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Chapter 6

Efficiency Optimization of WDM-POF Network in Shipboard Systems

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Additional information is available at the end of the chapter

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1. Introduction

Polymer optical fibers (POFs) are in a great demand for the transmission and processing of optical-based data communications compatible with the Internet, which is one of the fastest growing industries in automobile and domestic industry. Other industry such as aviation and maritime have also taking the advantages of POF. POFs become an alternative transmission media replacing copper cable for future shipboard networks. A proposed POF based technology over submarine network for multimedia data transmission, measurement system, navigation, sensors and several applications. As shown in Figure 1, the system is able to transmit a number of signals represent a different data transmission (such as video, audio, etc) using a WDM based network (refer to Figure 1).

In this chapter, we proposed a wavelength division multiplexing (WDM) system over POF due to the rapid increase of traffic demands [2]. WDM is the solution that allows the transmission of data in onboard the ship over more than just a single wavelength (color) and thus greatly increases the POF's bandwidth.

2. Fiber optic onboard ship

The utilization of optical fiber as major data communication media onboard ship especially on naval combatant ships is not a new discovery [1,2]. Equipments such as communications system, radars, navigation system, combat management system, platform monitoring sys-

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tems and LAN network have used fiber optic to transfer high rate data within equipment or as main data communication backbone. For instant, the platform control and monitoring system onboard ship is using dual redundancy Fiber Data Distribution Integration (FDDI) system to command, control and monitor the platforms onboard the ship. An example of FDDI architecture is shown in Figure 2. This FDDI architecture topology is glass fiber based that capable to transport high density data over long distance because the backbone is covering the entire ship. Numbers of commercial ships are also using FDDI topology as it is a proven system available commercially in the market [1-4].

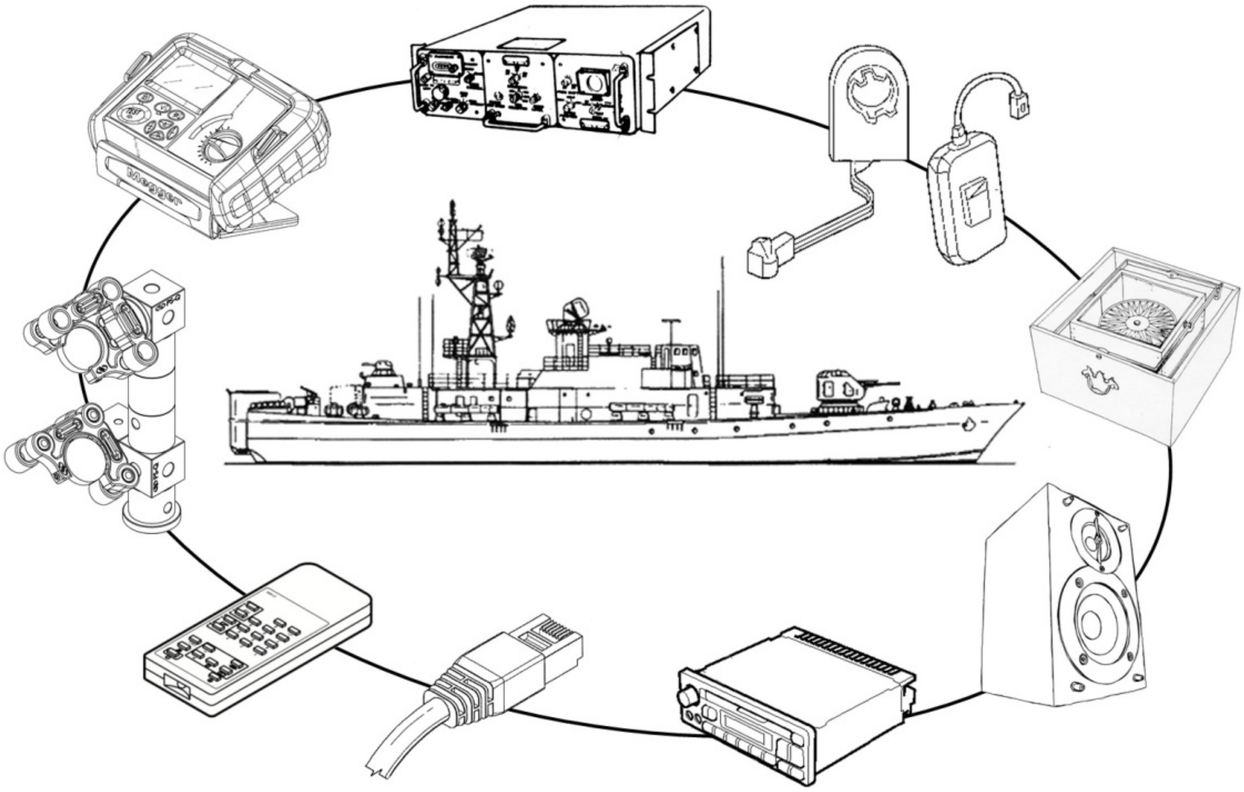

Figure 1. WDM-POF based network over novel system has been propose to ensure the high quality data transmission and communication system

In this chapter, the novel optical splitter/coupler based polymer optical fiber (POF) was successfully designed for the infotainment and data communication system over POF on-ship. The optical splitter consists of a single input port and N of output port (N=2,3,4,....). In principle, the bidirectional splitter performs two operational functions; either signal coupling (in multiple P2P direction) or signal splitting (in P2M direction). Thus, the usage of WDM onboard ship will become a new frontier in optical network.

This fiber optic onboard ship system is the most updated and promising innovation that will revolutionize in-vehicle data communication system which all data can be simply sent in visible light format rather than in electrical format at high speed data transmission. Data communication system is such all-in-one communication media system and the latest trend onboard

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ship network in which many appliances such as navigation system, platform surveillance & monitoring system, damage control & fire fighting system, onboard infotainment & training, sensors and many other appliances can be integrated *via* a WDM-POF. With this WDM-POF-based technology, all data such can be processed with environment-friendly LED conversion and low-cost multiplexing and filtering method besides the fact that it can extend the number of appliances in car interior. This invention enables simple POF cabling system for delivering each optical data as POF is the most updated cabling technology replacing conventional copper wire for short-haul communication. The advantages offered by POF over copper wire; economical installing cost, enabling eco-friendly LED conversion, Electromagnetic Interference (EMI) immunity, no grounding necessary, avoiding sparks, resistance to heat and vibration, lighter material, and narrow bending radius.

During the implementation of this project, several research activities to improve the efficiency of the system has been conduct. Temperature plays a significant role which can influence the performance of the data communication system in POF-based onboard ship. The characterization test was carried out is to determine the performance of the device in the test bench network. In the meantime, the fabricated splitter has been compared to other commercial one, in term of their performance; splitting ratio and power loss. An experiment has been set up in SPECTECH lab, Universiti Kebangsaan Malaysia, to evaluate the survivability of the device in environmental condition with varied temperature. Besides, the aim of experiment is to observe the temperature stability of the device while performing splitting/coupling function. The variation of temperature from 30 °C to 125 °C was exposed directly to the device.

In response to feedback from industries, the thermal aging experiment was undertaken to evaluate the durability of the device in very high temperature environment. The experiment was carried out within 9 hours while the device was exposed to high temperature at 105 °C. An analysis was made to observe the device performance with the variation of temperature. Several graph was plotted to analyze power loss and coupling ratio in varied temperature.

