WAVELENGTH DIVISION MULTIPLEXING OVER PLASTIC OPTICAL FIBER TECHNOLOGY – SMALL EFFORT HUGE IMPACT

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Abstract - A low-cost solution for wavelength division multiplexing (WDM) system application through Plastic optical fiber (POF) is presented. POF splitter has been fabricated by handmade fusion technique, as an effective transmission media to split and recombine a number of different wavelengths which represents different signals. Two different wavelengths were fully utilized to transmit two different sources of systems; LAN connection Network and video transmission system. Red LED which in 650nm wavelength capable to download and upload data through Ethernet cable while green LED in 520nm wavelength can transmit a video image generated from DVD player or CCTV system. Plastic transparent filter has been placed between the splitter and receiver-end to make sure the entire WDM system can select and generate a single signal as desired. Some parameters, such as optical output power and power losses on the devices were observed, and not mentioning about the effect of filter placement and the efficiency of the handmade splitter itself. This solution is the first reported up to this time in which the LEDs are used to form WDM network to increase the data capacity over plastic optical fiber. In the end of this article, we highlighted the application of WDM-POF network and cost comparison between the commercialized splitters with ours. Our splitter has better insertion loss and uniformity as compare to existing in the market. The article has also highlighted our research strategy in maximizing the output using Multi-dimensional Assessment (MDA) approach on the research. The way of presentation is based on the MDA.

Keywords - POF, WDM, Multiplexer, splitter, fusion technique.

1. INTRODUCTION

The optical devices play an important role in optical communication system. For instance, In Malaysia the customer access network, Fiber to the Home has been deployed to provide huge bandwidth for many applications at customer premises. Two optical devices are used for example Multiplexers to combine and separate wavelengths, means while optical splitter is used to divide optical signal according to the number of output port. Most of optical devices fabrication today used thin film technique utilizing couple mode theory (CMT) which require several parameters to control and determine the specification of the devices. Couple mode theory is defined as the migration of the propagated signal to the neighbor’s fiber alternately when two fiber more fibers are positioned closely to each other which determined by wavenumber, symbol as L. The coupling parameters such as coupling gap, coupling length, waveguide size and refractive index are used to control the wavenumber and further determine the types of the fabricating device. BUT in this research, we deem to find one alternative technique that having less parameter in-control and the most important thing is the users themselves are authorized to fabricate the devices according to their requirements.

This can be happened through new introduced technique named as Low-Cost Fused Taper (LFT). Nowadays, POF become alternative transmission media replacing copper or even glass fiber for short-haul communication. POF links are becoming increasingly popular for applications such as computer or peripheral connections, control and monitoring, board interconnects and even domestic hi-fi systems. Unlike glass fiber, POF remains flexible while having a large diameter core and high numerical aperture [5], lead to high capacity they can bring along the fiber. Moreover, the fiber is easy to handle with the potential for constructing networks using simple conductor and easy installation procedures while retaining some of the advantages of optical fiber such as Electromagnetic Interference (EMI) immunity, non-conducting cable, small size and security. Another feature is the use of visible light to transmit information which is safe to human eye retina [1]. POF provides much safer solution due to use of light emitting diode (LED) as a signal blinked carrier and offers lower cost in installation instead. Moreover, LED is small, consumes less energy and can be modulated very quickly. This is because the beam from LED is diverge to different angle and thus the power cannot be accumulated as compare to the laser in which the beam is converged.
Due to wide advantages of POF over copper or even glass fiber, POF are used widely in various optical networks. Recent communication system over POF desires increasingly more bandwidth and therefore the WDM system is the solution that allows the transmission of information over more than just a single wavelength (colour) and thus greatly increases the POF’s bandwidth. WDM is a technique that multiple signals are carried together as separate wavelengths (colour) of light in a multiplexed signal. In WDM-POF system, many transmitters with different lights colour to carry single information. For example, red light with 650nm wavelength modulated with Ethernet signal while blue, green, and yellow lights carry image information, radio frequency (RF), and television signal, respectively [8]. As shown in Figure 1, 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. The reverse process is called as de-multiplexing.

