

Low-cost Fused Tapered (LFT™) Splitter for Multichannel WDM-POF Network Design

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Abstract: This research was conducted to develop a low-cost solution for two channels of wavelength division multiplexing based on polymer optical fiber (WDM-POF) technology for short-haul communication application. $1 \times N$ POF splitter has been fabricated by fused tapering technique called $1 \times N$ low-cost fused tapered (LFT™) splitter as N indicates number of output ports we desired. This $1 \times N$ LFT™ splitter was fabricated as an effective transmission media to split and recombine two different wavelengths, which represents different signals. A $1 \times N$ LFT™ splitter includes an optical fiber bundle formed of a plurality of optical fibers, which further includes a center of the optical fiber bundle being twisted, fused and pulled by a skillful hand while indirectly heated and covered by a metal sleeve as produced a tapered region in the center, wherein the fused center part of the bundle fiber have a same size with one single fiber in diameter approached 1 mm. Application for this $1 \times N$ LFT™ splitter also reported, two different wavelengths were fully utilized to transmit two different sources of systems, LAN connection Network and video transmission system. Red LED which in ($\lambda = 665$ nm) capable to download and upload data through ethernet cable while green LED ($\lambda = 520$ nm) transmit a video image. Special 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 to mention about the effect of filtering technique and the efficiency of the $1 \times N$ LFT™ splitter itself.

Key words: *fused tapering technique, polymer, multiplexer, local area network, splitter*

INTRODUCTION

Nowadays, polymer optical fiber (POF) become an alternative transmission media replacing copper or even glass fiber for short-haul communication. POF networking turn into a trendsetter 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 [9], 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 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 (Appajaiah, *et al.*, 2007).

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 could be seen as one of the best solution allowing transmission of information over more than just a single wavelength (color) and thus greatly increases bandwidth of POF. WDM is a technique that multiple signals are carried together as separate wavelengths (color) of light in a multiplexed signal.

In WDM-POF system, numbers of transmitters with different lights color carrying single information. For example, red light with 665nm wavelength modulated with Ethernet signal while blue, green, and yellow lights carry image information, radio frequency (RF), and television signal, respectively (Ab-Rahman, *et al.*, 2009). As shown is Fig. 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, as the reverse process called de-multiplexing.

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

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fabricating POF splitter. These techniques include twisting and fusion, side polishing, chemical etching, cutting and gluing, thermal deformation, molding, biconical body and reflective body (Ehsan, *et al.*, 2009).

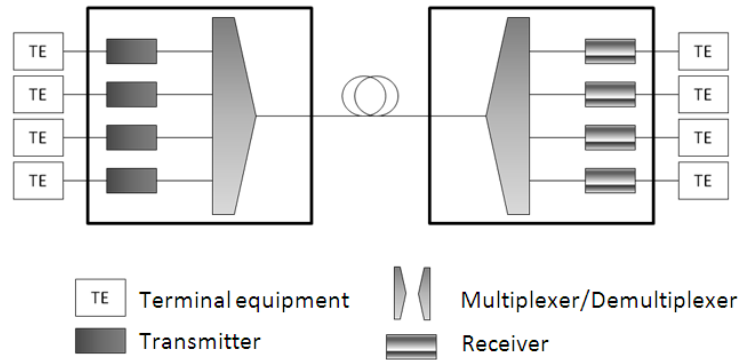


Fig. 1: Wavelength Division Multiplex with Optical Multiplexer and De-multiplexer.

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 (Ehsan, *et al.*, 2009). 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 (Ab-Rahman, *et al.*, 2009; Kelly, *et al.*, 1995). 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:

The $1 \times N$ LFT™ splitter is an optical device, which ended by N number of POF output 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 1×4 splitter developed by the jointing of four polymethylmethacrylate (PMMA) POF. Other specification for the design, the input POF is designed and fabricated to be fused tapered shape, as the fabrication process and 1×4 LFT™ POF splitter are illustrated in Fig. 2 and Fig. 3.

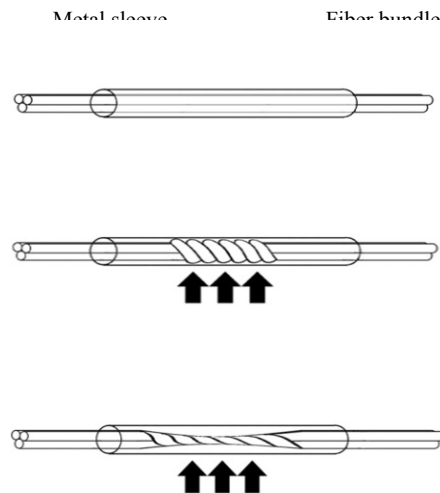


Fig. 2: Main fabrication process of LFT™ splitter: (a) configuration, (b) twisting and (c) fusion.