3. Results and discussion

In this study, single line POF is used to carry multiple wavelengths using WDM technology taking the advantage of its cheaper materials and fragility. Four different wavelengths are used to connect LAN connections, telephone line, surveillance cameras and central video/audio entertainments network throughout the ship for access by the user. The controller and server for ship LAN and surveillance cameras is at Machinery Control Room (MCR) that located at deck 1 aft of the ship. This is also the location of damage control and fire fighting headquarters onboard. The telephone PABX and central video/audio entertainment network controller is at Main Communication Center located at the centre of the ship on deck 1. The systems are also able to be monitored and controlled from the bridge located at 01 deck where the ship is navigated or from the combat Information Centre (CIC) where the ship warfare tactical information and status is collected, displayed, evaluated, disseminated and controlled for decision by the Commanding Officer.

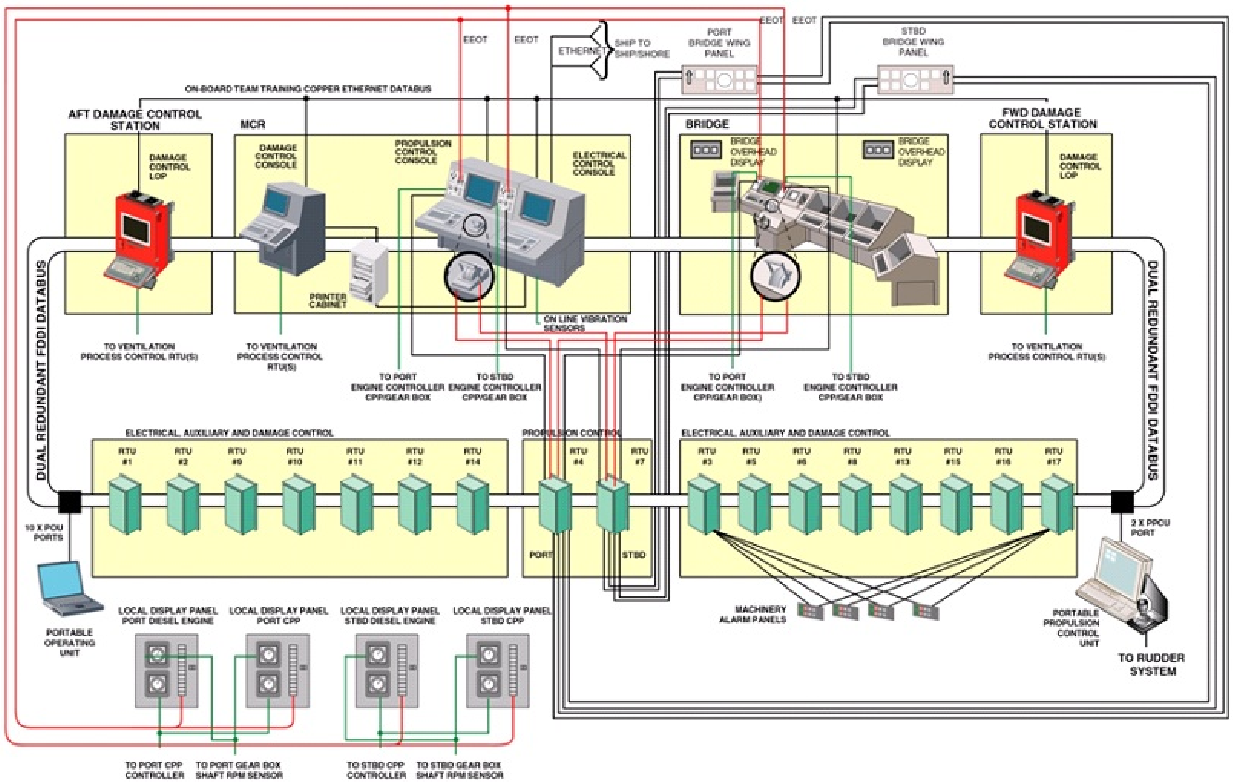


Figure 2. L3 Dual Redundant FDDI for Ship Control and Monitoring architectural network

The CCTV will provide surveillance and monitoring from flood, fire or unauthorized entrance of the high value compartments onboard. The LAN will enable ship staff to access all administration and orders, manuals, publications, maintenance requirements and training document from offices, common area and cabins. The central video/audio entertainments network is providing the ships' crews with central entertainment such as ship's live radio, movies and news broadcasted throughout the ship. The controller is placed at ship's main broadcast & recreation centre. The suggested backbone topology throughout the ship is as shown in Figure 3.

Each deck are interconnected to form a Dual Redundant POF-WDM (DRePOF-WDM) backbone arranged as one ring that interconnected to the equipments and end user devices. The backbone is arranged in mesh topology via an Optical Add Drop Multiplexer (OADM) which acts as optical switches. These switches will be able to be controlled and monitored at MCR, CIC or bridge for redundant connection through the backbone to ensure survivability and interconnectivity of the network. The connection [5] is shown in Figure 4. The devices need for this system is: fiber couplers, Multiplexer, Demultiplexer, Optical Add Drop Multiplexer (OADM) and POF's switches.

Figure 4 as shown above indicates overall arrangement of the system from the backbone to the equipments and the end users located on the various decks onboard the ship. On each deck, equipments and users in the rooms or compartments is linked to the DRePOF-WDM backbone topology using WDM sequenced by time division multiplexing TDM *via* a transceiver. The multiple different signals enter and exit from the devices onto the single wavelength data streams are done by passive devices multiplexer and demultiplexer. Many transmitters with different lights colour are used to carry single information. For example, red light with 650nm wavelength modulated with LAN signal while blue, green, and yellow lights carry image information, radio frequency (RF), and video signal, respectively. As shown is Figure 4, WDM 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 [6-7]. 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, called demultiplexing.