High speed small world communication system has become promising when plastic optical fiber has been invented. It has vast application especially in-home networking, in vehicle infotainment ship, naval system, CCTV system and many more. POF provides numerous advantages to home builders, installers, content providers and consumers alike. With “garden hose” connectivity, POF is quick and easy to terminate, enabling it to be easily installed in the wall cavity, along baseboards, under carpet; and due to its immunity to interference, it is even next to electrical cabling, making its installation quicker, more flexible and cost-effective than CAT5/CAT6.

Hence, the development of wavelength division multiplexer based on POF splitter is possible.

Uniformity is an important parameter to upgrade the splitter to the demultiplexer.

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 [2]. 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 [3,6]. 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.

**Multi-Dimensional Assessment (MDA)**

This approach is to maximize research results by viewing from as much as possible point of views [8]. Having said that, different point of views requires different kind of people which means a number of academics from different fields can get together and produce a number of publications from one research result. Among the measures taken under this technique are listing the areas related to the research and obtaining views from experts in their respective fields. Figure 2 shows an example of different point of views derived from a single research result. MDA has widened the scope of research exploration and therefore more output will be coming from the research. This concept of the paper presentation is based on the MDA in which the six elements are highlighted.
II. EXPERIMENTAL

**Specification of Design**

The handmade 1xN POF splitter is an optical device, which ended by N number of POF ports, 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 1x4 splitter developed by the jointing of four PMMA POFs. Other specification for the design, the input POF is designed and fabricated to be fused taper-twisted shape. This shape enables coupling four individual optical pulse input. Each input and output are connected with POF connector as shown in Figure 3.

![Figure 3: The design of the handmade 1 x 4 Plastic Optical Fiber Splitter](image)

For the filter design which able to eliminate unwanted signal and select the wavelength of the system as desired as shown in Figure 4.

![Figure 4: WDM-POF system design using low-cost splitter and filters](image)

**Material**

In development process of 1xN splitter based on POF technology, multimode SI-POF type made of Polymethylmethacrylate (PMMA) 1 mm core size fully utilized in this paper, as PMMA is one of the most commonly used optical materials. Due to its intrinsic absorption loss mainly contributed by carbon–hydrogen stretching vibration in PMMA core POF [1].

III. APPROACH AND METHOD

**Fabrication**

To fabricate the final product of optical 1xN splitter, some stages has to be done, start from fiber fusion, bundle formation and finalized with cable jointing. Fabricated through fusion method by fuses and combine N number POFs (in bundle arrangement) 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 as shown in Figure 5.

![Figure 5: The modified fusion technique for fused taper-twisted splitter fabrication](image)

Connection between 1xN splitters and POFs cable joint by POFs connector. POF connector has two sockets, each socket has wide pit on a side while on the other side is narrower. The end of taper-twisted POFs inserted into the socket through wider slot and glued properly, so that the connection will be even strong. While the other socket inserted by POFs cable as depicted in Figure 6.

![Figure 6: Connection between the output optical 1xN splitter with 1 mm POF cable](image)

After successfully linked the only one POF input of 1xN splitter, the fabrication method continues by connecting N number of POF outputs in the same way explained before. The connection is visualized in Figure 7.

![Figure 7: Connection between the inputs of 1xN splitter and 1 mm POF cable](image)

**Characterization**

Here we choose some samples of 1x4 splitter to measure the efficiency of the handmade splitter. The developed splitter must be able to properly coupling an optical signal to generate a single coupled signal efficiently, 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 of zero error as displayed on the meter.
Bidirectional optical loss measurement is carried out in order to determine either side of the 4x4 splitter with lower optical loss as final product of 1x4 splitter before cutting the middle of the 4x4 splitter. Red LED injected through each of inputs individually and separately from the right side (lights propagate leftward) in order to measures output powers and calculates the optical loss.

