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# Optimum Efficiency Analysis of Ecofriendly WDM-POF Optical Coupler

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## Abstract

This chapter was presented to promote the development of Wavelength Division Multiplexing, WDM networking system based on Polymer Optical Fiber (POF).  $1 \times 3$  POF coupler has been fully utilized to couple the WDM optical signals. An optimum efficiency analysis and mathematical modeling has been conducted to produce an effective device to be integrated into WDM-POF system. But despite its high speed data transmission feature, optical fiber technology remains an expensive option in optical network, although the installation costs associated with fiber through the transmission network can be minimized through the fabrication of  $1 \times 3$  POF coupler. The objective of this chapter is identifying the differences in factors affecting the output power of the POF  $1 \times 3$  coupling. It is then able to develop an efficient WDM-POF network system with high output power at a minimal cost. Several measurements using a power meter record performance and analysis device losses and power outputs. The demultiplexer efficiency is approximately 70%. Demultiplexer fabrication is easy with color and epoxy filters, although for some parts it requires careful attention. The output shows that Ecofriendly WDM-POF Optical Coupler can be used as one of the low-cost media for home networking and automotive applications.

**Keywords:** PMMA, optical fiber, POF, WDM, network

## 1. Introduction

The research in this chapter was carried out to optimize the efficiency of components and the entire system of Wavelength Division Multiplexing, WDM networking system based on Polymer Optical Fiber (POF). To achieve this purpose, a deeper analysis was performed on  $1 \times 3$  POF coupler using fusion techniques in order to obtain and observe a number of parameters which directly affect the value of coupler's efficiency.

POF has many advantages compared to silica fiber and copper wires for short-distance applications, such as low cost, easy installation and connection, the integration of low cost LED and so on. These advantages lead to a high demand on data transmission in various applications, especially regarding home-networking and In-Vehicle Infotainment, or IVI's system on automotive field.

POF was initially used in automotive application for the first time in 1998 by Daimler-Chrysler. The development of optical data path is known as Domestic Digital Bus (D2B). Sensing is just one application area in automotive where photonics is used [1]. Typically, transport data path protocol so-called Media Oriented System Transport (MOST) with a speed of 24.8 Mbit/sec is used in many cars. However, this transmission data with Time Division Multiplexing (TDM)'s based network (as shown in **Figure 1**) has its own disadvantages where in the event of one or more malfunction lines (in the ring topology) will affect other line or more in MOST system.

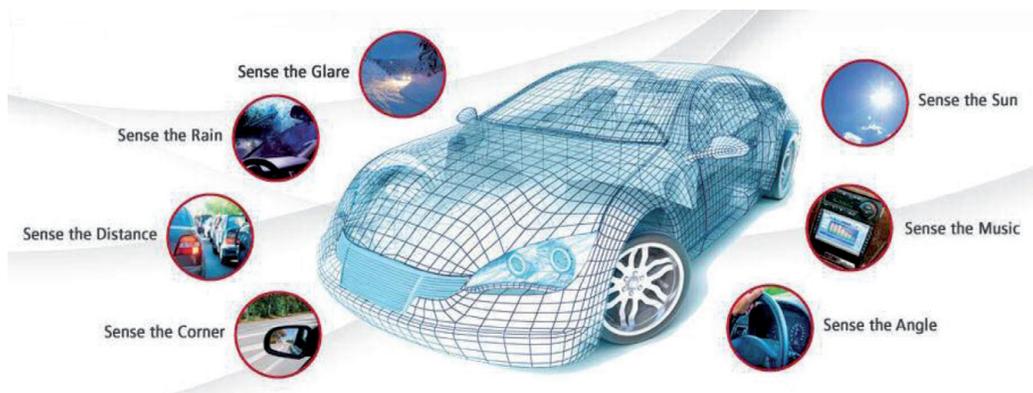
In this analysis we aim to provide a better solution to a problem in the topology of ring bandwidth that many foreign carmakers use for the infotainment system of their network.

Laser can be very hazardous as best transmitting medium that can be used alongside GOF until the leakage taken place from the GOF body structure. A fiber-released extremely high intensity light ray can potentially burn a human retinas and lead to a permanent blind. It was hard to imagine if this silica-based technology was put in place inside the vehicle where consumers used this data transmission services directly.

In the meantime, the combination of POF, which is very suitable for a light-emitting diode (LED) system, can be seen as the best solution to offer a more secure data communication network, not to mention the lowest cost we can get for initial and production costs. For applications such as machine or peripheral connections, control and monitoring, board interconnections and even domestic hi-fi systems, POF links are becoming increasingly popular. Unlike GOF, POF remains versatile with a large core diameter and low numerical aperture, resulting in a high capacity that they can bring along the fiber.

The 'ecofriendly' area involves a rapidly changing group of methods and materials, ranging from energy generation techniques to non-toxic cleaning products. The general perception is that in recent decades the IT-revolution is bringing innovation and improvements to daily life of a similar scale. In these early stages, it is difficult to predict what may potentially constitute 'ecofriendly' [2].

In the current world, IT-societies face an increasingly serious challenge: on the one hand, the multimedia-rich data transmitted travels at amazing speed, and on the other the total energy consumption of communication and networking devices and the resulting global CO<sub>2</sub> emission are rising at an enormous rate. It is reported that currently, 3% of the world's energy is used by ICT, a system that generates roughly 2% of the world's CO<sub>2</sub> emissions, equal to worldwide CO<sub>2</sub> emissions by aircraft or a fifth of the world's CO<sub>2</sub> emissions by vehicle [3].



**Figure 1.** Sensor application using photonics in automotive area (source: hamamatsu.com).

According to Ericsson Media Relations' recent research survey, cost of energy account for roughly half the operating costs of a mobile operator. Telecommunications technologies may therefore have a clear, tangible impact on reducing greenhouse gas emissions, power consumption, and effectively recycling infrastructure waste [4].

Therefore, finding solutions for optical communication's system that can greatly improve energy and resource efficiency not only helps the global environment, but also makes economic sense for telecom operators promoting viable and profitable business. Within the context for 'ecofriendly' a range of paradigm shifting technical solutions can be anticipated, including but not limited to energy-efficient network architecture & protocols, energy-efficient wireless transmission technologies (e.g. reduced transmission capacity & radiation), cross-layer synchronization strategies, and opportunistic spectrum exchange without creating dangerous inter-radiation [4].

The Ecofriendly WDM-POF is provided on the basis of a network system consisting from POF. Ecofriendly WDM-POF is developed using a method that is environmentally friendly to divide and recombine a range of wavelengths. The Ethernet connection, DVD player and CCTV system was extensively used in three different wavelengths from ecologically friendly LED transmission systems. Red LED that is able to download and upload information over a 650 nm wavelength via Ethernet cable and green LED sends a video signal at a wavelength of 520 nm for DVD player while 470 nm LED will distribute the captured video using CCTV system. The Ecofriendly WDM-POF system will select a specific signal and produce it, if required. Special filter has been placed between the coupler and the receiving point. System and network performance are observed. In this chapter the product, production process, device and implementation strategy is focused on an environmentally sustainable solution for reducing energy usage and waste without impacting overall performance. The first documented approach in this paper is our Ecofriendly WDM-POF network implementation.