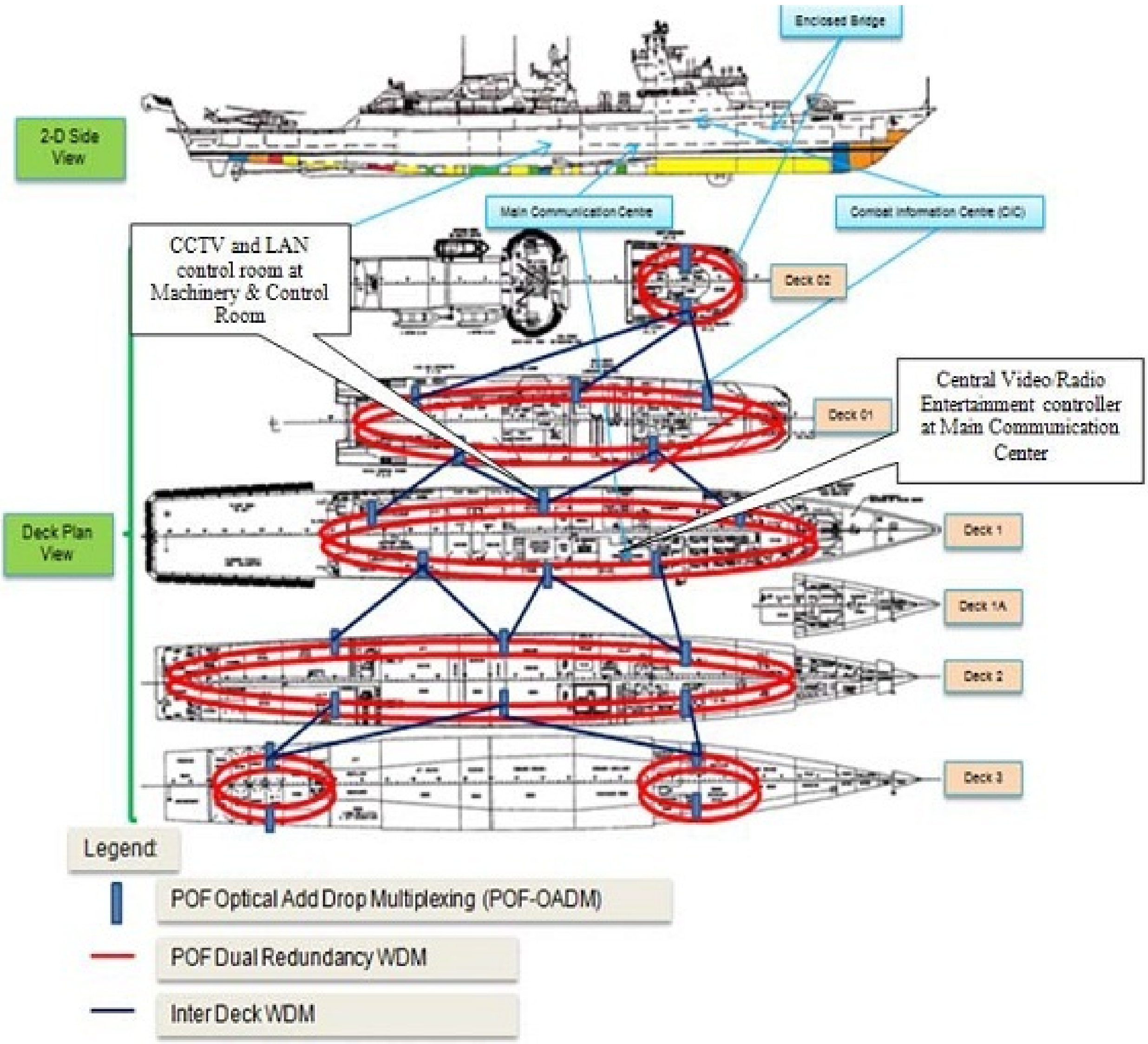


Figure 3. Deck-by-deck dual redundant POF-WDM backbone architectural network

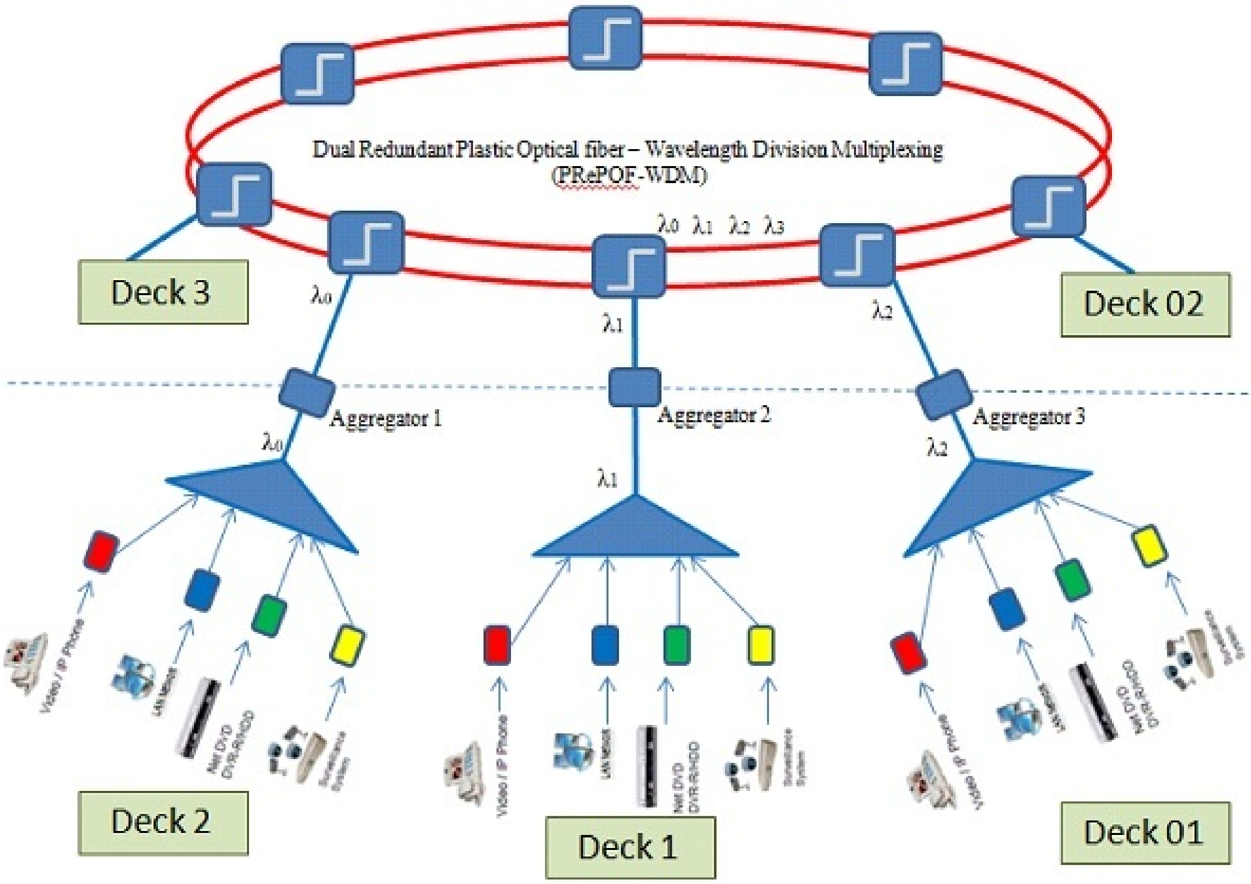


Figure 4. Connection from DRePOF-WDM backbone to each deck and equipments

During the development of the onboard project, several research activities to improve the efficiency of the system has been conduct. The characterization test was carried out is to determine the performance of the device in the test bench network.

3.1. Design and characterization of POF splitter

3.1.1. First generation

The first generation of low-cost fused taper (LFT™) splitters is initially demonstrated as novel innovation in optical splitter technology particularly for POF since it is fabricated via handmade fusion technique that is performed by handwork skill associated with simple tools; candle and metal rather than biconical fused taper. The fabrication method is cost-effective and less time-consuming (11 minutes per unit).

In comparison, the first generation of LFT™ splitter is more cost-effective than other POF-based commercial splitter e.g. Diemount™ grinded splitter, Harz-optic™ splitter, Industrial Fiber Optic™ (IFO) Fused Splitter and many others. The high costs of these commercial splitters are mainly due to the fabrication method that is complicated and implemented with fabrication machine that expensive. For LFT™ splitters, new handwork fusion method lead to low fabrication cost of splitter. The price for IFO™ fused splitter which uses same type as LFT™ splitter cost around USD110 while LFT™ splitter is only cost at ~ USD20. Figure 5 shows the price comparison between the commercial splitter and LFT™ splitters.

