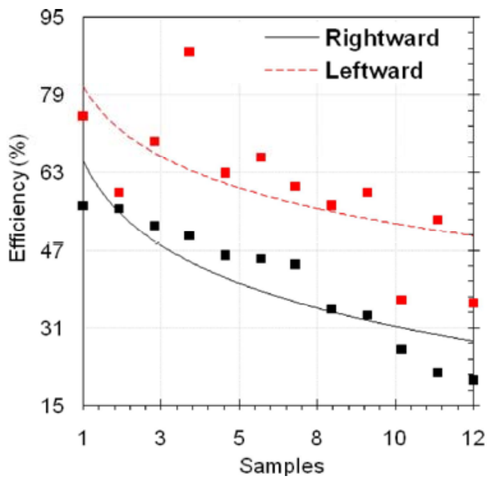

Fig. 5: Efficiency for fused bundle fibers from best to worst sample in both directions; rightward (X to Y) and leftward (Y to X)

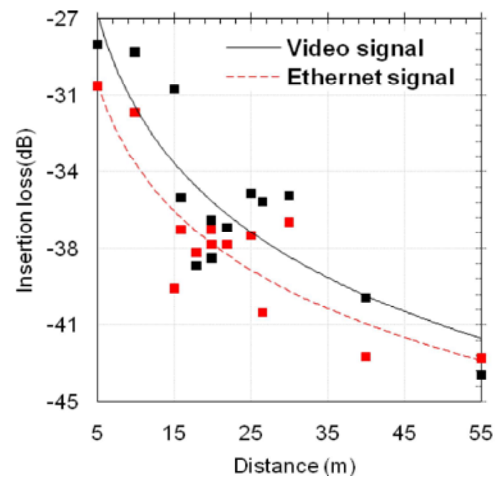

Fig. 6: Power loss comparison between green and red LED, where green LED represent the video quality of the system while red LED represent the rate of download and upload through internet line

According to the observation above, it is revealed that the optical loss for fused bundle in different direction was not identical. Analytically, fused POF bundle has lower optical loss in rightward direction. Thus, right side of fused POF bundle selected as POF splitter because it might couple multiple optical signals and produce single optical signal with lower attenuation and higher efficiency compared to the other side. Indeed, optical loss for fused bundle mainly caused by physical changes on POF especially on fused taper twisted in which POFs in bundle arrangement were all fused, twisted and merged.

The change of original diameter of POF considerably led to the change on optical properties including numerical aperture and maximum acceptance angle. All of these changes spoil light propagation principle based on total reflection; there would be much more rays of light refracted and propagate beyond cladding to atmosphere [15].

Comparison of handmade and commercial splitter have been observed, in term of market price. Overall price for 1 × 4 handmade POF splitter cost is less than 3 USD, but for the commercial one which available in market is cost not less than 250 USD. Nowadays, many technologies have been provided to coupling a signal, for example low cost 1 × 2 acrylic-based plastic optical fiber coupler [8]. But knowing that the fabrication techniques were very complicated and expensive, here handmade POF splitter can be seen as one of promising solution to face this problem.

In this study, the optical loss is categorized as extrinsic loss due to the physical change of POF, LED projection to POF and the core-to-core connection and [3, 16]. It is obtained that the physical change of POF caused by fabrication process, where by diameter of POFs increasingly decrease to approach 1 mm and the POFs finally has fused tapered shape. In characterization process, optical loss may present through the direct LED projection to POF surface. Besides, optical loss may also present through the connection between the fused tapered POF and POF cable [16].

The other aspect that playing an important role to transmit two different signal represented by different wavelength on transmitter devices is the filter which is placed between the splitter and the receiver section. In this research, two different LED was utilized; red LED (665 nm) transmit an internet line through LAN connection and green LED (570 nm) to deliver a high quality video signal to be displayed on a monitor screen. Analysis on the effectiveness of the filter itself also carried out. Here the comparison result of the efficiency of both green and red LED on their way to deliver a different signal to be split by POF splitter and optical power meter was placed in the output port right before the receiver port, as shown in Figure 6.

