Cost-effective 1x12 POF-Based Optical Splitters as an Alternative Optical Transmission Media for Multi-Purpose Application

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Summary

Multimode fiber cables can conduct many light rays and can operate free of disruption and with a greater bandwidth than a wireless connection. However, due to a slight variation in the speed of the light rays through the multimode fiber, a signal transmitted by all of these rays becomes spread out. Consequently, the signals become broader and therefore fewer signals fit in the fiber, limiting the transmission capacity. Hence new ways of splitting methods must be found to satisfy all application demands. Home-made 1x12 optical splitter based on polymer optical fiber material base is one of the most innovative technologies on optical component which can be applied on some useful application. A perform technique has been used to fabricate kind of splitter. Multimode Step-Index Polymer Optical Fiber (SI-POF) type made of polymethyl methacrylate (PMMA) with $Ø_{core}$ = 1 mm and NA: 0.50 fully utilized in this research, as PMMA is one of the most commonly used optical materials. This material has been chosen as a base of splitter body in a fused-taper-twisted shape, produced by a unique fabrication stages. PMMA-POF can easily be used near it operating temperature between -40ºC to +115ºC. By injecting 650nm wavelength of red LED, characterization process start plays an important role in investigating level of efficiency of the device. Some parameters, such as optical output power and power losses on the devices were observed. Although the maximum output power efficiency of the splitter is about 60% but it can be improved gradually through experience and practice.

Key words:
Polymer Optical Fiber, Plastic Optical Fiber, POF, Home-networking, Optical splitter.

1. Introduction

As telecommunication traffic increases due to the rapid growth in use of phones, faxes, computer networks, and the internet, fiber capacity will have to keep pace.
The wavelength division multiplexing (WDM) technique arises as a promising technology solution to realize very high capacity long distance transmission systems by exploiting the wide bandwidth available in optical fiber.
Because of the dramatic increase in capacity of optical communication using WDM, there has been an increasing interest in the development of particular devices to manage a number of wavelengths. The WDM technology actually encompasses of 3 sub-system, transmitter technology, devices technology and receiver technology. Transmitter research field demonstrate the Laser and LED, cooled and un-cooled laser, internal and external modulated. Meanwhile, various types of optical WDM devices have been proposed and demonstrated which are included fused-type fiber and waveguide-type devices, Bragg reflector and thin film technique for filtering and channel separation, EDFA and RAMAN for amplifier gain.
POF is an established medium in industrial and automobile networks due to its high reliability in even the most rugged environments," says Hugh Hennessy, Firecomms vice president of worldwide sales and marketing. "With data rates of up to one Gigabit, and assured quality of service to every device in the residence, POF is the most robust technology for 100 Mbps Optical Ethernet and 250 Mbps Optical FireWire in the home. These features of POF are especially advantageous for emerging IPTV implementations and other triple play services."[4]

2. Home Networking

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 - even next to electrical cabling, making its installation quicker and more flexible and cost-effective than CAT5/CAT6 [13].
Because it’s optical, polymer fiber is completely immune to electrical noise. That means existing copper wiring will not interfere with data passing through POF, so it can even be installed next to electrical cabling. Even other existing networks or wireless systems in the house cannot interfere with data passing through the POF cable. This is very important for multimedia data transmission, in which the quality of the signal could be negatively impacted by external noise. Troubleshooting is quick and easy as POF uses an eye-safe visible red light. In fact, it’s the only

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interconnect technology where the signal can be seen at both ends [7][9][14].