## **2. The advantages of LED lights for the environment**

Taking care of the environment is a duty that everyone should feel responsible for. Most of us already know of environmentally friendly practices such as recycling to minimize pollution and reduce our carbon footprint. Most citizens, though, do not learn of new and upcoming technology that we can use to help reduce carbon emissions. Light-emitting diode (LED) lighting is a good example of this, which brings some environmental benefits. LED is a light source with a semiconductor that emits light when the current passes through it. Electrons, recombine with electron holes in the semiconductor, releasing energy in photon form. The color of the light (corresponding to the photons' energy) is determined by the energy that electrons need to reach the semiconductor's band gap. White light is generated on the semiconductor device using several semiconductors or a film of light-emitting phosphorus.

LED lighting is up to 80% more effective than conventional lighting including fluorescent or incandescent lamps. 95% of energy is turned to light in LEDs and only 5% is lost as heat. This is contrasted to fluorescent lights that turn 95% of energy to heat and only 5% to light LED lights can have much less power than conventional lighting; a traditional 84 watt fluorescent can be replaced with a 36 watt LED that offers the same amount of illumination. Lower energy consumption reduces demand from power plants and lowers emissions of greenhouse gases.

LED lights do not contain toxic materials. Many workplaces still use fluorescent strip lamps containing harmful chemicals like mercury. It contaminates the

atmosphere when disposed of in waste pits. Disposal needs to be managed via a certified waste carrier so that switching to LED reduces costs and time to enforcement—which helps protect the environment against further toxic waste.

LEDs have a better light transmission efficiency and focus light in one direction, compared to other types of light that waste energy in all directions, often illuminate areas where no light is needed (e.g. the ceiling). It needs fewer LED lights to achieve the same level of luminosity as fluorescent and incandescent lamps. Less lighting can reduce energy usage and thus benefit the environment.

A longer life span means lower production of carbon LED lights last up to six times longer than other lamp types, eliminating the regular maintenance demand. This leads to the use of fewer lamps and therefore fewer resources for production, processing and transport processes [5].

### 3. A novel fused coupler

A novel fused coupler and the special filter—an advanced design of WDM-POF network implementation, are two key elements of the WDM-POF system in this chapter. We suggest an innovative fusion technology that is simple and inexpensive to use with Bunsen burner and metal tube to produce indirect heating processes with low structural defects, low excess losses and a good splitting ratio in the production of POF-based coupler.

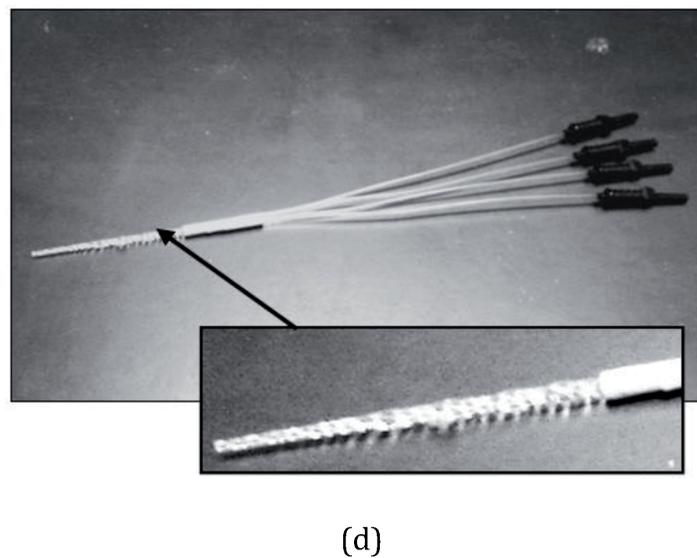
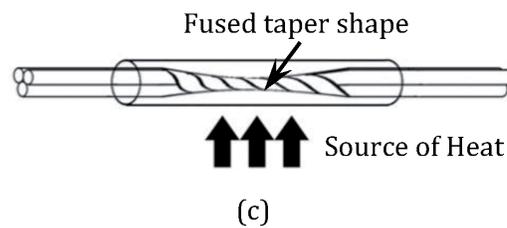
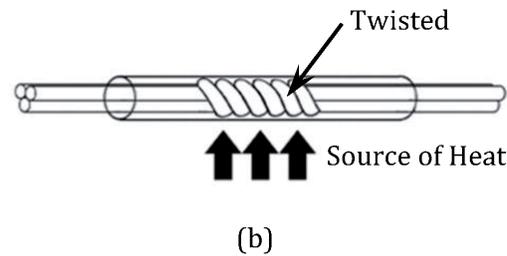
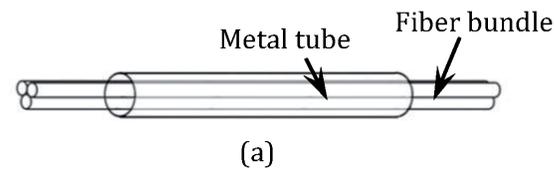
The term '*fusion*' typically describes the operation or method of liquefying and melting by applying heat. The fabrication approach varies notably from traditional biconical technique. Seeing that the fabrication of polymer fiber is not subject to very high temperatures, POF's are liquefied with yellow flame Bunsen burners (1000°C) indirect heat treatment rather than with an oxyhydrogen burner (heating temperatures  $T = 2660^\circ\text{C}$ ) applied conventionally to the production of GOF-based couplers [6, 7].

Metal tube is used to protect the POF structure from direct heater during the fiber fusion process of indirect heating. POFs which are vulnerable to severe damage in their core cause heating a bundle of POFs directly to the burner flame.

In the new method of fusion, as shown in **Figure 2**, fusion length  $L_f$ , twist  $T$  number, fusion time  $t_f$ , pulling length  $L_p$  and other parameters are controllable parameters. The multimode step indexed POF with a core diameter of 1 mm of *Polymethylmethacrylate* (PMMA) was used as material for second-generation couplers. PMMA is one of the optical components most frequently used. The inherent absorption loss is mainly due to the stretching vibration of carbon hydrogen in PMMA core [7]. *Polyvinylchloride* (PVC) is another component used to cover the POF ports as a jacket.

The high cost of industrial coupler was posed as a crucial obstacle for the creation of wavelength division multiplexing (WDM), according to Kagami's 2006 Toyota R&D analysis report [8]. The fabrication process of expensive BFT device is considered a high production cost factor. The diameter of the fused taper area is extremely small by traditional BFT fabrication process, in which strain is accumulated and result in poor structural survivability.

Following the adaptation of the fused tapering technique for traditional multimode fiber, we successfully established the fabrication process for fused taper couplers with  $1 \times N$  POF. The handmade  $1 \times N$  coupler is an optical device that ends with  $N$  number of POF output terminals, while the other ends with one POF port. Like other traditional couplers, bidirectional operation is also possible, working from the  $N$  ports to 1 port (for coupling signal purposes) or vice versa (for splitting signals purposes). For instance, the optical  $1 \times 4$  coupler formed by combining four *Polymethylmethacrylate* (PMMA) POF [9]. The output



**Figure 2.** Fabrication process of fused tapered coupler: (a) configuration, (b) twisting and (c) fusion and (d) prototype of the  $1 \times 4$  handmade coupler fabricated by fused tapering technique.