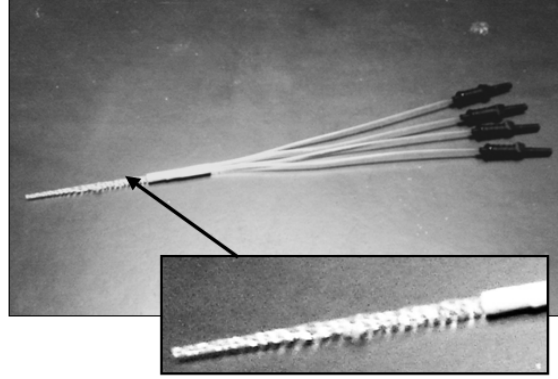


Fig. 3: Prototype of the 1×4 LFT™ POE splitter fabricated by fused tapering technique.

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

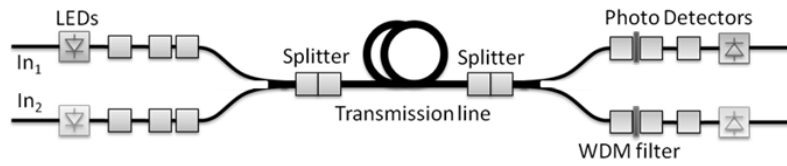


Fig. 4: WDM-POE system design using $1 \times N$ LFT™ splitter and filters.

In development process of $1 \times N$ LFT™ splitter, multimode SI-POE type made of Polymethylmethacrylate (PMMA) 1 mm core size fully utilized in this paper. Furthermore, 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 POE (Appajaiah, *et al.*, 2007).

Here we choose some samples of 1×4 LFT™ 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 POEs. Before the switch opened, it is obtained that 0.02 mW of zero error as displayed on the meter.

Bidirectional optical loss measurement is carried out in order to determine either side of the 4×4 splitter with lower optical loss as final product of 1×4 splitter before cutting the middle of the 4×4 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 Fig. 5.

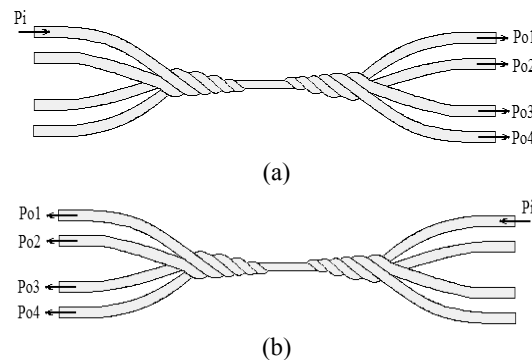


Fig. 5: The procedure of (a) rightward and (b) leftward optical loss measurement for fused bundle characterization.

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 Fig. 6.

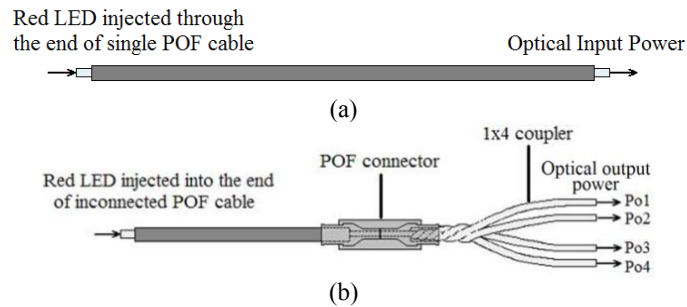


Fig. 6: The illustration of (a) input and (b) output power measurement.

For commercial purpose, research also produces a $1 \times N$ LFT™ splitter come out with a proper housing with concept of '*IMalaysia*' (called *one Malaysia*) as shown in Fig. 7, the housing wrapped by a beautiful Malaysian's attire sticker to promote the specialty of this local product. The efficiency of the signal transmitted by this splitter can be seen in Fig. 8. By utilizing this LFT™ POF splitter, research also conduct a second project called low-cost wavelength division multiplexing (WDM) based on POF technology by integrating a $1 \times N$ LFT™ splitter together with color filter inside the POF connection as shown in Fig.9. 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.



Fig. 7: Packed Prototype of the $1 \times N$ LFT™ splitter and demultiplexer called *IMalaysia*™ splitter.