Then, similar procedure is repeated for rightward measurement. Finally, optical loss for fused bundle in both directions analytically compared. The procedure explained above visualized as in Figure 8.

In order to measure the power efficiency of splitter, at first, red LED injected from transmitter pit into single POF cable (1 mm of core diameter) and obtained power defined as input power while output power obtained by injecting LED into POF splitter (through single POF port) and each POF ports (on cascaded side) measured by optical power meter. The procedure of input/output power measurement depicted in Figure 9.

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 [1, 5]. It is learned 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 taper-twisted 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 taper-twisted POFs and POF cable [5]. The other aspect that playing an important role to transmit two different signals represented by different colour on transmitter devices is the filter which is placed between the handmade splitter and the receiver part. In this research, two different LED was utilized; red LED (650nm) transmit an internet line through LAN connection and green LED (520nm) 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 results of the efficiency of both green and red LED on their way to deliver a different signal to be split by handmade splitter, and optical power meter was placed in the output port right before the receiver port, as shown in Figure 10.

Figure 9 shows that red LED have a higher loss compare with the green one. LAN networking very sensitive with the varies of the distance, the longer distance took, the faster LAN system drop, lead to the slower of speed rate of data transfer through fiber.

The deviation between both signals was reach 3dB, 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 11.
Comparison for the optical line either using the filter or not, has been analysed. The insertion loss of the cable with or without red filter is visualized in Figure 12, also with its logarithm and linear function of the data.

Figure 11: video quality of WDM-POF system of (a) 50m, (b) 30m, (c) 20m and (d) 10m of optical transmission line.

Figure 12: (a) Insertion loss of the cable before and after we place the red filter, and its (b) logarithm and (c) linear function.
The above data shows that almost 0.5dB breakdown occurred once we placed a red filter into the line. But this deviation is not really influenced either speed rate on LAN network or the video quality which is displayed in monitor. From the Figure 13, it is shown that the less insertion loss is about -3dB and the highest is reach -7dB.

The POF splitter device with excellent uniformity can be extended to perform as demultiplexer after joining together with Rosculux filter. The filter is used at the end edge of fiber and the color of the filter technically will determine the exact color of signal passing through. The placement of filter can be done at the edge of fiber or inside the connector. The filter design which is able to eliminate unwanted signal and select the wavelength of the system.

Why Uniformity is important and need to be characterized? Figure 13 shows the two conditions of demultiplexer fabrication by using uniform (a) and not uniform (b) optical splitter. The demultiplexer based on not uniform optical splitter has failed and could not perform the demultiplexer. The signal extracted from not uniform splitter has different in amplitude of the signal.

![Optical Splitter & Demultiplexer](image1.png)

**Figure 13.** The two conditions of demultiplexer fabricated from different uniform POF splitter.

V. WDM NETWORK CONFIGURATION

WDM-POF system was developed and successfully adapted in many useful applications, such as in-house surveillance system (Sensor & CCTV) and solution for in-vehicle entertainment network application, as an integration of POF network together with simple and inexpensive embedded system. Different colours generated by light emitting diode (LED) from transmitter-end indicates a different system such as LAN network, video transmission network and broadcasting network, which also indicates a different wavelength for transmitting an optical signal over WDM-POF system (Figure 14). Different wavelength means different LED colours are being applied. Colour transparent filter located in splitter-end has been utilized to ensure that WDM-POF system filters a colour as desired, for further process at receiver-end. Performance parameters of this splitter including excess loss, insertion loss, output power and channel cross talk were measured. Characterization of the splitters was analysed by injection of red, green and blue LED into the splitter.