Figure 6 shows that red LED have a higher loss compare with the green one. LAN network was very sensitive with the varies of the distance, the longer distance it took, the faster LAN system drop, lead to the slower of speed rate of data transfer through fiber.

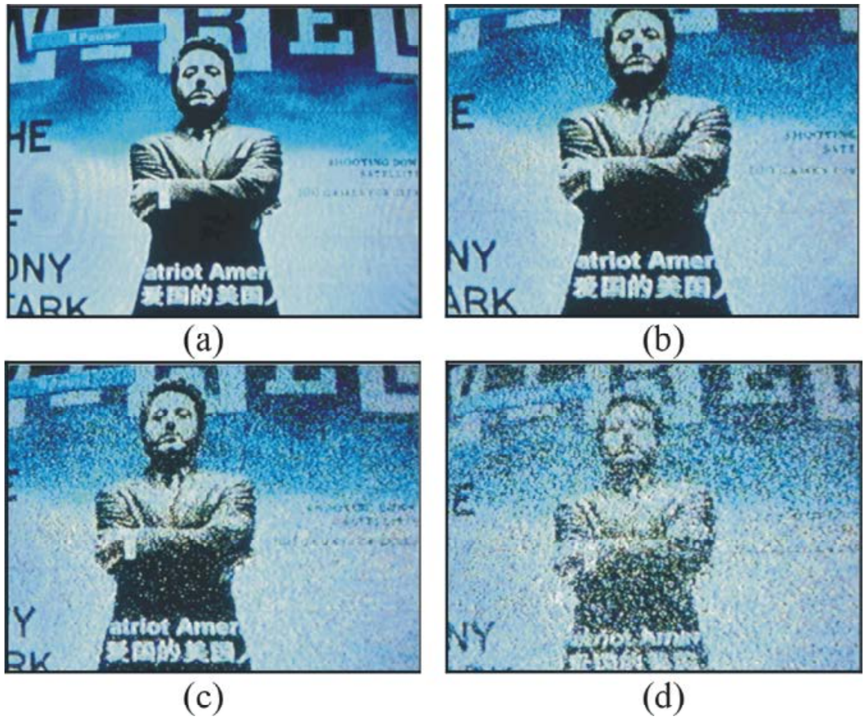

Fig. 7: Video quality of WDM-POF system of (a) 10m, (b) 20m, (c) 30m and (D) 50m of optical transmission line.

The deviation between both signals was reach 3 dB, while video transmission system showed a better quality of transmission system in low-cost WDM-POF system. The image quality of the video through WDM-POF method can be seen in Figure 7. The longest distance it takes to transmit the signal, the lower quality displayed in monitor. Beside, it was proved that the higher the bandwidth, the more loss of information bits in a single unit of time could happen [17].

Comparison for the optical line either using the filter or not, has been analyzed. The insertion loss of the cable with or without red filter is visualized in Figure 8. From the results gathered, it is seen that when all the components are set up and red LED is injected, the insertion loss measured by the power meter shows small increase of losses when the film is attached to the socket. This is also true when blue and green LEDs are injected. For the characterization of same film using different sources, we take a red film A (filter labeled *#4690*) as the primary filter and it is injected with all three LEDs, red, green and blue transmitters.

As the results depict, the red filter injected with red transmitter shows a small increase of losses which is about 0.8 dBm compared to the initial loss before the film is attached to the fiber. Same goes to the power output when the film is attached to the fiber. As shown in Figure 8, deviation occurred right after the resin placed into the connector; approximately 1 dB insertion loss took part on it. An increase of 5.3 µw of power output is observed. This is expected since the used of *epoxy resin* and the transmission limitation of the film gives the obtained data. However, different results are observed when blue and green LEDs are injected to the red filter. Small decrease of losses is observed when the fiber is attached with the film compared to before the fiber is attached with the film. The utilization of *epoxy resin* is ruled over by the higher transmission of green and blue transmitter through the particular red film. Above case happens when the transmission percentage of the particular red film also shade or covers some percentages of green and blue wavelength region.