Fig. 8: Prototype of $1 \times N$ LFT™ splitter. The input signal is split into four channels which are suitable to distribute the application equally to the number of destination



Fig. 9: 1×2 LFT™ demultiplexer is used to split the signal to different frequency (color). The multiplexed signal is separated according to the application (data & video signal) respectively

RESULTS AND DISCUSSION

From the design of $1 \times N$ LFT™ splitter, the fused taper-twisted part (refer to Fig. 2), 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 (Ab-Rahman, *et al.*, 2009; Ab-Rahman, *et al.*, 2009; Ab-Rahman, *et al.*, 2009).

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 (Jeong, *et al.*, 2009).

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 Fig. 10.

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 (Held, 2010).

Comparison of hand-made and commercial splitter have been observed, in term of market price. Overall price for 1×4 LFT™ POF splitter cost is less than US\$3, but for the commercial one which available in market is cost not less than US\$250. Nowadays, many technology have been provided to coupling a signal, for example low cost 1×2 acrylic-based plastic optical fiber coupler (Ehsan, *et al.*, 2009). But knowing that the fabrication techniques was very complicated and expensive, here LFT™-POF splitter can be seen as one of promising solution to face this problem.

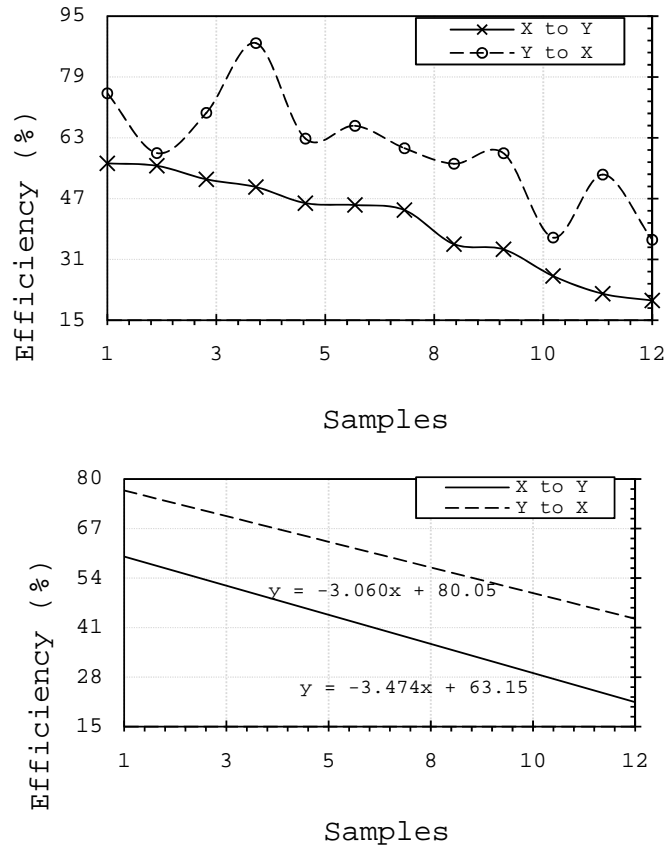


Fig. 10: Efficiency for fused bundle in both directions and the linear function of the $1 \times N$ LFTTM's efficiency.

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 (Appajaiah, *et al.*, 2007; Kuzyk, 2007). 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 (Appajaiah, *et al.*, 2007).

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 LFTTM POF splitter and the receiver section. In this research, two different LED was utilized; red LED (665nm) 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 result of the efficiency of both green and red LED on their way to deliver a different signal to be split by LFTTM POF splitter, and optical power meter was placed in the output port right before the receiver port, as shown in Fig. 11.

Fig. 11 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.

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 Fig.12.

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 Fig. 13, also with it logarithm and linear function of the data.