The proposed fabrication process for handmade splitter and WDM-POF system are simple, easy, cost-effective and suitable to be used for short-haul communication applications with distance range of 100 to 300 m for single LED usage. The standard communication over POF uses only one single channel. To increase bandwidth for this technology, the only possibility is to increase the data rate, which lowers the signal-to-noise ratio and therefore can only be improved in small limitations. More LED colours usage more bandwidth can be increased. With three LEDs colour the achievable bandwidth is 800 Mbps.

![WDM-POF Network](image2.png)

**Figure 14.** WDM-POF Network with LED colours to transmit signal for many application for example internet, CCTV, video and online-gaming.
VI. APPLICATION

Home networking over POF
A multimedia network for audio, video and data access needs a stable connection. The home network system is a modular concept based on polymer optical fiber or POF. Using the home network system with plastic optical fiber each private household can afford such an optical network infrastructure. POF increases the application for use in household, gets rid of the bottleneck that occurs between the Optical Network Unit and electronic appliances.

Surveillance System
The most powerful campaign of this handmade splitter is about integrating this device into Closed-Circuit television (CCTV) application to split a video signal efficiently with a very low initial and instalment cost, which can now compete with a commercial CCTV system in the market. The solution can be achieved by two alternative method, First using TDM scheme in which one wavelength carry many AV signals from video cameras by means of electronic multiplexing; and the second approach is using WDM scheme in which one video camera is assigned with one specific wavelength/LED colour.

In-vehicle Network
Here, we utilize our fully developed prototype, fused splitters and the interference filters, three number LEDs as a source, three number photo detectors at receiver-end, and low-cost filters to develop a whole system of WDM-POF for in-vehicle entertainment network application system [7]. Existing 3 separated network such as MOST, FlexRay and CAN network to carry infotainment, communication and sensors signal in automotive can be replacing with simple 3 LED WDM network. In this research, three different LEDs are utilized: red LED (650 nm) that transmits an internet line through LAN connection and green LED (520 nm) that delivers a high-quality video signal to be displayed on a monitor screen and red LED (650 nm) represents an audio signals distributed inside the vehicle as shown in Figure 14.

VII. COST ANALYSIS

One of the main goals for employing WDM over POF in the vehicle networking was reducing wire harness. Eco-friendly WDM-POF networking seems to be the future technology for distributing the entertainment data with high speed and high capacity solution. Fig 15 shows the result of LED WDM communication in the in-car application. The small diagram below shows the LED WDM communication configuration. Our proposed system is the lowest cost of WDM system that is reported up to this time. Cost comparison our prototype as compare to existing product in the market. Typically, the commercial POF splitter that manufactured commercially by some manufacturer pricedexpensively at approximately more than 280EURO 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, moulding, biconical body and reflective body [4].

VIII. CONCLUSIONS

In conclusion, handmade fusion technique has been successfully practiced to fabricate optical 1xN splitter based on POF technology. Basically, the 1xN splitter is a part of fused POF bundle (or namely as 4x4 splitter). The handmade 1xN splitter has been formed based on left side of fused bundle as the prototype has lower loss in leftward light propagation. Final analysis shows that efficiency of 1xN POF splitter output has splitting ratio 25:16:31:28 % and 2.41 dB of minimum optical loss.

Hence, the obtained result reveals that handmade 1xN POF splitter has great potential to be employed as an economical wavelength division multiplexer because it able to couple several different wavelengths with few main advantages that are low optical loss and low-cost. However, the homogeneity of this prototype is not yet satisfied. An intensive study suggested in order improving the homogeneity of this prototype. In fact, handmade fusion technique afflicted with some disadvantages: has no consistency of producing splitter. It is impossible to fabricate POF splitter with good performance consistently.

This device is highly recommended for WDM-POF system as it is not as costly as other commercial POF splitter. 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 colour band gap from the filter itself, speed rate of the internet still stable and the resolution of the video image is quite good.

ACKNOWLEDGMENTS

This research has been conducted in Computer& 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. The research had won gold medal award in Innova-Eureka 2013 in Brussel and several awards in national and international exhibition.

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