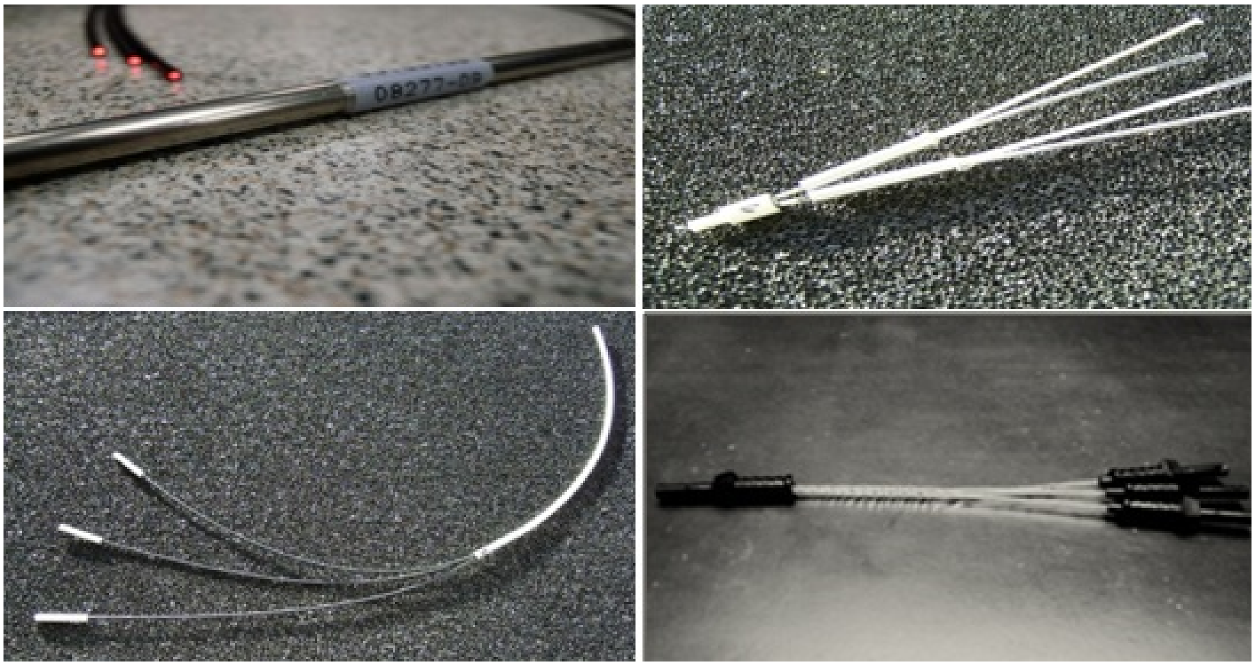


Figure 5. The price comparison between the commercial splitters (a) Industrial Fiber Optic™ (IFO) Fused Splitter (b) Diemount™ grinded splitter, (c) Harz-optic™ splitter, and (d) LFT™ splitters which cost at USD110, USD90, USD50 and USD20, respectively

3.1.2. Second generation

The second generation of LFT™ splitter is the successor of poor-performance fused splitter (first generation). The splitter is remain fabricated through handwork fusion technique. However, the procedures of fabrication method is changed with minor modification whereby the method include a new step particularly for the purpose of fusing the polymer fibers. As shown in Figure 6(a), second generation of LFT™ splitter is designed to have small area of POF imperfection, in which the length of fused and tapered fibers is reduced below 4 cm. The multimode step-indexed *polymethylmethacrylate* (PMMA) POF having a core diameter of 1 mm is used for splitter fabrication. Besides, polyvinyl chloride (PVC) is another material that used as jacket for insulating input and output fiber ports of fused splitter.

In the splitter, the tapered structure is the most critical region in producing low-loss and excellent power-splitting device. The structure has to be designed and fabricated having high fusion degree, in which all POFs are completely fused and coupled so that the wavelength of interest can pass through the coupling region with low power deviation and excellent power-splitting ratio. Therefore, no twisting effetcs are present in tapered region since the twisted spiral fiber is refined via fusion process. Figure 6(b) shows the cross-section of highly fused region in 3 × 3 or/and 1 × 3 tree coupler (splitter). Through fused and pulled region having a cross-section as depicted in Figure 6(b), the optical power input is coupled to each fiber output port with excellent power-splitting ratio. In the other word, one third of power capacity is distributed to every single of output fiber port.

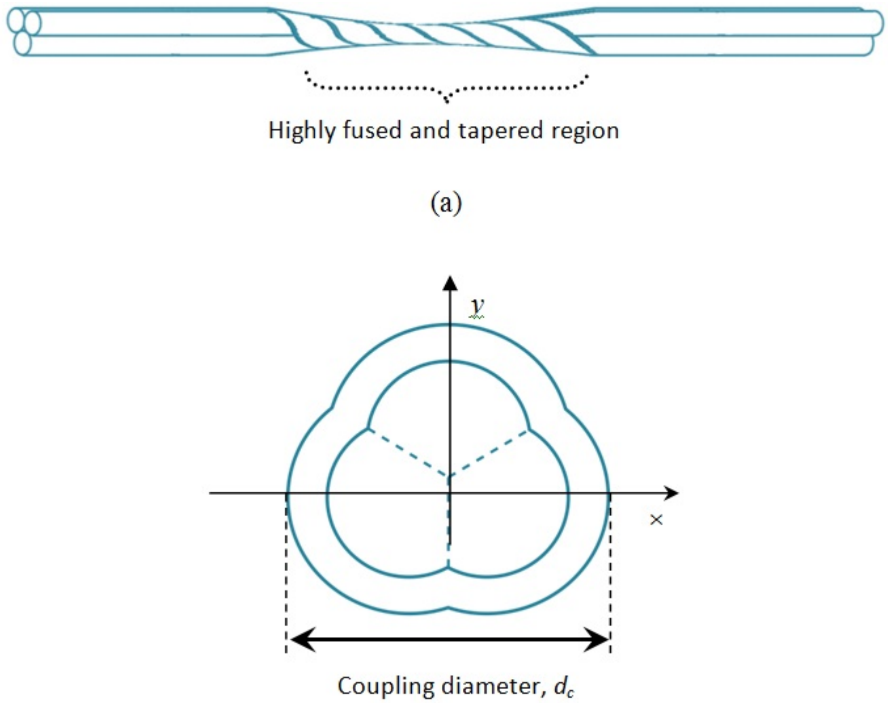


Figure 6. New schematic design of (a) highly-fused taper structure in the center of fiber bundle and (b) cross-section of fused region in fused 3 × 3 biconical coupler

Basically, the term of '*fusion*' defines the act or procedure of liquefying or melting by the application of heat. The maximum temperature required to ensure POFs reach melting point is 85°C [6]. In general, the technique includes four processes; fiber bundle configuration, fabrication of spiral fiber, fusion and fiber tapering. Among these process, fusion is new step that firstly demonstrated in fabrication method for the second generation splitters.

a. Fiber bundle configuration

b. Fabrication of spiral fiber

c. Fusion

d. Fiber tapering

Since the length of tapered fiber is reduced below 6 cm to minimize area of POF imperfection. An experimental characterization was undertaken on the relationship between the length of tapered and optical loss to observe a possible range of tapered length enabling low-loss power splitting. Figure 7 shows the relationship between the length of tapered and optical loss. Figure 8 shows the relationship between coupling ratio and the length of tapered. These results are essential in determine excellent dimension for the fabrication of second generation of LFT™ splitter. Coupling ratio is a parameter that indicates fusion characteristic in fused fibers. The ideal coupling ratio is 0.33 for each output port of splitter. The coupling ratio of 0.33 for each port shows that each fiber has been fused completely to be as a new single core.