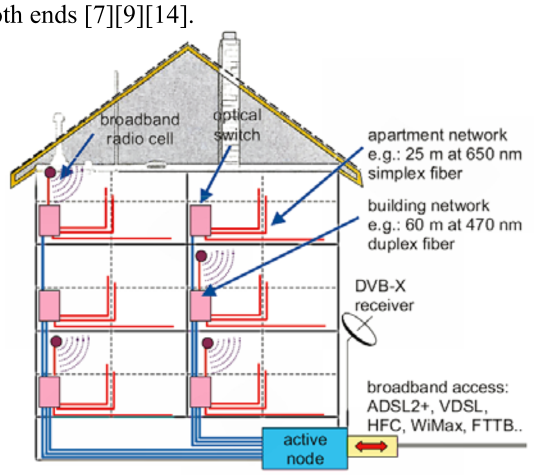

Figure 1 POF based application for home-networking

The introduction of WDM technology to POF network has increased the efficiency and also survivability of POF network. The reliable and feasible mesh topology and the specifically assignment of wavelengths as the data carrier has enable the restoration scheme can be embedded to the system, such as dedicated protection and shared protection scheme as implemented in FTTH customer access network [1]-[3]. The data signals (e.g. MEMs sensor signal, voice, video, information) are modulated using the multi-wavelength respectively and then send to the destination through the POF devices such as splitter, wavelength selective splitter, directional splitter and ADM. The WDM-POF has also approved the silica-fiber based device also could be fabricated using the POF specification. The proposed WDM-POF also increased the capacity of data communication. For example, the bandwidth of one LED is about 20 MHz at rate 200 MHz, therefore if we used five LED to develop the WDM system, the transmission is expected to have five times bigger than the existing TDM based technology.

3. Automotive Blind Spot Tracking System

In the past few years, number of applications in automobile technologies based on optical fiber so rapidly developed as in the area of optical short-range communication. Demand POFs in application of automobile technology was relatively high. POFs have attracted much attention in past decades especially in automobile field because POFs have some unique characteristics, such as flexibility, easy to handle, relative low cost in coupling due to their large core diameter, heat-proof, immune for noise (external electromagnet disruption), suitable for data communication for long distance up to 100 meter, high speed data transmission (400 Mbps for SI's type and 1 Gbps for GI's type), wider broadband (exceed 4 GHz) and have losses below 25 db / km additional loss once it bent [8]. In vehicles, airplanes and rail transportation more and more digital communications connections are being utilized. As a result, increased demands on the architecture of the data connections as well as the transmission media are being made [12].

Due to fact, that automobile field the step towards digitalization has long been made, POFs can meet many of these requirements to an optimum degree and are therefore increasingly of interest. Likewise, in the automotive technologies based on passive night vision, POFs can be applied to support these systems. Proposed study for passive night vision was defined by passive imaging system based on optical fiber sensor application. This sensor application was kind of technology based on optoelectronic and optical data communication through optical fiber. Optical fiber sensor gave more advantages compared with electronic sensor due to it quality, high sensitivity, high-speed data rate, low power budget, and low cost components required [5]. Optical imaging through optical fiber defined as a light transmitting system which being reflected by one of an end of optical fiber to another. This process will be successfully worked once a source of light applied on it, triggered the switching speed, with an appropriate wavelength and high optical output power. It is called passive system; they used the surrounding light as source to lighten up focused objects [11].

Many research come out with their own proposed technology have been carried out, start from conventional side mirror (see Figure 2) until costly advanced ultrasonic sensor which put in the bumper part of vehicle. Although various methods were introduced to track blind spot area yet respectively has distinctive weakness. Therefore, further study need to be developed to solve the blind spot area tracking problem and overcome the weakness of previous methods.

Passive night vision with POF-based technology expected to be able to compete with other previous method to overcome the blind spot area tracking problem. Study for characteristics of POFs was strictly required to conduct for achieving desired design with some detail modification. In this case, the proposed fabrication design finally comes out with a real fused-taper-twisted POF splitter (see Figure 2).

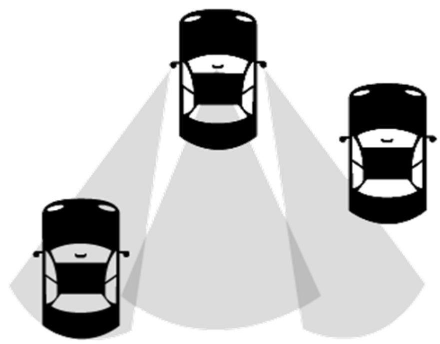

Figure 2 Blind spot tracking area solution over POF based sensor

4. Small World Communication Application

The concept of "small world" networks has recently received much attention, although its origins stem from early work done some forty years ago on large, complex systems under assumptions that the underlying network stricture is random [13]. Many real world situations, including the World Wide Web [2], electric power grids [14], and the network of mathematicians with finite Erdős numbers [13], can be modeled as small world networks. The two main characteristics of small world networks are strong local clustering, and small diameter. Informally, clustering is the fraction of possible edges among neighbors of a node that are actually present, averaged over all nodes. Clustering, or locality, is a common property of many computations that require the exchange of information among processors, and clustering of communication is typical of many applications [11-13].