POF is designed and fabricated to fuse the tapered shape in some detail. **Figure 2** shows the process  $1 \times 4$  POF coupler.

Standard multimode SI-POF is used with its core diameter of  $980 \mu\text{m}$ , cladding thickness of  $10 \mu\text{m}$  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 [10].

#### 4. Ecofriendly WDM-POF

For applications like home networking, car industry, board interconnection, also residential hi-fi networks POF connectivity is increasingly prevalent. POF is versatile,

as compared to GOF, with a wide core and a lower numerical aperture [1] and it can carry a high fiber capacity. The optical coupler plays an important role among passive components for POF technologies, which is enabled by the versatility of a full product range. A POF coupler has been developed with various techniques. Thermal deformation, refining and merging, hand polished, scraping, etching, molding, reflecting body and biconic body are all common techniques have been applied in recent years [11].

In order to increase bandwidth to wavelength division multiplexing (WDM) in beginning topology, our current POF communication system enables data to be conveyed over more than one single wavelength. WDM is a system in which several signals are transmitted together in a multiplexed signal as separate wavelengths of light. As the **Figure 3** shows, WDM Multiplexer is the first active WDM-POF network designed to merge optical signals onto a single fiber from multiple single-wave end devices. If one of the signals (audio, video, Ethernet, *etc.*) breaks down, the network will not impact others if the primary transmission line is ineffective.

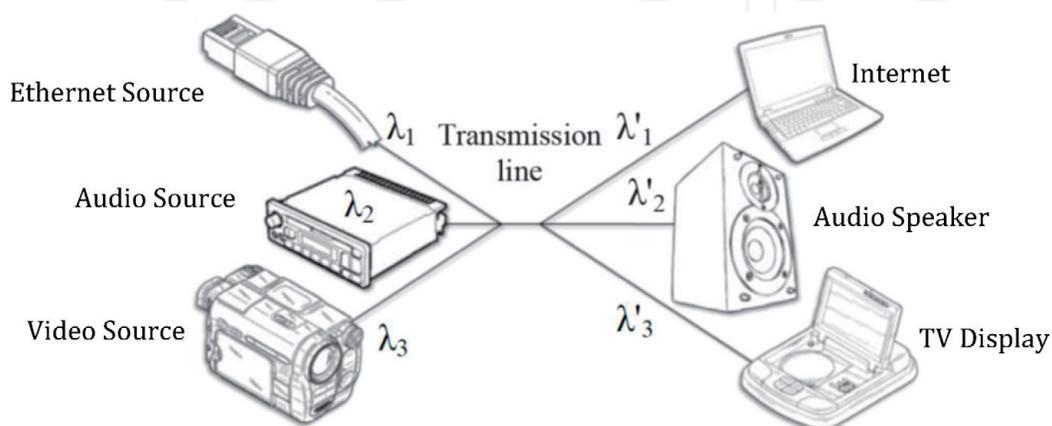
In WDM-POF system, many transmitters with different lights color to carry single information. For example, red light with 665 nm wavelength modulated with Ethernet signal while blue ( $\lambda_1$ ), green ( $\lambda_2$ ) and yellow ( $\lambda_3$ ) lights carry image information, RF and TV signal, respectively [7]. The Multiplexer (MUX) must couple the light and separate it by demultiplexer (DEMUX).

Due to its simple device approach for extending, WDM has extended over the past 20 years, the average bit rate of transmission into GOF-long-range systems: introducing another source of specific transmission wavelengths in combination with the MUX/DEMUX component directly increases the utilizable speed. The wavelengths for the WDM from 400 to 700 nm, as shown in **Figure 4**, are used because of the attenuation in POF.

By practice, the same device can also conduct the reverse of the same WDM methods, in which several wavelength information streams are split up into multiple single wavelength data flows. The reverse is termed de-multiplexing. Conceptually, as a single coupled signal, POF coupler has the same purpose, functions to couple or combine multiple optical data signals. Hence the design of POF couple-based WDM is feasible. A low-cost solution will be presented for POF-WDM system implementation.

Multiplexing the wavelength division has several advantages over the other approaches proposed to enhance a link's capacity:

1. Deals with appliances of low speed [12]
2. Works for existing single mode cable [12]



**Figure 3.** Proposed design for WDM-POF network in star topology able to transmit three different signals: Ethernet ( $\lambda_1$ ), audio system ( $\lambda_2$ ) and CCTV ( $\lambda_3$ ) at the same time through one fiber.

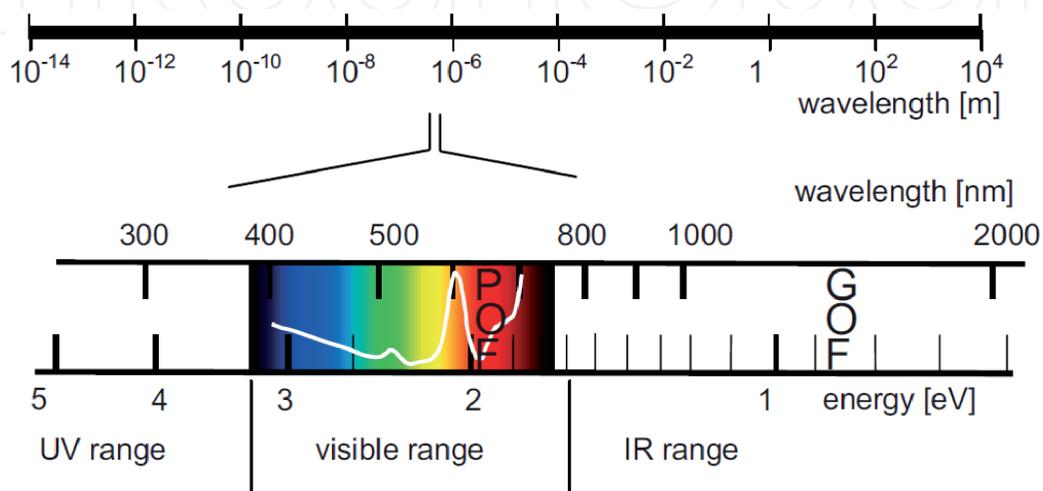
3. *Is transparent*: does not rely on the protocol to be transmitted [2, 12]
4. If consumers need it, it is simple for network providers to add additional capacity in a few days. It offers WDM businesses an economic benefit. Part of a fiber can be leased to a consumer who gets quick access to networks without link to others. On the other side, the telecom company still has a separate part of the network for other clients [12, 13]
5. *Is scalable*: a new channel can easily be added to existing channels instead of moving to a new technology. Companies only have to pay for the bandwidth they actually need [12, 14].

In the form of an effective transmission medium, a novel fused POF coupler is fabricated to split and recombine a range of wavelengths that represent different signals. Three separate wavelengths are used for the propagation of three specific networks sources: network link, infotainment network and video transmission system. With a 665 nm wavelength red LED capable of downloading and uploading information via Ethernet cable, while a 520 nm green LED could transmit a video image created from DVD player, and a 470 nm blue LED is an video transmission network for CCTV system within the building.