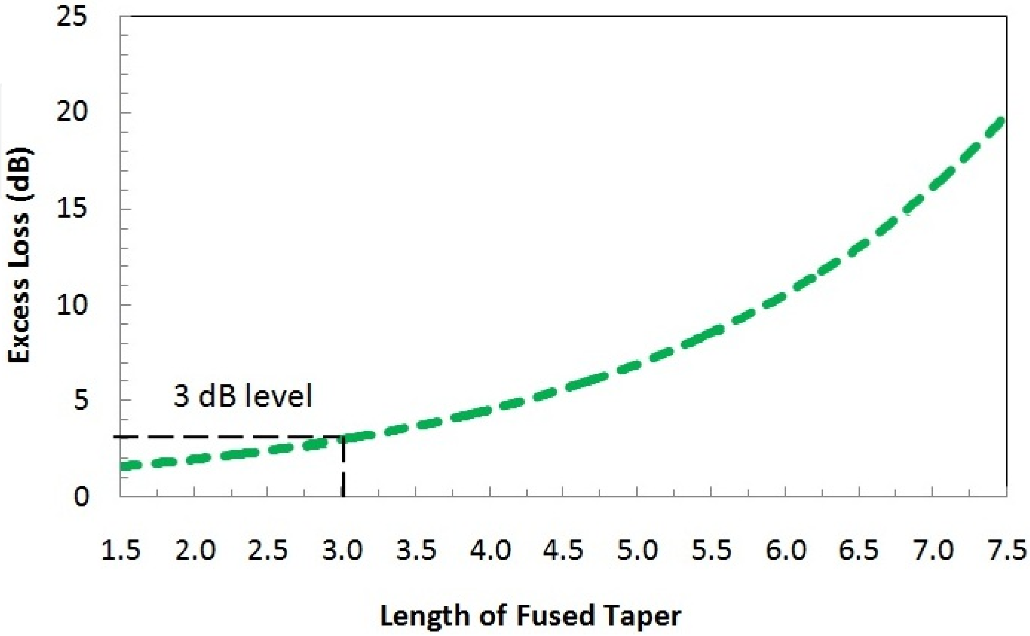


Figure 7. The excess loss of 3 × 3 coupler with range of tapered length vary from 1.5 cm to 7.5 cm; low excess loss < 3 dB occur in coupler in the range of tapered fiber length of 1.5 – 3.0 cm.

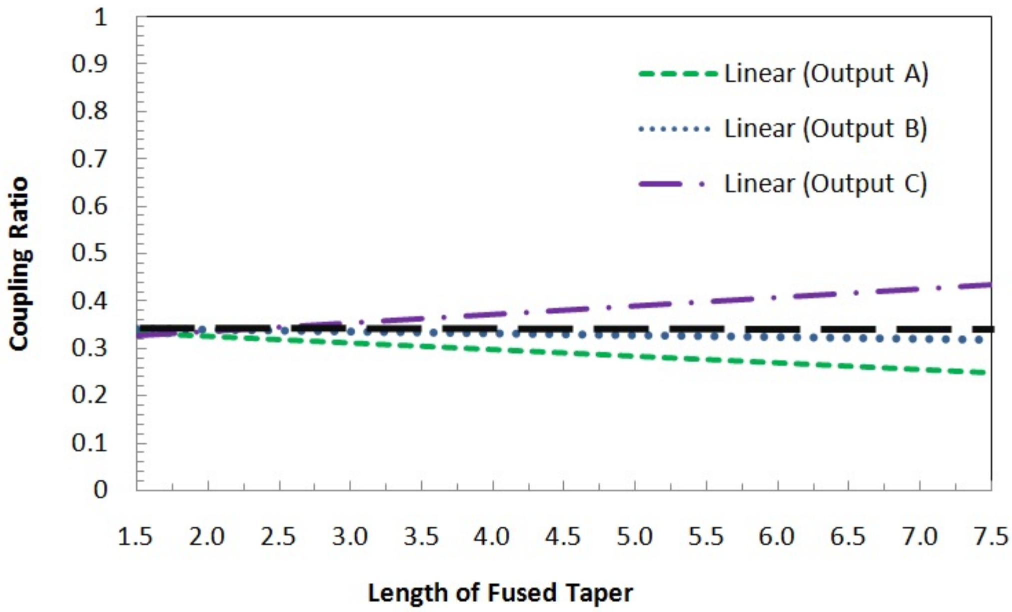
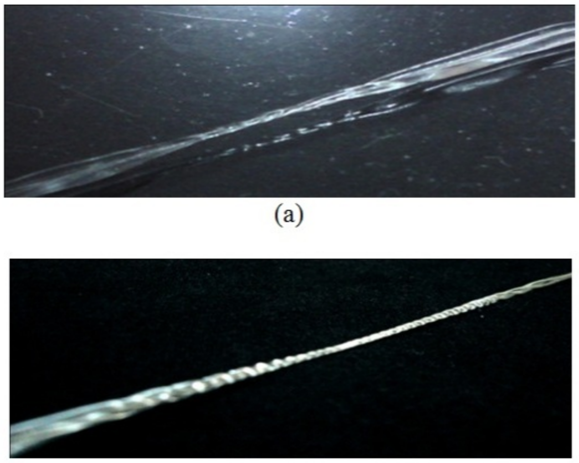


Figure 8. The coupling ratio of 3 × 3 coupler with range of tapered length vary from 1.5 cm to 7.5 cm; the coupler has good coupling ratio (~ 0.33) for each port within the range of 3 cm to 1.5 cm

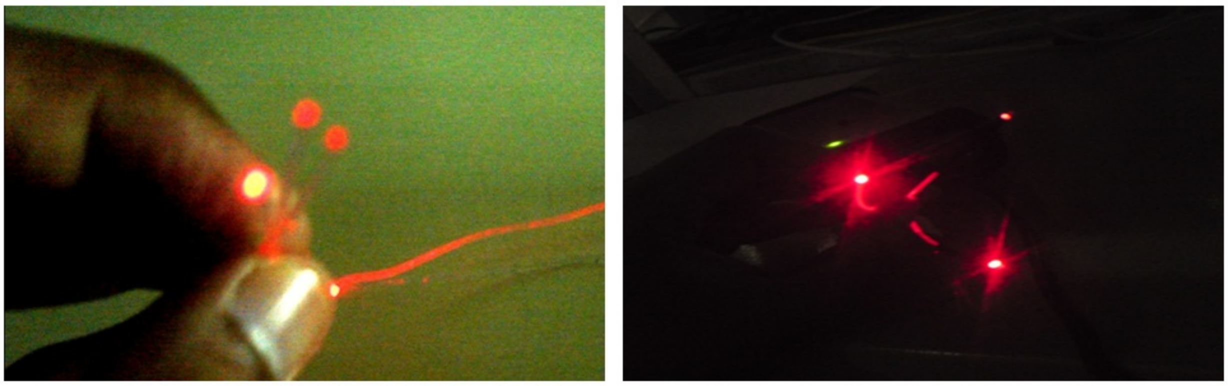
From the graph, it is indicated that low optical loss < 3dB presents in tapered fiber length range of 1.5 – 3.0 cm. Furthermore, the fused and tapered fiber has good fusion characteristic in the range of 1.5 – 2.0 cm since the coupling ratio of each output fiber reach ~ 0.33 within this range. It is found that 1.5 cm is the minimum length required for fused input fiber to be suited into a small channel having ~1 mm diameter in DNP connector. Therefore, the range of 1.5 – 2.0 is selected for excellent dimension of fused and tapered length in order to permit low-loss power splitting and homogenous splitting ratio. Figure 9 (a) shows the structure of fused and tapered output fiber featured in the second generation of LFT^{TM} splitter, in which the diameter of POF cross-section decrease to ~1 mm that fabricated through modified handwork fusion technique.



(a)

(b)

Figure 9. The features of (a) novel highly fused tapered having short taper length and plane surface (without twisting effect) and (b) conventional fused taper having long taper length and ripple surface (with twisting effects)



(a) (b)

Figure 10. The results of experimental optical injection with 650 nm light source; (a) for the first generation of splitter and (b) for the second generation of LFT^{TM} splitter.

As shown in Figure 10 (a), when the only one fused input port is injected with red LED transmitter having 650 nm, it is observed that each output port emits high-intensity red light. In comparison, as shown in Figure 10 (b), in the past experimental injection test, each output port of the first generation splitter emits red light with low power intensity except one output fiber among them. The power splitting with high intensity shows that the second generation of fused splitter is able to perform low-loss optical data splitting.