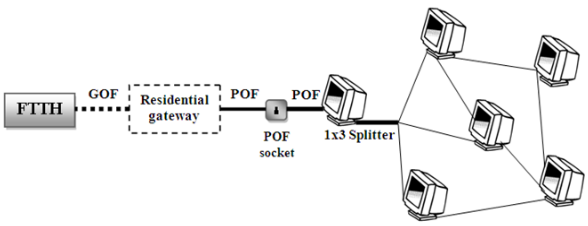

Figure 3 splitter function in connecting some nodes through some PC users

As computing power increased and real world network began to become available, empirical analysis extended to real-world networks with non-random characteristics. Albert and Barabasi (BA) (2002, pp. 48-49) found that large complex networks posses three properties, such as short average path length, high level of clustering, Power-law and exponential-degree distribution. Short average path length indicates that the distance between any two nodes on the network is short; they can be reached in a few numbers of hops along edges. Clustering occurs when nodes locate topologically close to each other in cliques

For the purposes of practical use of small world communication systems, POF-based technology can be applied on it to connect some nodes. In the past few years, number of applications in communication and transportation based on optical fiber so rapidly developed as in the area of optical short-range communication. Demand POFs in application of communication was relatively high [1,4,5,6], due to some characteristics strength of it, such as flexibility, easy to handle, relative low cost in coupling due to their large core diameter [2], heat-proof, immune for noise (external electromagnet disruption), suitable for data communication for long distance up to 100 meter, high speed data transmission (400 Mbps for SI's type and 1 Gbps for GI's type), higher bandwidth (exceed 4 GHz) and have losses below 25 db / km additional loss once it bent [3,4,6,8].

5. Experimental

POF-based splitter is an optical device which ended by N number POFs, while the other port ended by one port. Furthermore, they both work bidirectional. However, they can work from the 1 POF into N POF or vice versa, in order to achieve a high efficiency transmission media, based on the objective of the research it has to be ensure that, N separate optical signals able to linked into one coupled signal by means of data, voice and video for some multipurpose application. Final product for cost-effective POF-based splitter can be seen in Figure 4 and 5.

Figure 4 Final product of 1x12 POF based optical splitter and also 1x3 and 1x4 splitters

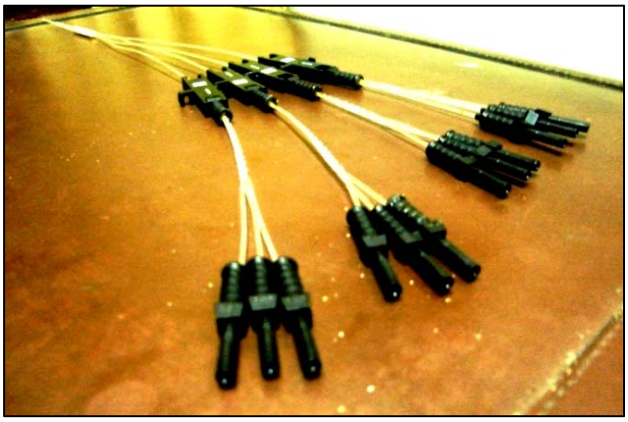

Figure 5 cost-effective 1x12 POF-based optical splitter

In development process of 1x12 splitter based on POF technology, multimode SI-POF type made of polymethyl methacrylate (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 [6]. Prototype development gives a priority in fabrication method due to expectation to generate an optical splitter with the specifications which meet research's requirement. Development process for the proposed technology can be seen in Figure 6.