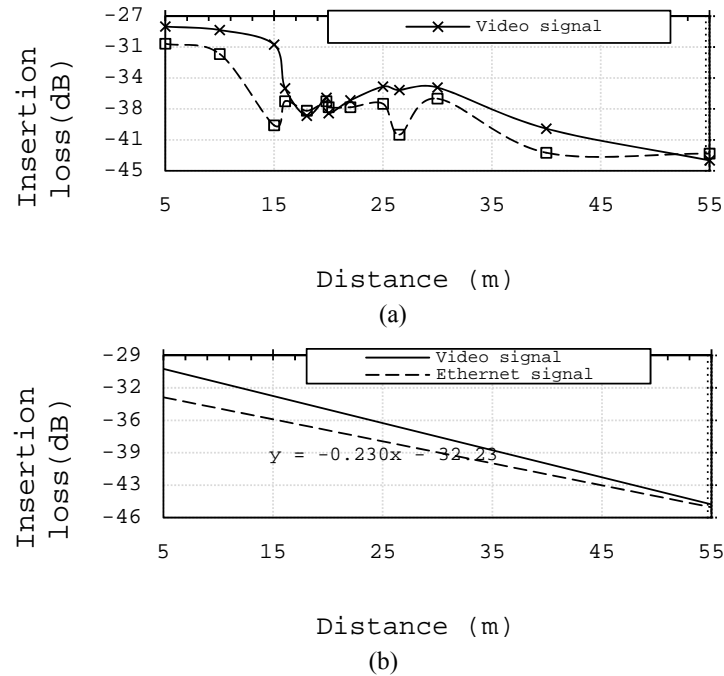


Fig. 11: (a) Power loss comparison between green and red LED and (b) in linear function, green LED represent the video quality of the system while red LED represent the rate of download and upload through internet line.

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 Fig. 13, it is shown that the deviation of insertion loss is about less then -3dB and the highest is reach -7dB.

Conclusion:

In conclusion, tapered fusion technique has been successfully applied to fabricate optical $1 \times N$ LFT™ splitter based on POF technology. As the experimental test bed was installed, The LFT™ 1×2 splitter has been formed based on left side of fused tapered bundle fiber as the prototype has lower loss in leftward light propagation. Final analysis shows that 1×2 LFT™ POF splitter has 2.41 dB of minimum optical loss. 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 LFT™ $1 \times N$ splitter itself. 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.



Fig. 12: video quality of WDM-POF system of (a) 50m, (b) 30m, (c) 20m and (D) 10m of optical transmission line

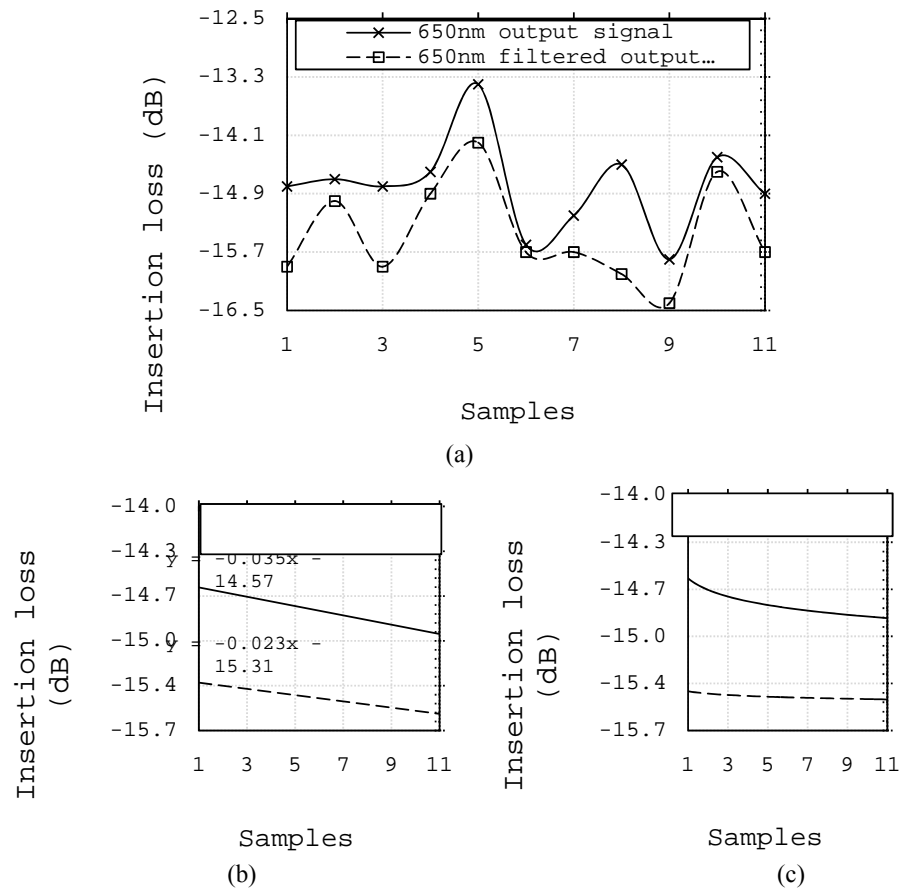


Fig. 13: (a) Insertion loss of the cable before and after we place the red filter, and its (b) logarithm and (c) linear function.

ACKNOWLEDGMENT

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. All of the handmade fabrication method of POF splitter, 1Malaysia™ splitter, $1 \times N$ LFT™-POF splitter and also the low cost WDM-POF network solution were protected by patent numbered PI2010700001.

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