For the first generation splitters, as shown in Figure 11, the insertion loss of each output port is high which the range is 10 - 20 dB. In contrast to the first generation splitter, the second generation splitters perform with low insertion loss since each output fiber has insertion loss varying from 4 dB to 17 dB.

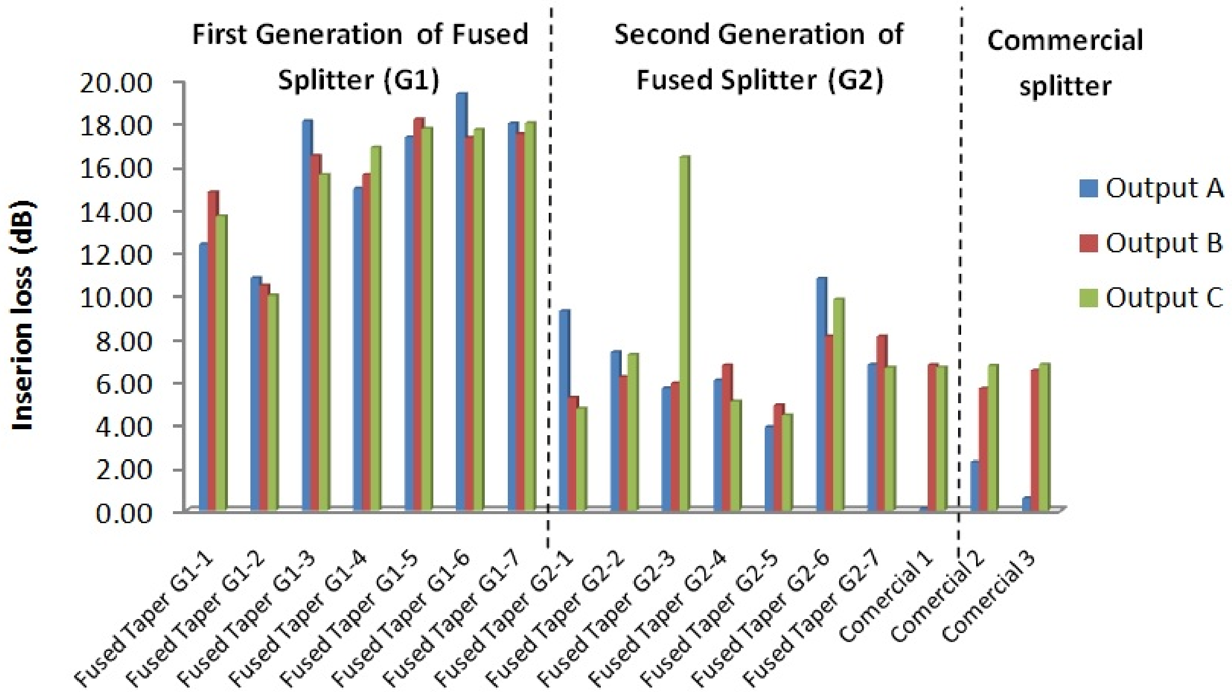


Figure 11. The comparison for insertion loss of each output fiber

Figure 12 shows the result for excess loss of the first and the second generations of LFT^{TM} splitter and commercial splitter. The result shows that the excess loss of the second generation splitter is lower than the first generation; this means that the performance of low-cost fused splitter has been improved effectively.

3.2. Temperature effect experiment

In the experiment, temperature of hot plate was increased by 5 °C to reach stable condition. Figure 13. shows the influence of temperature variation T from 30 °C to 125 °C on output power P_o for the splitter.