The coupler and the receiver ends will be filtered with special interference so that the whole WDM system can select a single signal as needed. These solutions for interference filters are known for the visible spectrum and can be used not only in the infrared.

To removed unnecessary signals and select the wavelength of the system as desired for the filter design. Other parameters will be observed, e.g., the effect of the filter position and the efficiency of the WDM-POF system, including optical output power, power loss, optical noise ratio and sensor crosstalk.

The color filters are made up of two types of plastic, almost the same as POF material About 65% of the line is made of polycarbonate plastic co-extruded. The remainder of the line is deep dyed polyester [15, 16]. By subtracting those color wavelengths, filters generate light. A red filter, therefore, absorbs blue and green so that only the red wavelengths can pass. The method is non-additive subtractive, so a full spectrum must be emitted by the light source. The swatch book provides detailed information about each filter's spectral energy curve. The curve defines the color wavelengths that each filter transmits. Supergel 342, for instance, transmits



**Figure 4.** Attenuation behavior of a POF in the area of the visible spectrum. (source: Gupta [2]).

about 40% of the blue and violet energy in the spectrum and 70% of the orange and red energy. In the yellow and green range, it absorbs all energy [15, 16].

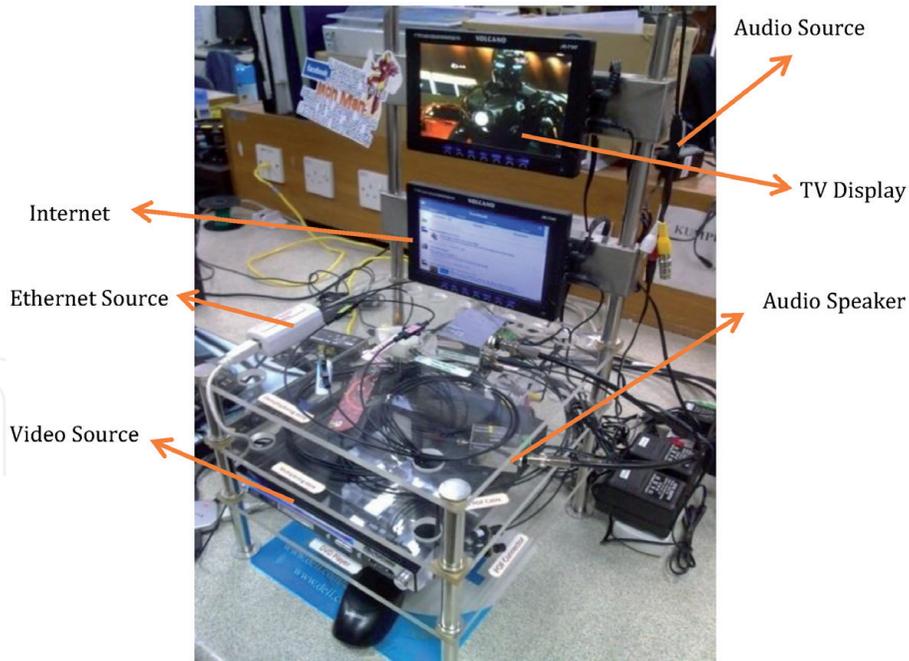
In this analysis, several colors of red, blue and green filters are evaluated and selected for optimum experiment performance. By reading the curves of the spectral energy distribution (SED), the way the filter colors are selected. In the infrared range above 700 nm, filters that transmit high levels at 700 nm can also transmit high levels. The visible red light, for example, has a wavelength of around 665 nm. Red's filter color is chosen by which film offers the highest percentage of transmission and minimal loss. The same goes with choosing green and blue color filters. Eleven different colors were chosen for each red, green and blue filter in this experiment. The goal is to observe which one of the options is better, showing maximum transmission and minimal losses.

The demultiplexer is produced by attaching the multimode POF at one end of the fiber with a connector. A small piece of color films are cut out and prepared for installation on the socket. The glue used in this fabrication is epoxy resin, which consists of resin and hardener as mentioned before. When both the resin and the hardener are mixed a strong adhesive is produced that holds the components to be rigidly attached together. Using resin, the small piece of color film is then applied to the edge of the socket after polishing the end of the fiber connected to the socket. Instead, after applying the film on the resin to be applied to the socket, the part is then held tightly together for about 2 minutes to ensure that there is no gap between them and that a strong bond produced. This part has to be done carefully since it is important to avoid the epoxy resin coating the surface of the fiber as much as possible so that any power losses can be avoided when measuring. Nevertheless, since the socket edge is quite thin and sharp, it is not possible to avoid the spread of the epoxy resin to the fiber surface 100%.

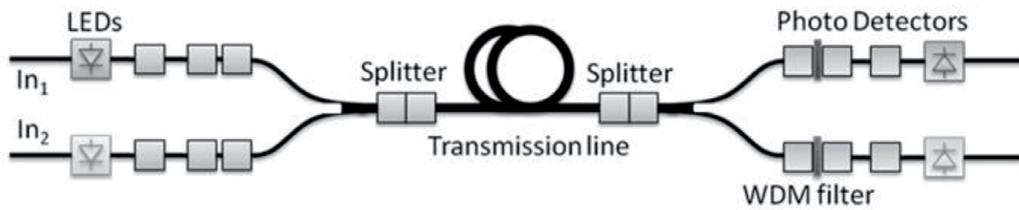
After the adhesive is sealed, the POF is placed in a secure location so that the adhesive is not contaminated and is left to dry up. It usually takes nearly a day to completely set the resin. Upon curing of the epoxy, the film that attached to the end of the connector is cut in circle according to the shape of the socket's end. After the production process is carried out, the injection loss and energy consumption for each POF is measured and recorded. The power meter is the device used for reading. Most samples were produced in this test to get the best results and see which of the color filters showing the most transmission and providing the least losses. The POF's length is set at 3 meters long.

As shown in **Figure 5**, The test bed has been set up for  $1 \times 3$  WDM-POF networks to calculate the performance of the handmade coupler-filter combination for the entire system. Red, green and blue LED transmitters inject each of the red filters and readings are taken accordingly. The same is done for the filters blue and red. It is found that measurements should be visible on the meter when calculation is performed with the power meter, otherwise the samples cannot be used to evaluate the characterization. Next, the POF with film must be attached to another short fiber using connector to calculate and obtain the readings. Then the other end of the short fiber to the power meter socket will be connected. The power meter comparison for red LED is set to -10.7 dBm, as is the case for blue and green LED. The other end of the POF (that without film) is attached to the transmitter before the readings can be taken. The LED is then inserted by the fiber and the injection loss rate and energy consumption is measured for each sample accordingly.