For characterization of same source injected through different filters, red LED is taken as the primary source. From the result, it is observed that sample 3 shows least losses and decrease of efficiency, while sample 9 shows the opposite. The utilization of *epoxy resin* may also contributes to the deficiency of power output (efficiency) since the losses increase a lot for sample 9 apart from the reason it being a dark film with small percentage of transmission. On the other hand, the effect of efficiency of sample 3 is small because the larger percentage of transmission for red LED. Refer to SED *swatch book* from

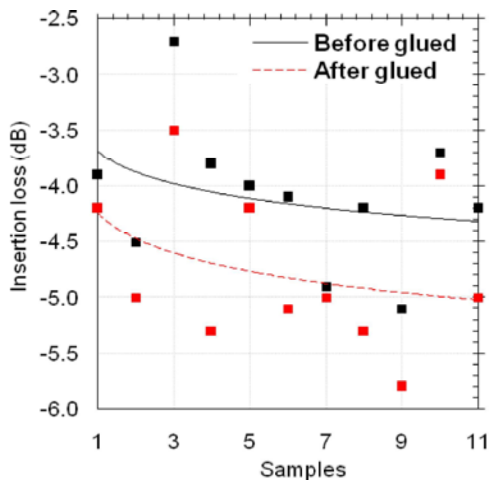

Fig. 8: Effect on resin for demultiplexer filters approximately 1 dB insertion loss occurred on the measurement between before and after connector glued by *epoxy*

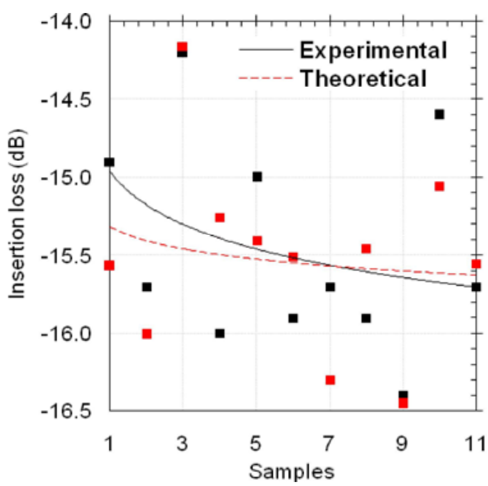

Fig. 9: Comparison between result from experimental and theory measured from red filter signal injected by red LED with 665 nm wavelength

ROSCO we can obtained the expected result from the theory of the color filter, now we can compare between the filtered signal gained from the experimental setup and the expected signal. From the graph shown that the different between result from experimental and theory averagely less than 1 dB.

For red transmitter injected through different color films with different wavelengths such as green and blue films, the green and blue films theoretically will filter out or block red LED because of the different wavelength range. From the data analysis shown for red LED transmitted through green filters, sample 1 blocks most of

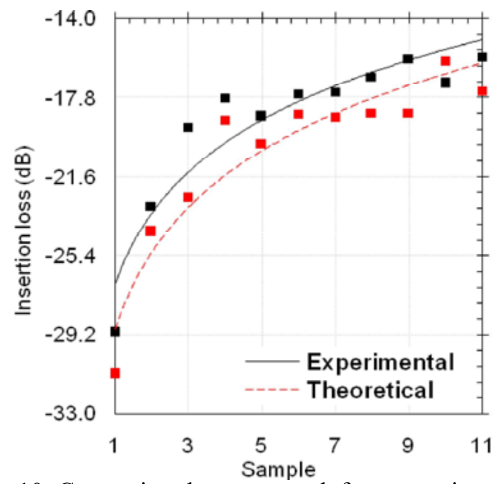

Fig. 10: Comparison between result from experimental and theory measured from green filter signal injected by red LED with 665 nm wavelength