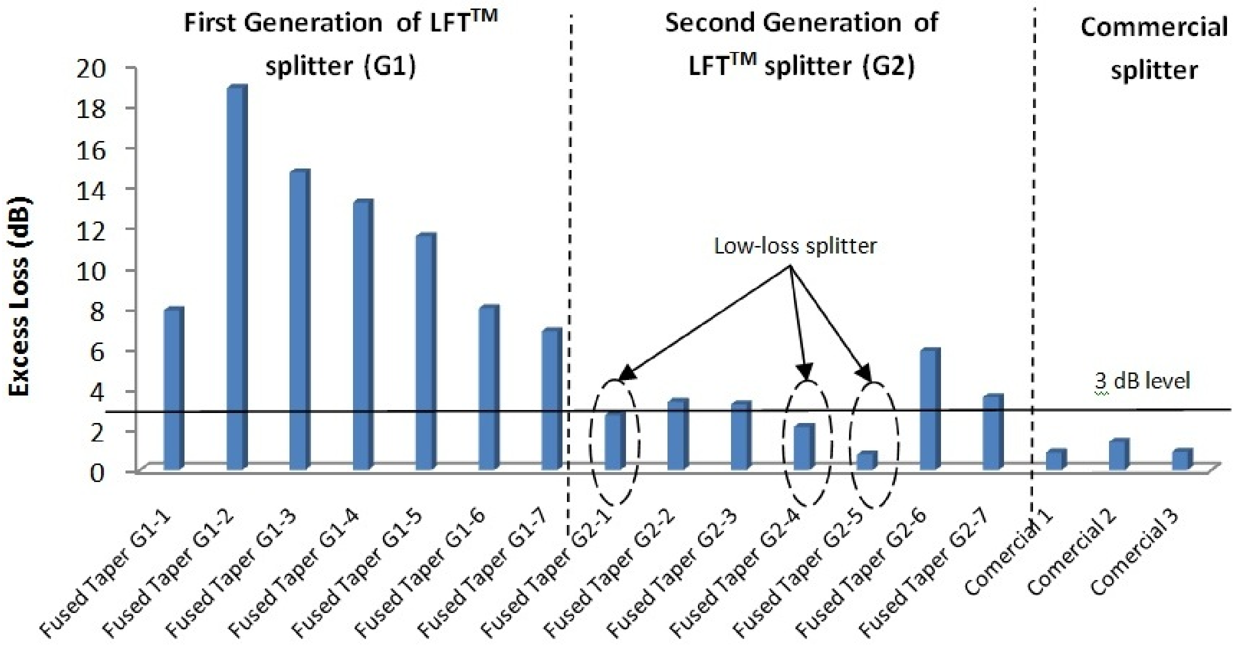


Figure 12. The comparison for excess loss

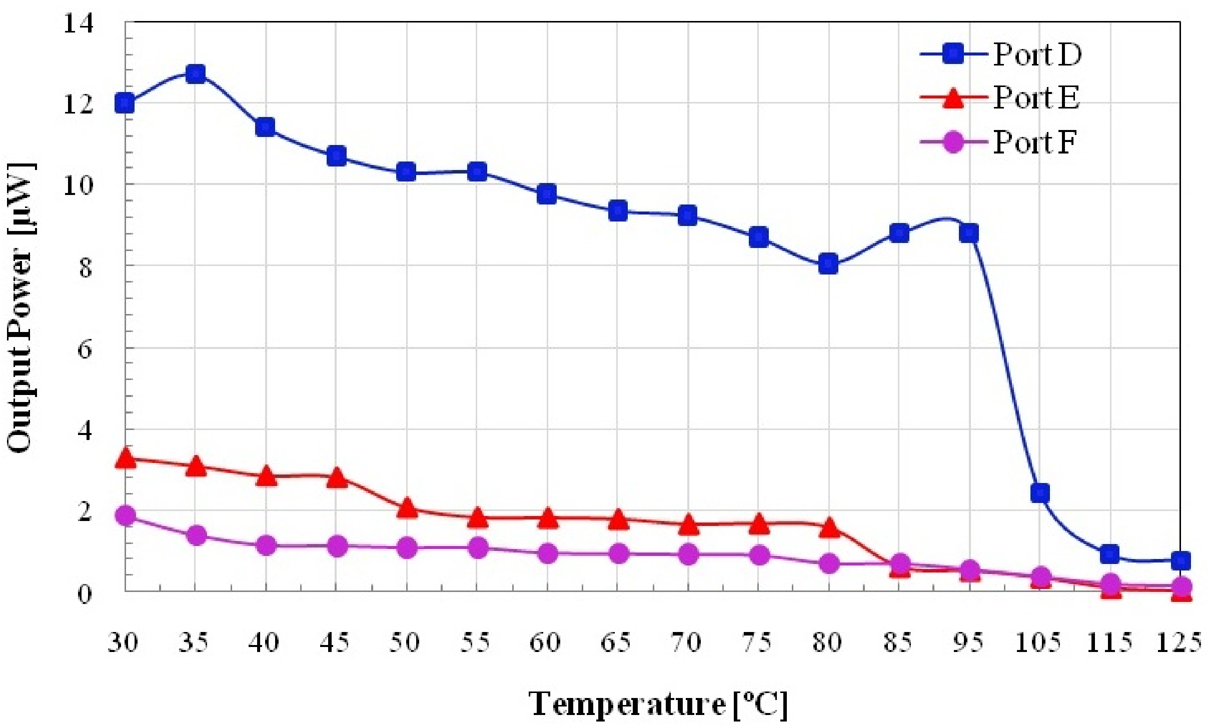


Figure 13. The relationship between temperature variation (30 °C to 125 °C) and output power for Low cost POF splitter

As shown in Figure 14, in each fiber port, output power decreases with respect to temperature rise. The type of fused polymer splitters were completely damaged when heating temperature increased T = 125 °C. The temperature point at 95 °C can thus be defined as damage threshold because the splitter loss temperature stability at this point. Figure 14. shows Excess loss variations as function of temperature for the splitter in bidirectional power injection.

As shown in Figure 15, the excess loss increase gradually with temperature increase. In this case, the splitter has temperature stability while maintaining their performance until T = 100 °C. Figure 15. shows temperature dependence of coupling ratio for the splitter in their throughput and cross-coupled fiber ports in bidirectional light guide propagation.

3.3. Thermal aging experiment

Figure 16. shows the durability of the Low cost POF splitter within 9 hours at fixed temperature T = 105 °. The graph shows that the splitter has high temperature stability within 9 hours when the splitter was exposed to very high temperature. The result shows that the splitter has high durability.

Figure 17. shows the durability of the Low cost POF splitter in term of output power in μW within 9 hours at fixed temperature T = 105 °.

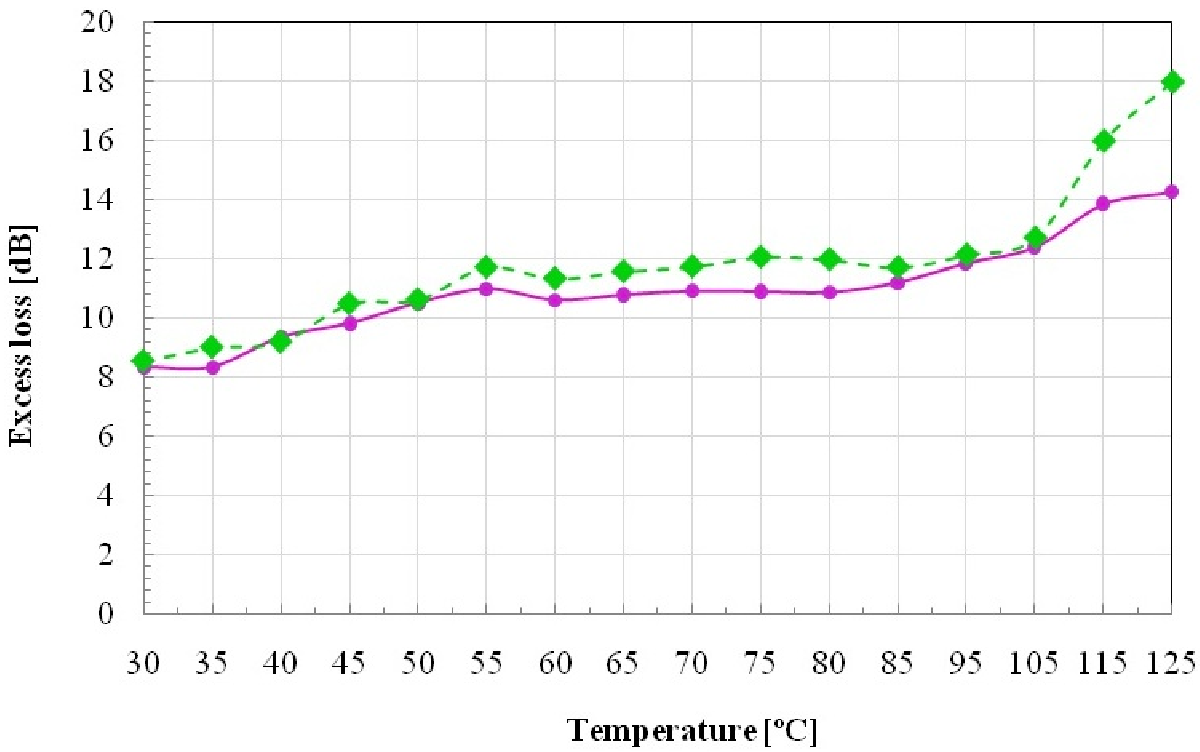


Figure 14. Excess loss variations as function of temperature for the splitter in bidirectional power injection