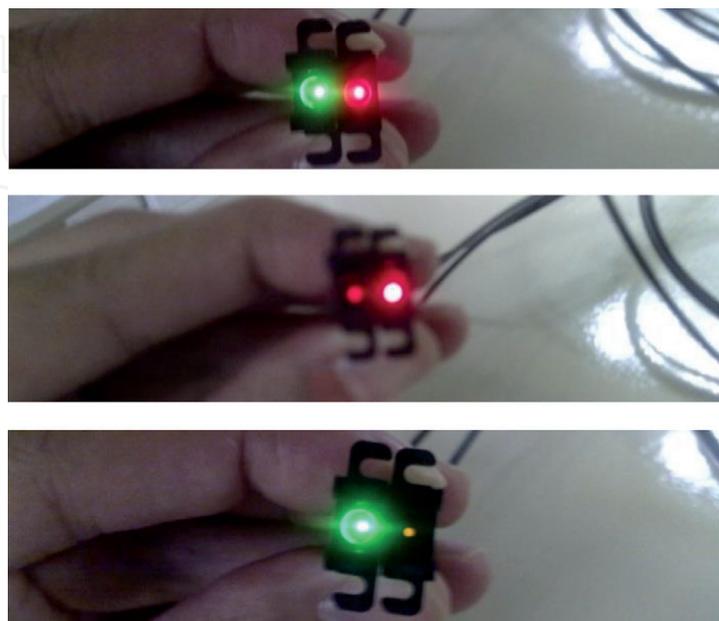
The transmitters carry a certain amount of information or data when each transmitter carries signals of different wavelengths defined by the LED. When filtering any other wavelength, the specially tailored color films are used. This requires only a photon to travel through the image and so transmits the data sent to the receiver. In **Figure 6** it is simple to understand filtering and signal coupling operation and **Figure 7** for the experiment of  $1 \times 2$  POF-WDM system through a



**Figure 5.**  
Test bed for 3-channels WDM-POF system to transmit three different (ethernet, CCTV and DVD player) signals.



**Figure 6.**  
WDM-POF system design using  $1 \times 2$  handmade coupler and filters.



**Figure 7.**  
 $1 \times 2$  demultiplexer is used to split the signal to different frequency (color). The multiplexed signal is separated according to the application (e.g. data & video signal) respectively.

combination of red and green filter. **Figure 7** explained the activity when one of the source deactivated, the crosstalk between both fibers occurred affect the efficiency both transmission, red and green LED.

### 5. Results

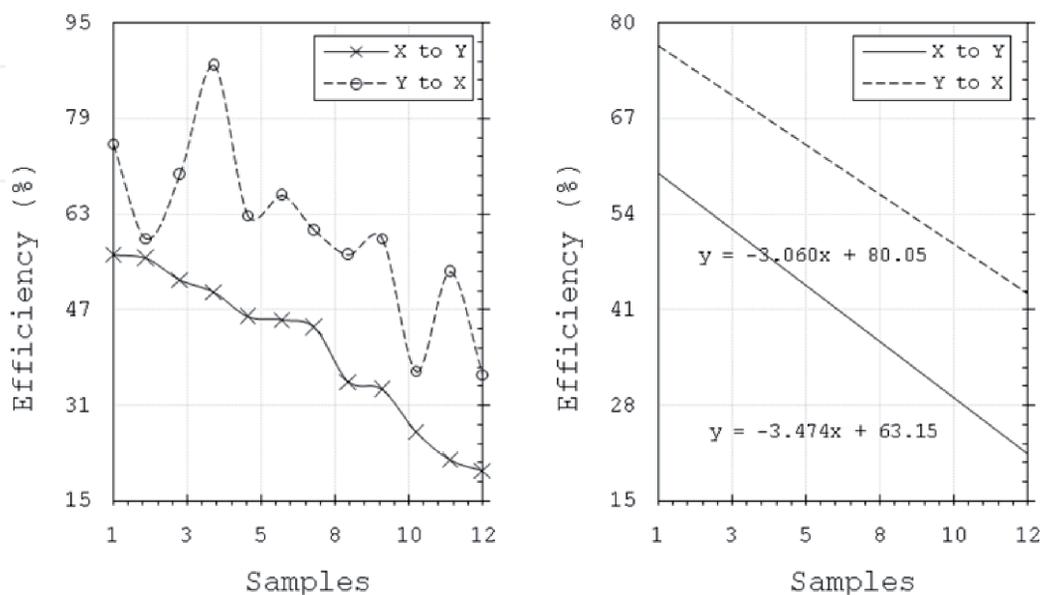
The  $1 \times 3$  coupler design plays an important role in combining three optical signals by the fused taper twisted component (see **Figure 2**) in which all three POFs fused and combined as so-called single POF. The fused tapered POFs should be manufactured and all bundled fibers fully fused. Otherwise, it would likely not be possible to pass on the signal led to a failure when combining the single signal numbers. [10, 17, 18].

Either during manufacturing processes or during characterization test stages the error may occur. Controlled heat anomalies during the fusion process become one of the major problems because it makes the core structure of POF more responsive to the heating process. When impaired, it becomes impossible or even difficult to let a light pass through the core To avoid micro-scaled cracks on core it's important to stop twisting and tightening POF. For that cause, if indirect heating is done through fiber, we use the metal tube to reduce the damage to the system.

The excessive deformation in the fused fiber bundle was reduced by indirect heating. It makes the fabrication of the fused-tapered fiber simpler and more effective. In particular, the constant processing capability ensures that fabrication time and productivity is minimized. This approach would significantly reduce the cost of making the coupler [6].

Bidirectional optical loss calculation was performed to investigate exactly the value of the energy intensity for each fused bundle POF output, whereby the red LED was inserted on both sides of the Fused Bundle independently through each POF input.

For both directions (left and right), the average optical loss for the fused POF bundle was measured and analytically compared. The analysis can be seen as shown in the **Figure 8**.



**Figure 8.** Efficiency for fused bundle fibers from best to worst sample in both directions and the linear function of the  $1 \times N$ .

The finding above indicates that the optical loss in different directions for the fused bundle was not comparable. The fused POF bundle has an evaluation in the right direction of reduced optical loss. Therefore, it has been chosen as a POF coupler from the right side of the POF bundle because it can integrate multiple optical signals and produce an optical signal with decreased attenuation and greater efficiency than the other. Nevertheless, optical losses for the fused bundle are caused primarily by physical modification of the POF, especially of the Fused Taper.

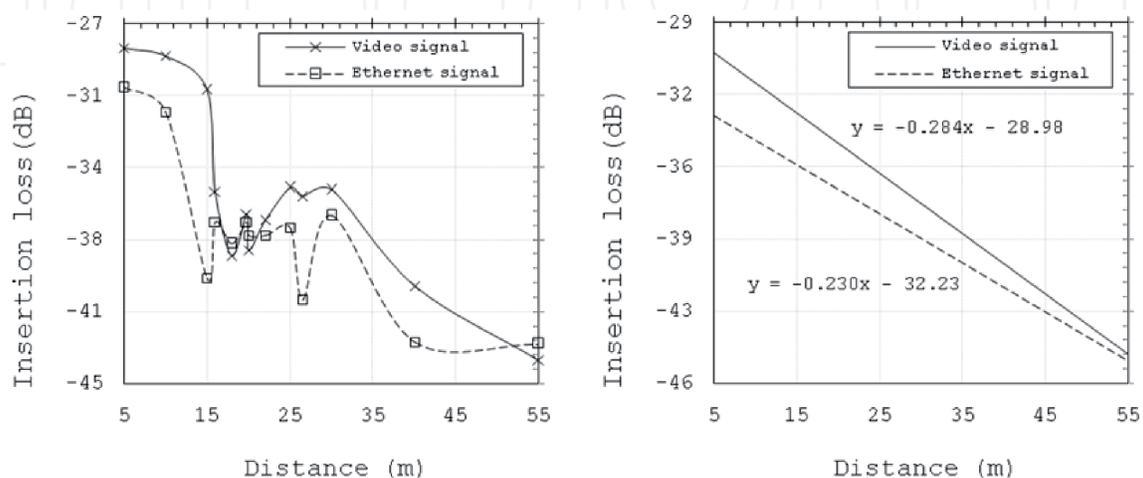
The improvement in the initial POF diameter resulted in a significant change in optical properties with the numerical aperture and maximum acceptance angle. All these improvements are based on the principle of spoil light propagation; there are more refracted beams of light and they are scattered out beyond the atmosphere [19].