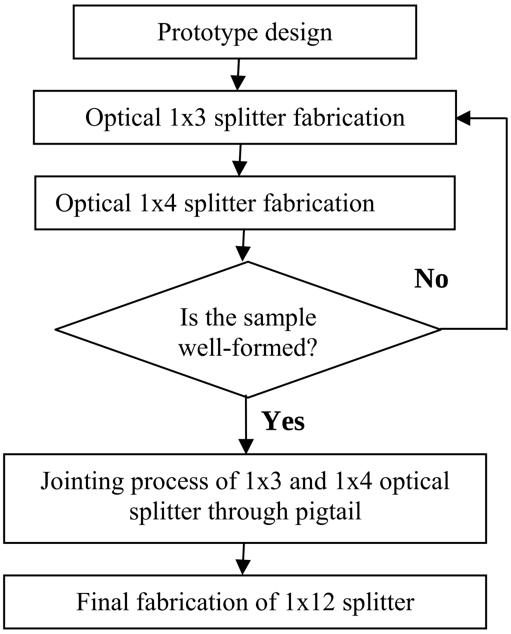

Figure 6 Flowchart for prototype development process

In this study, optical 1x12 splitter developed by the jointing of Optical 1x3 splitter and Optical 1x4 (both devices fabricated based on fused-taper-twisted POF). Other specification for the design, the 1x12 splitter reach data transmission distance up to 25 cm. therefore, a POF cables (11 to 13 cm length) is required to be linked with end part of 1x3 splitter (as an output) to input of 1x4 splitter. Basically, this optical 1x12 splitter design (see Figure 4) formed by all four optical 1x3 splitters arranged in series, and this series arrangement connected with optical 1x4 splitters parallel. To fabricate the final product of optical 1x12 splitter, some stages has to be done, start from fiber fusion, bundle formation and finalized with cable jointing. Fusion method either for optical 1x3 or 1x4 splitter has just the same principle. Fabricated through fusion method by fuses and combine 3 or 4 POFs (in bundle form) and fabricate it ends part in a shape of fused-taper-twisted fibers (diameter 1 mm). POFs will be twisted and pulled down while it is fused in a heat of flame. Heating process was done indirectly, while POFs covered by metal tube. Thus, heat was provided for POFs through metal tube heating (see Figure 7).

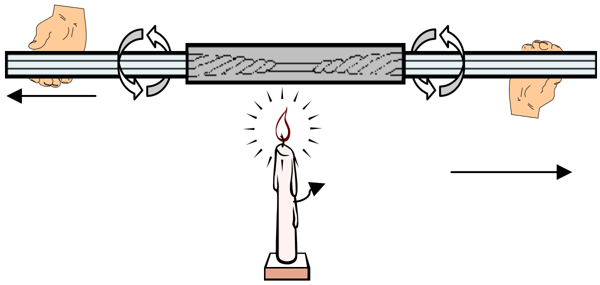

Figure 7 Fabrication method of bundle POFs

Right after twisted closely of POF's center part obtained, metal tube will heated up until center part starting melt. Than, gently pull the POFs in opposite direction, until the shape of that part getting taper-twisted

However, some of the POFs successfully fabricated before, some damaged sample still found from the fabrication aspects of it, e.g. imperfect shape. A sample can be called ideal once its diameter uniformly fused-taper-twisted approaching 1 mm. To confirm that samples unable be used in characterization testing, these sample will be tested by red-LED injection. It is obtained that red-LED will not came out from the samples in a bad quality. Thus, the samples cannot be use in characterization testing (see Figure 8).