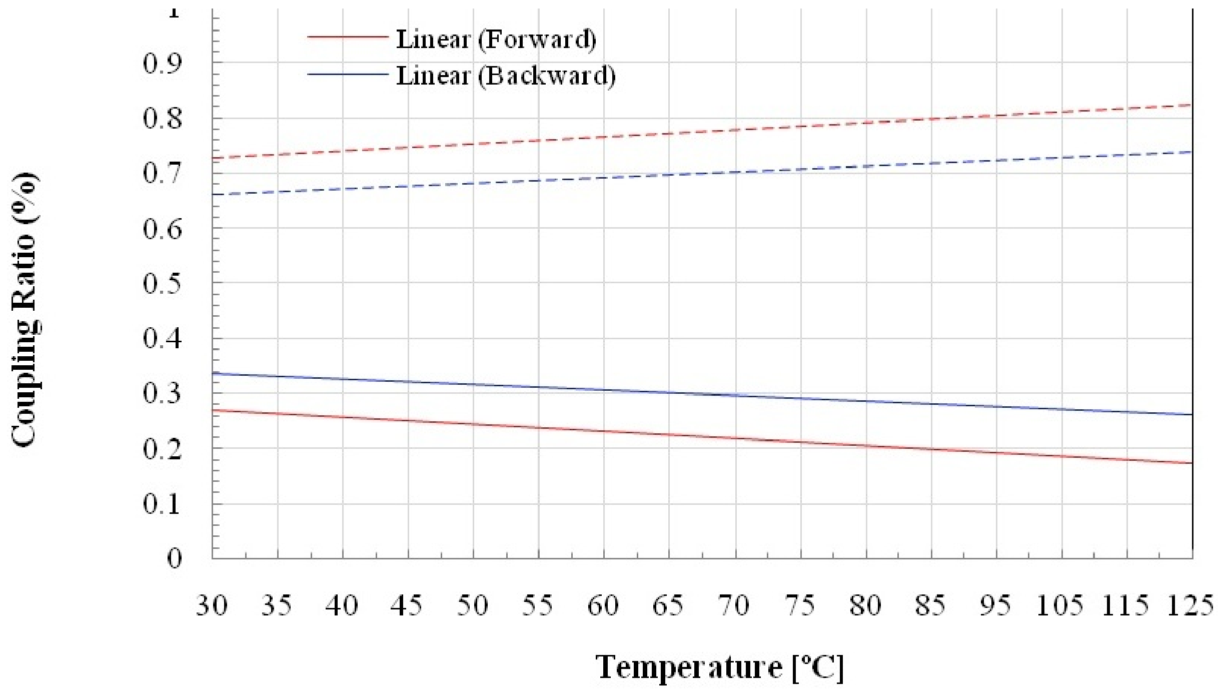


Figure 15. Excess loss variations with temperature increase for the splitter

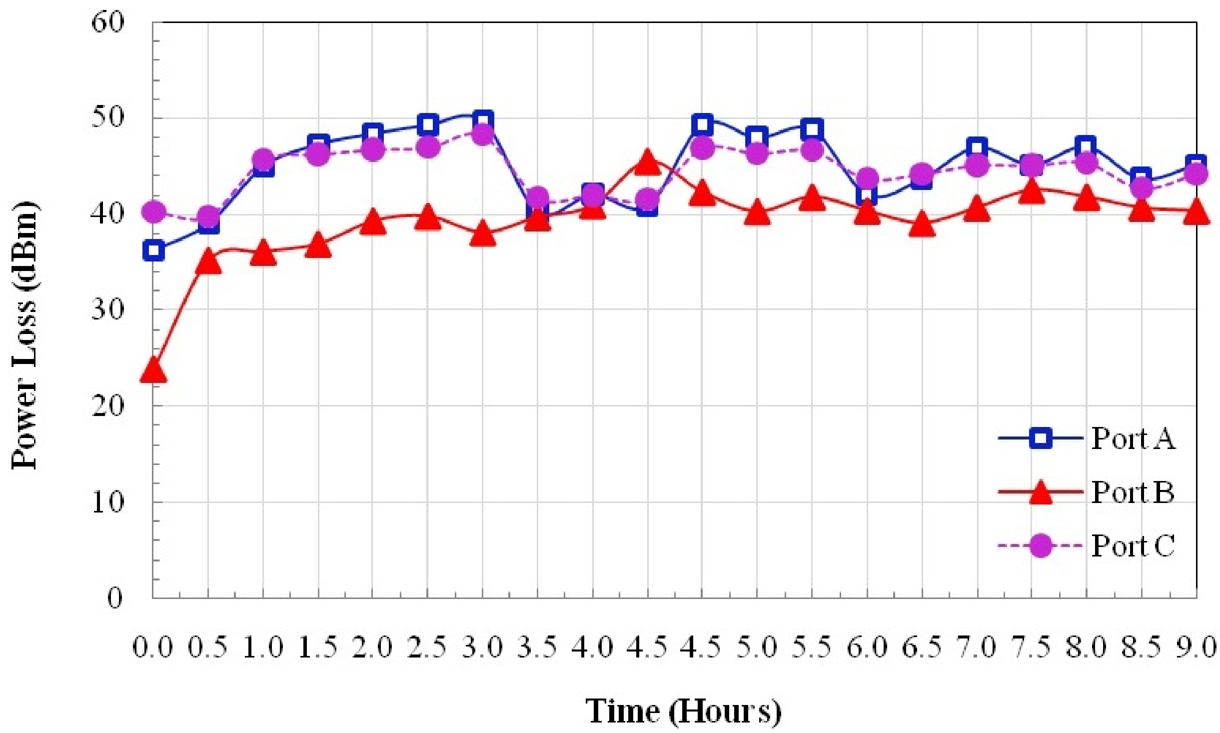


Figure 16. The relationship between heating time and power loss of the splitter

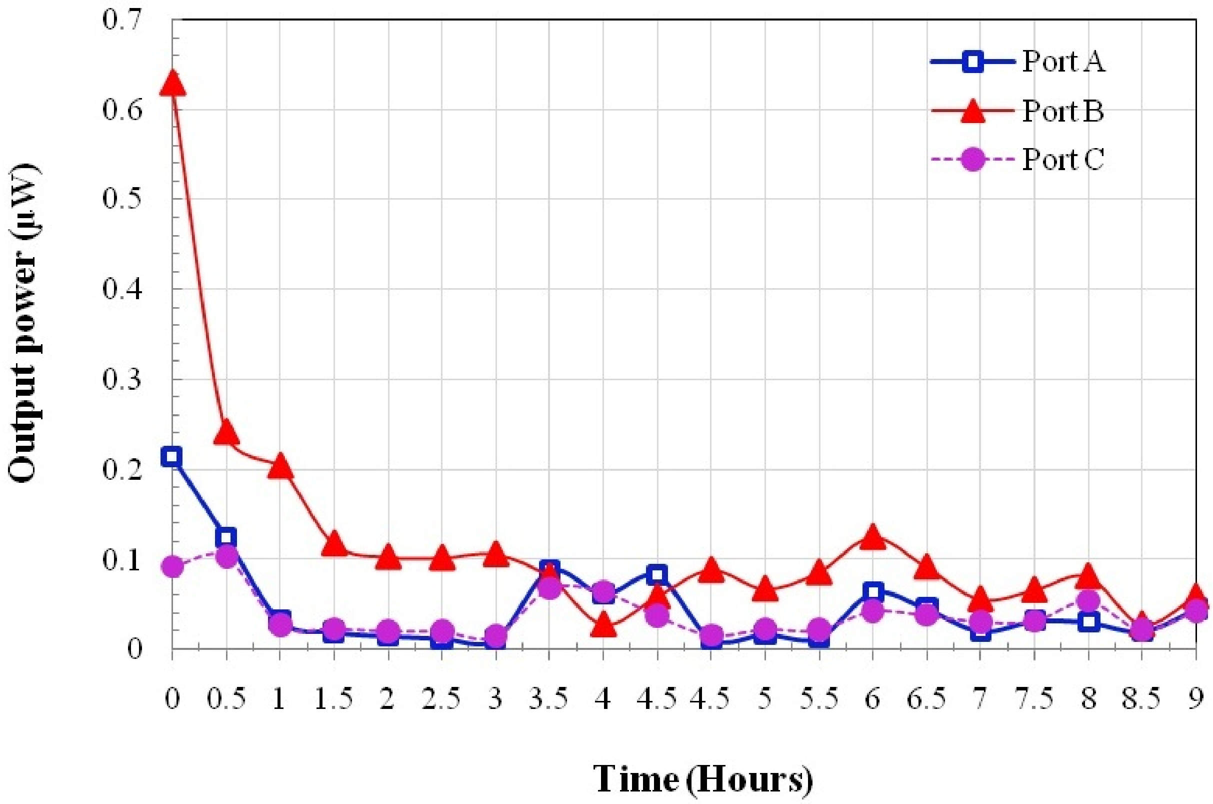


Figure 17. The relationship between heating time and power loss of the splitter

4. Conclusion

In conclusion, the Wavelength Division Multiplexing application over the Polimer Optical Fiber was used for data transmission onboard ship system. The network has been designed via dual redundancy POF-WDM interconnected deck-by-deck using mesh topology, introducing the design philosophy of Dual Redundant POF-WDM (DRePOF-WDM) backbone network. OADM acts as switches is used to make redundancy circuits [5, 8]. Four different wavelengths has been used to connect the overall equipments throughout the ship. This system is very promising hence the payback of less overall ship's weight and therefore will improve the speed and less fuel consumptions of the ship for future new build or ship embarking life extension program. The efficiency related to the temperature effect and thermal aging has been observed in order to optimized the onboard ship communication network. Any system or equipment to be fitted onboard can use this existing DRePOF-WDM backbone.

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