In terms of market value, correlation of handmade and commercial couplers was observed. The total cost of a  $1 \times 4$  handmade POF coupler is less than 3 USD but not less than 250 USD for a commercial coupler available on the market. Currently, many devices are in use to couple a signal, such as a low-cost plastic optical fiber coupler from  $1 \times 2$  acrylic-based [11]. Nevertheless, since the manufacturing processes were very difficult and costly, the handmade POF coupler can be considered a potential solution to this issue.

This research categorizes the optical loss as extrinsic loss because of the physical change of POF, LED projection to POF and the core-to-core connection end [3, 16]. The physical change in POFs caused by the fabrication process is observed to decrease by POFs in diameter to 1 mm and POFs have eventually fused into tapered form. Optical degradation may be caused by the direct LED projection to the POF surface when analysis takes place. In addition, the connection between the fused tapered POF and the POF cable can cause optical loss [20].

The other factor which is critical in transmitting two separate wavelength signals on transmitters is the filter between the coupler and the receiver point. Two separate LEDs were used in this research, related to video signals (CCTV and DVD player); blue LEDs (470 nm) transmit DVD player images through fiber and green LEDs (570 nm) for CCTV, so that the high-quality video signals can be viewed on a monitor screen.

The filter itself has also been tested for its effectiveness. The correlation comes from both green and red LED output during the propagation of a different signal to be divided by a POF connector and the optical energy meter was placed directly before the port of transmission of the transmitter, as shown in **Figure 9**.



**Figure 9.** (a) Power loss comparison between blue and green LED and (b) in linear function, green LED represent the video quality of the CCTV while blue LED represent the DVD player image quality.

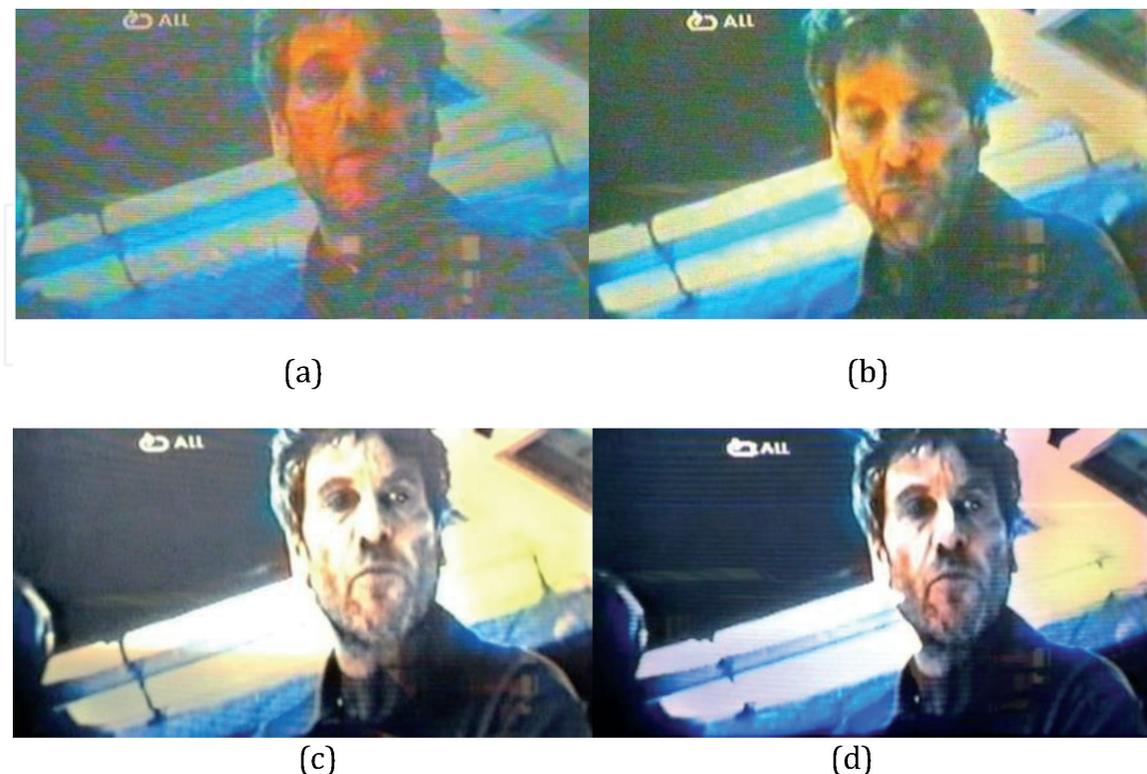
The blue LED shows a higher loss as compared to the red LED in **Figure 9**. DVD images are highly sensitive to varying distances, the greater the distortion, the more the distortion resulted in the screen, the less performance of fiber data transfer.

The variations between the two signal rates were 3 dB and the performance of the video transmission system on the low-cost WDM-POF platform was increased. **Figure 10** demonstrates the video quality using the WDM-POF process.

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 11**, also with it logarithm and linear function of the data.

From the result, the insertion loss measured by the power meter is showing small loss rates when a film is attached to its socket when all the components are configured and red LED is injected. This also applies when injecting blue and green LEDs. We are taking red film A (filer labeled #4690) as the main filter for characterizing the same film using different sources and inject it with all three LEDs, red, green and blue. The results show a small increase in losses, compared to initial losses before the film is attached to the fiber, in the red-injected filter with a Red-outlet-transmitter. When the film is attached to the fiber it is the same for the power output. As **Figure 12** shows, an injection loss of 1 dB was reported right after the resin was inserted into the connector.