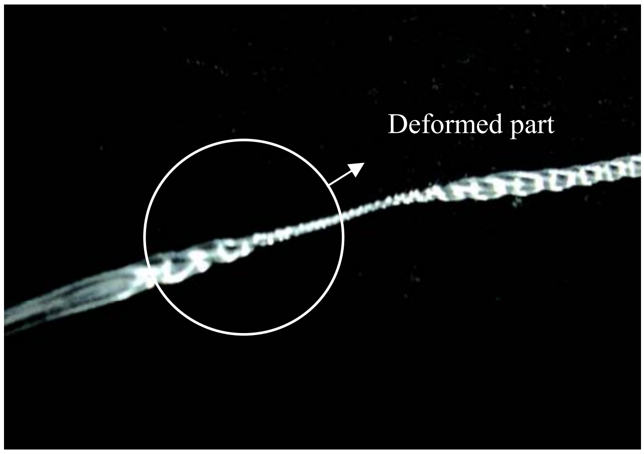

Figure 8 Final product of fused-taper-twisted POFs in deformed shape

To connect optical 1x3 and 1x4 splitter, research suggests using 1 mm POFs cable. Connection between 1x3 splitters and POFs cable joint by POFs connector (1 mm core diameter with jacket). POF connector contains two difference socket side, the one with a wide socket pit while other have a narrower. The end part of 1x3 taper-twisted POFs inserted into the socket with a wider slot and glued properly, so that the connection will be difficult to be pulled out. While the other slot side of connector inserted by POFs cable (see Figure 9).

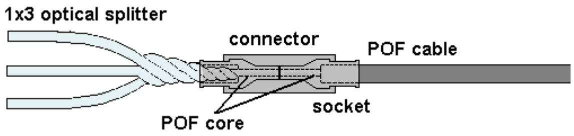

Figure 9 Connection between optical 1x3 splitter with 1 mm POF cable

After successfully linked the optical 1x3 splitter with one side of POFs cable, fabrication method continue by connecting the other side of POFs cable with optical 1x4 splitter with the same method explained before (see Figure 10).

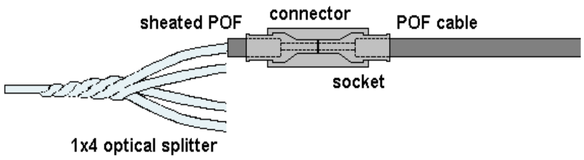

Figure 10 Connection between 1x4 splitter with 1 mm POF cable

In this study, characterization process need to be carried out for each fabricated optical splitter. Each of developed splitter must be able to coupling every optical signal to generate one coupled optical signal with low power loss. Optical power meter has been used to measure the optical power from POFs. Before the switch opened, it is obtained that 0.02μW for it zero error exists on the meter. It is stated that 11μW optical power of red LED was injected as an optical input power for each POFs (see Figure 11 and Figure 12).

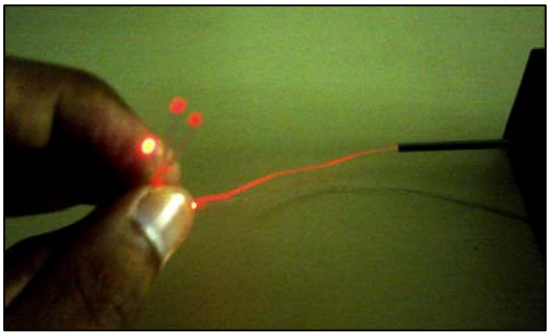

Figure 11 Characterization process by utilizing 650nm wavelength for red LED injected into bundle fiber to observed level of efficiency for each fiber

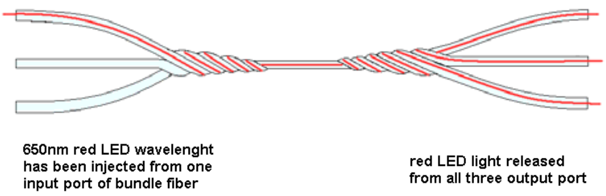

Figure 12 Coupling method for the three optical coupled signal

6. Results and Discussion

The analysis of the prototype characterization was carried out, especially for it efficiency percentage of each POFs for all three stages in characterization process. So, the comparison for the all efficiency of optical 1x3 splitter based on POFs has been observed, which the 1 end-POF act as an input and the other port which consist of 3 POFs stated as an output.

Some samples of POFs have been fabricated, red LED with 650 nm wavelength with 3μW input power, have been fully utilized to measure the efficiencies of all fabricated samples. Ten of the fabricated samples have been measured, it power output for each 3port bundle fiber (see Figure 13) and average efficiency of all bundle fiber compared with ideal and commercial splitter (see Figure 14). It is clear that, the best 1x3 splitter sample obtained is sample B with high (average) efficiency, although the fact that power output not separated equally from all three POFs output port of sample B.