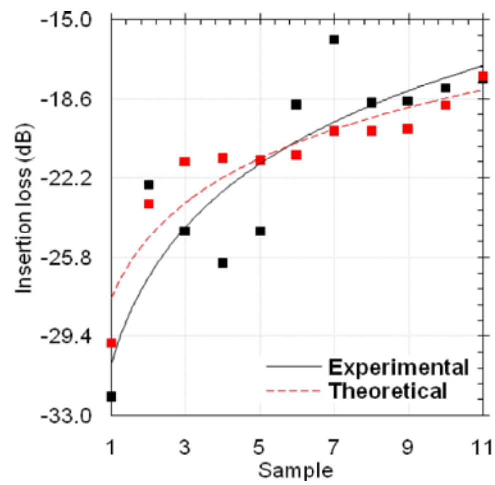

Fig. 11: Comparison between result from experimental and theory measured from blue filter signal injected by red LED with 665 nm wavelength

the transmission where the power output (efficiency) decreases almost 32 dB and its losses is the highest among all samples (see Figure 10). Same goes for blue filters where the red LED transmission is blocked for the most part of it (Figure 11). The darker the color films (green and blue) the smaller the transmission for different wavelength source, in this case, red LED. Lighter color film allows some red LED transmission.

Compare with red filters, green and blue filters block most of the red LED transmission since it is clear that only red wavelength (λ = 665 nm) will be allowed to get through the film. The film filters any other wavelength transmission that is not within the range. This concept is used as the primary idea for designing the demultiplexer.

CONCLUSION

In conclusion, before the concept of WDM is applied, single channel or single wavelength is used for POF transmission and this leads to bandwidth limitation [18, 19]. WDM system solves this problem by increasing the bandwidth of POF system. The concept of WDM shows performance that has become the alternative in short distance communication. A technique has been used for fabricating the optical splitter based on POFs technology using multimode SI-POF type with 1 mm core size. Fabrication and characterization stages have been carried out to develop the splitter [2]. A technique also has been used to develop a demultiplexer for short-haul communication based on polymer optical fiber.

This experiment shows the transmission of multiple signals with different wavelengths carried through one fiber. The concept of multiplexer and demultiplexer are the basic of this system. The system only utilizes three colors for the transmitters and also the filters for the demultiplexer which are blue (λ = 430 nm), green (λ = 570 nm) and red (λ = 665 nm). Light source from the red, green and blue transmitters are combined by using multiplexer and separated using demultiplexer.

Filter play an important role in giving a higher insertion loss from the WDM-POF system, but the quality of a number of output port is not badly destructed due to the color band gap from the filter itself, speed rate of the internet still stable and the resolution of the video image is quite good. Some parameters, such as optical output power and power losses on the devices were observed and not to mention about the effect of filter placement and the efficiency of the handmade $1 \times N$ splitter itself.

Red LED with a 665 nm wavelength has been injected to different color filters for the purpose of characterization test in order to analyze the level of power efficiency of the demultiplexer. Analysis shows that efficiency maintains for filter of the same wavelength as the transmitter while other range of wavelengths will mostly be filtered out or blocked. This main idea is fully utilized for the designing of demultiplexer for short-haul applications. Final analysis shows that efficiency of the filter can reach up to 70%. Improvement of performance can be made through practice. Although the setup system exhibits very high attenuation of the transmission, this concept of handmade optical splitter and demultiplexer has been tested for sending data for video, audio and Ethernet and the output shows successful performance.

Hence, the obtained result reveals that WDM-POF has great potential to be employed as economical wavelength divisions multiplexer because it is able to couple different wavelengths with main advantages that are low optical loss and low cost. An intensive study suggested in order improving the homogeneity of this prototype. In fact, fusion technique afflicted with some disadvantages has no consistency of producing splitter as it was almost not possible to fabricate POF splitter with good performance consistently. This WDM-POF technology can be improved gradually through experience and practice. This device is highly recommended for WDM-POF system as it is not as costly as other commercial POF splitter. Furthermore, the fabrication and installation process is simple, easy and suitable to be used for short-haul communication application.

ACKNOWLEDGMENT

This research has been conducted in Computer and Network Security Laboratory, Universiti Kebangsaan Malaysia (UKM). This project is supported by Ministry of Science, technology and Environment, Government of Malaysia, 01-01-02-SF0493 and Research University Grant fund UKM-GUP-TMK-07-02-108. All of the handmade fabrication method of POF splitter, $1 \times N$ handmade™-POF splitter and also the low cost WDM-POF network solution were protected by patent numbered PI2010700001.

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