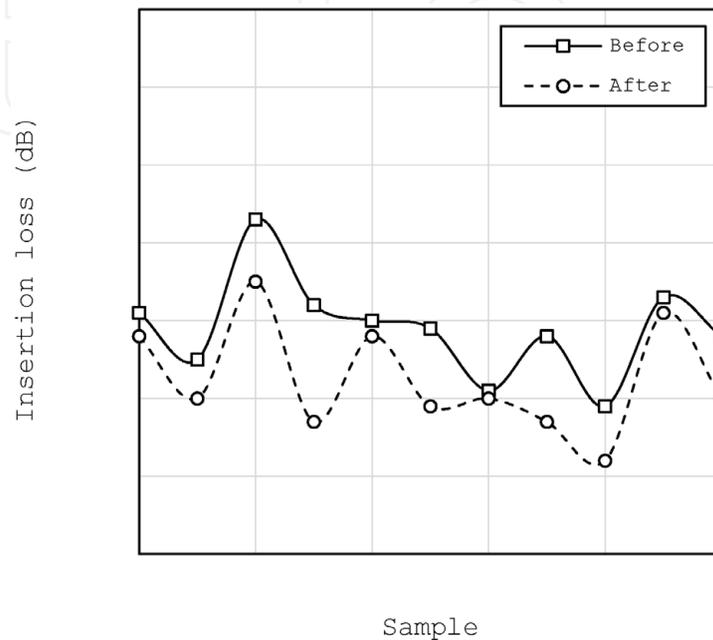
An increase of  $5.3 \mu\text{w}$  of power output is observed. This is expected since the used of epoxy resin and the transmission limitation of the film gives the obtained data. However, different results are observed when blue and green LEDs are injected to the red filter. Small decrease of losses 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



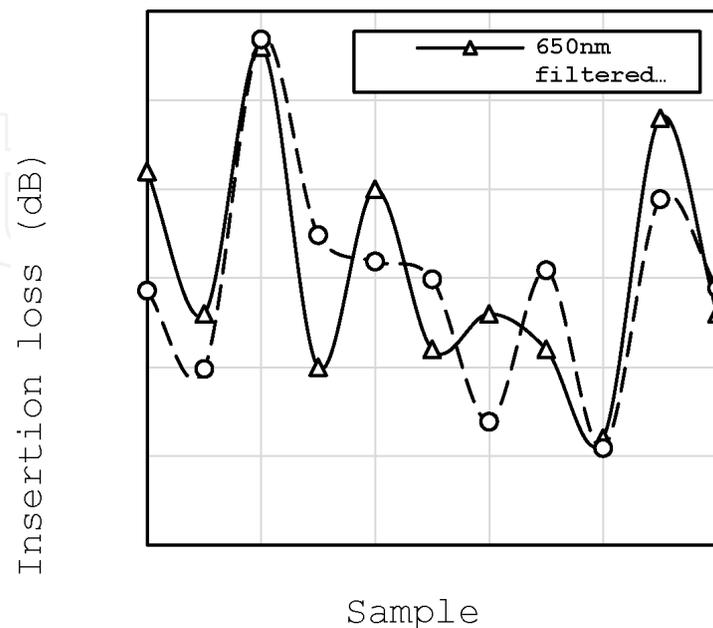
**Figure 10.** Video quality of WDM-POF system of (a) 50 m, (b) 30 m, (c) 20 m and (d) 10 m of optical transmission line.

the transmission percentage of the particular red film also shade or covers some percentages of green and blue wavelength region.

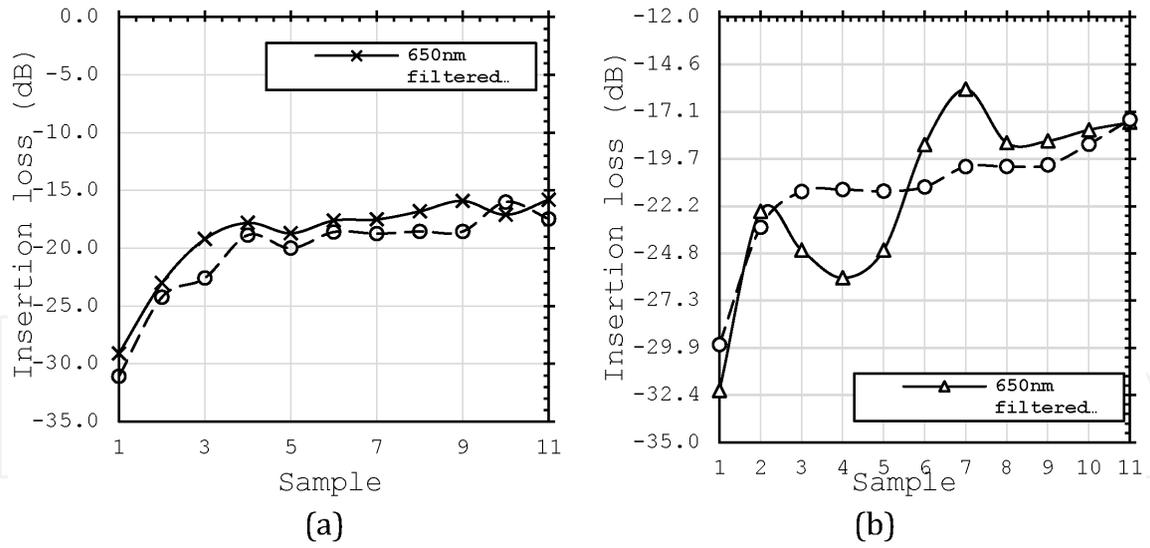
For characterization of same source injected through different filters, red LED is taken as the primary source. From the result, it is observed that sample 7 shows least losses and decrease of efficiency, while sample 3 shows the opposite. Since sample 3 being the one among the darkest film color meaning that only small or narrow transmission percentage of red LED or transmitter is allowed



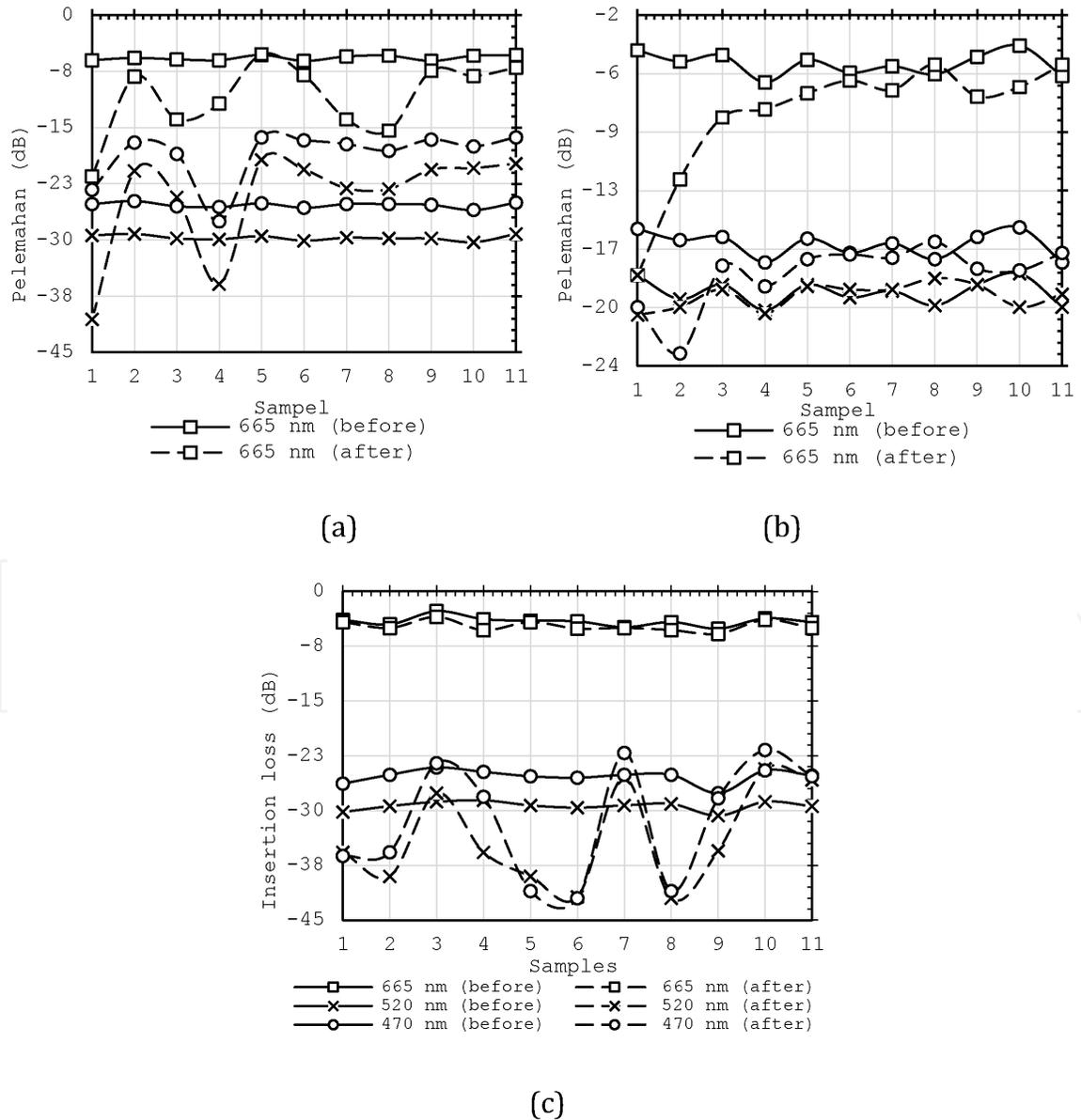
**Figure 11.** Effect on resin for demultiplexer filters approximately 1 dB insertion loss occurred on the measurement between before and after connector glued by epoxy.