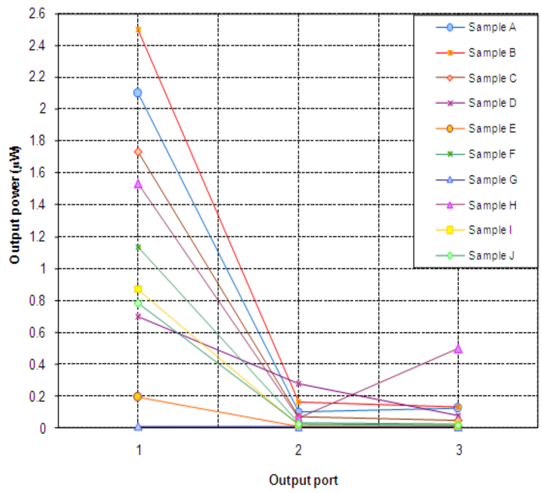

Figure 13 Power output for all 3port of each bundle fiber

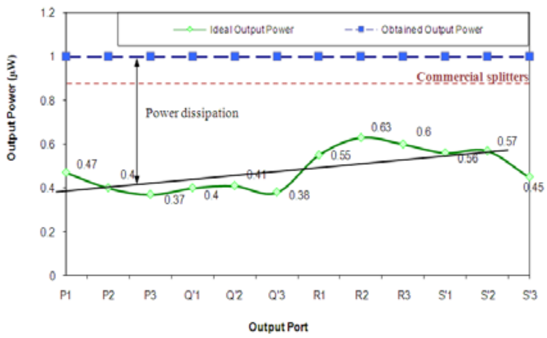

Figure 14 Comparison for output power efficiency of ideal splitters, commercial splitters and hand-made cost-effective 1x12 POF-based splitter which the deviation is 20% approaching the ideal splitter.

From the observation above, the power efficiency of each output shows a different value. It is true; because error could be happen on it either while fabrication process or characterization test stages imposed on them.

Irregularities of controlled heat while fusion process exposed on the POFs become one of the major problem, due to it lower melting point makes core structure of POF could be more sensitive on heating process. Once it is damaged, it is hard to let a light pass through the core, or even not pass at all.

After the best samples have been chosen, the measurement of end-to-end efficiency of sample B need to be conducted to choose the best side of the sample before it connected to Ø1mm POF cable using POF connector.

The procedure for this characterization is red LED was injected into the all three input of the POFs and measure for the three output of the other side of POFs, and vice versa. In here, both sides of samples A, B and C have been observed to compare the two side of it (see Figure 15).

From the observation showed some imperfection of the shape of POFs if it is seen from the different side. The deviation power efficiency of the different side POFs measurement approximately reaches 30%.

From this characterization, the right side of 3POFs have been chosen to be used on the next stage of splitters development, due to it high efficiency. The research continue by connected the POFs with the Ø1mm POF cable from both input and output side of the splitter, than measurement also conducted for the purpose of analysis whether the POF connector gave some impact on power efficiency of the splitter while it transmits the power, and the result indicates that deviation not significantly drop.

The presence of surrounding light, could be one of the factor cause an error on optical power meter, although have a low intensity they gave a high sensitivity on it. Optical power meter able to reach nanowatt external power, hence, disruption from external source of light ensured to be avoided during the power measurement conducted.