**Figure 12.** Comparison between result from experimental and theory measured from red filter signal injected by red LED with 665 nm wavelength.



**Figure 13.** Comparison between result from experimental and theory measured from (a) green and (b) blue filter signal injected by red LED with 665 nm wavelength.



**Figure 14.** Effect on combination of working function between optical sources and filters, whereas all three filters (red, green and blue) were injected by light source (a)  $\lambda_1 = 470 \text{ nm}$ , (b)  $\lambda_2 = 520 \text{ nm}$  and (c)  $\lambda_3 = 665 \text{ nm}$ .

to get through. The utilization of epoxy resin may also contribute to the deficiency of power output (efficiency) since the losses increase a lot for sample 3 apart from the reason it being a dark film with small percentage of transmission. On the other hand, the effect of efficiency of sample 7 is small because the larger percentage of transmission for red LED. According to the ROSCO SED Swatch Report. The predicted outcome can now be correlated with the expected signal from the color filter hypothesis, from the sample setup and the actual signal. The figure shows that on average less than 1 dB is the difference between experiments and theory.

The green and blue films technically are filtered out or block red LEDs due to a different wavelength spectrum of red transmitters that are released by various color films of different wavelengths, such as green and blue films. The red LED data analysis shown through green filters reveals that sample 1 blocks most transmission in areas with approximately 35 dB lower efficiency and the lowest loss among all samples (see **Figure 13a**). The same applies to blue filters, which mostly block the red LED transmission (see **Figure 13b**). The lighter color films (green and blue) the smaller the output, in this case red LED, with various wavelength sources. The lightweight color film permits the transmitting of red LED.

Contrast the red filters with green filters and the blue ones, block some red LEDs as it is clear that the film can only be crossed by red wavelengths ( $\tau = 665 \text{ nm}$ ). The film blocks any other propagation not within the spectrum of the wavelength. This principle is the main idea for the demultiplexer model.

Furthermore, combination of working function between LED sources and color filter plays an important role in WDM-POF system. Some samples each attached with three different color filter (blue, green and red filter) has been injected with three different sources (blue, green and red LED) and the graph of each insertion loss has been plotted in **Figure 14** below.

See **Figure 14** above, all data have more variations directly after light hit the filter via fiber as blue filter was inserted by all three optical sources blue green and red color. Likewise, all light sources will fluctuate the data transmission capacity except the blue LED. This fluctuation was caused by the SED percentage of each filter and by the intensity of each light source. The greater light source strength was transmitted by the more fluctuating graph and the less significant of SED percentage deviation was the less fluctuating effect.

## 6. Conclusions

To summarize, the idea of a single channel or wavelength for POF is extended before the WDM definition is introduced, which results in a restriction of bandwidth. By increasing the bandwidth of the Ecofriendly WDM-POF solves this problem. The theory of WDM indicates efficiency, which in short-distance communication has become the alternative. An optical division was made using multi-mode SI-POF type with 1 mm core size based on POF technology. The coupler was developed through fabrication and characterization stages. A technology was also employed to develop a short-haul communication demultiplexer based on optical polymer fiber.

This experiment shows multiple signals received via a single fiber of different wavelengths. This model was based on the principle of multiplexer and demultiplexer. The system uses just three wavelengths: blue ( $\lambda_1 = 430 \text{ nm}$ ), green ( $\lambda_2 = 570 \text{ nm}$ ), and red ( $\lambda_3 = 665 \text{ nm}$ ) to transmit the transmission components as well as demultiplexer filters. The red, green and blue light source are mixed by multiplexer and separated by demultiplexer.

Filters play a key role in giving Ecofriendly WDM-POF device a greater insertion loss, but because of the filter's color band gap, the internet speed is always constant and the video image resolution is quite good, the performance of a range of output ports has not been badly damaged. Several parameters have been noted, such as optical output power and energy losses on the devices and not to mention the impact of filter placement and efficacy of the handmade  $1 \times N$  Ecofriendly WDM-POF coupler.

For characterizing analysis the power level of the demultiplexer has been studied in red LEDs with a 665 nm wavelength inserted into various color filters. Analysis shows that filters of the same wavelength as the transmitter retain performance when other wavelength ranges are either filtered out or blocked. This main concept is fully utilized for the designing of demultiplexer for short-haul applications. Final analysis indicates that filter efficiency can exceed 70%. Performance enhancement can be accomplished through practical means. Although the integration device exhibits very high transmitting attenuation, it has been tested for the sending of audio, DVD player and CCTV images data, using this method of handmade Ecofriendly WDM-POF coupler.

The results show that Ecofriendly WDM-POF coupler can be used as a cost-effective wavelength multiplexer, as it can combine different wavelengths with main advantages that are low optical loss and inexpensive. An extensive experiment to enhance the homogeneity of this model was proposed. Nevertheless, fusion methodology with certain drawbacks has no uniformity in fabricating Ecofriendly WDM-POF coupler, as POF coupler with good performance could hardly be manufactured reliably. With experience and practice, this Ecofriendly WDM-POF system can be enhanced. The Ecofriendly WDM-POF system is very preferred because it is not as pricey as other consumer POF coupler. In addition, the production and deployment process is simple, quick and suitable for implementation for short distance communication.

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