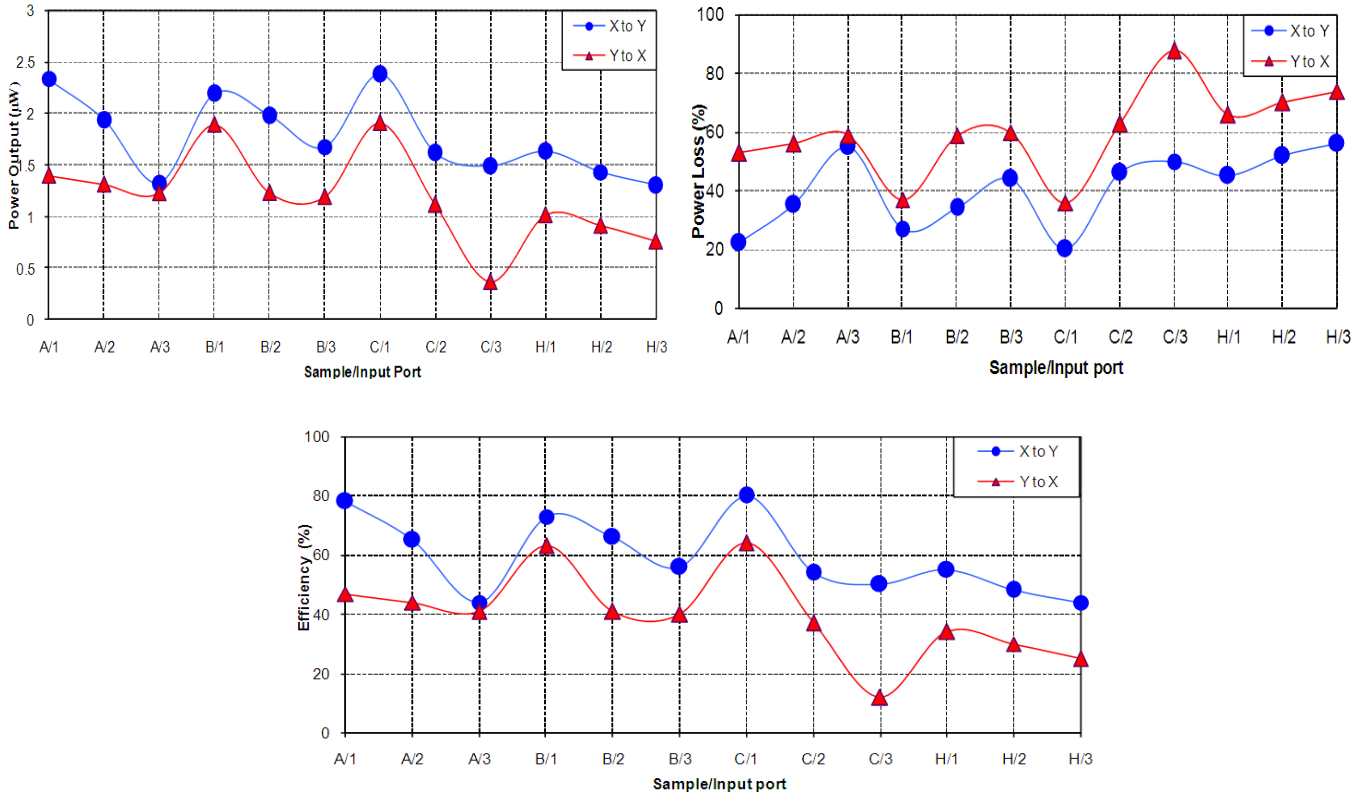

Figure 15 Output power comparison for two different side of splitter of it (a) power output, (b) power loss and (c) power efficiency

7. Conclusion

Optical based application especially related to home networking, automotive and other short-haul technology, is now rapidly growth due to the high demand of the optical device it self, which is easy to assembly and low cost from the view of fabrication process and apparatus itself. In order to upgrade the system and add some sub-system which have the same efficiency of the main system, optical splitter is the only solution to accomplish it.

A perform technique has been used to fabricate optical 1x12 splitter with based on POFs technology. Multimode SI-POF type with 1 mm core size fully utilized for the base material of the splitter. Some procedures, such as fabrication and characterization stages have been carried out to develop the splitter. Red LED with a 650 nm wavelength has been injected into the splitter for the purpose of characterization testing to analyze the level of power efficiency of the splitter. Final analysis shows that efficiency of splitter output able to reach up to 60%. The device performance can be improved gradually through experience and practice. Main point here is, the fabrication process is simple, easy and suitable to be used for household. The POF-based optical 1x12 splitter have been suggested to be applied in some useful application, such as home networking, to avoid the bottleneck occurs between ONU and electronic appliances, resulting increase the speed of data communication.

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