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A Novel Star Topology POF-WDM System

Improving Current Technology for In-vehicle Infotainment system

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***Abstract*—A novel WDM-POF technology, a cost-effective and eco-friendly optical data transmission unit is the most updated and promising innovation that will revolutionize interior automotive infotainment system which all data can be simply sent in visible light format rather than in electrical format at high speed data transmission. Infotainment system is such all-in-one entertainment media system and the latest trend in automotive network in which many appliances such as interactive gaming console, video player, ethernet navigator, camera reverse sensor and many other appliances can be integrated and equipped in car interior in ring topology. With novel WDM-POF 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 such as video, audio, Ethernet as POF is the most updated cabling technology replacing conventional copper wire for short-haul communication.**

Keywords-component; pmma; pof; polymer; optic; wdm

I. INTRODUCTION

Recently, silica or glass fiber (GOF) has become a '*trendsetter*' in fiber to the home (FTTH) technology to provide a high capacity communication data to be transmitted to a user from central office. But, a few people or even service provider alerts of the safety concern of the technology, especially for user.

Laser, as the best transmission media to be utilized together with GOF could be very dangerous once the leakage occurred from the body structure of the GOF. A very high intensity ray of light released by fiber can possibly burn a human retinas and lead to a permanent blind. It was quiet hard to be imagined that if this silica-based technology implemented inside the vehicle where users are directly use this data transmission services.

Meanwhile, combination between plastic optical fiber (POF) which very suitable to a light emitting diode (LED) technology can be seen as the best solution to provide a communication data services which is more safe and not to mention about the cheapest price we can get for the initial and fabrication cost. 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 GOF, POF remains flexible while having a large diameter core and high numerical aperture, lead to a high capacity they can bring along the fiber [1, 2].

Media Oriented Systems Transport (MOST) is one of sophisticated cooperation which also use this POF-LED capability to transmit a number of signals represent a different data transmission (such as video, audio, *etc*) use a ring topology system network (refer Fig. 1).

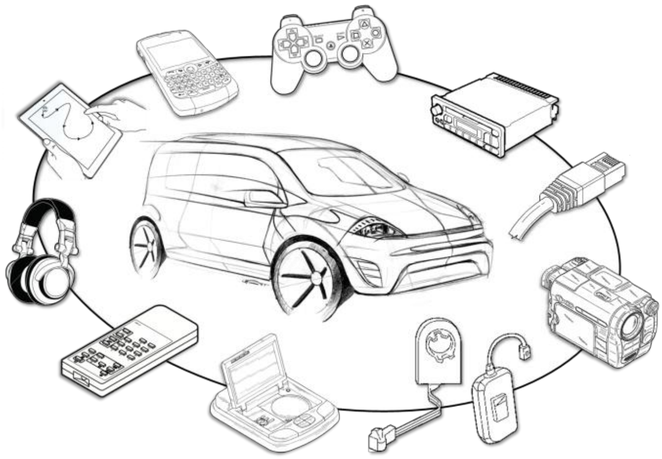

Figure 1. Nowadays, a ring topology in-vehicle Infotainment system facing a serious problem, regarding a vital single transmission line with no '*backup*' pathway will become a fatal once failure occur along the line.

MOST, a gigantic company from German, has provide a high bandwidth data transmission service using POF and LEDs as light source. They offer a multimedia networking technology based on ring topology network to distribute audio and video signals in real-time control along the single transmission line [3]. This topology promising a higher bandwidth together with a better speed rate, although, the greatest weakness was still found once failure occur along the single transmission medium, all the data transmission process will be affected, lead to a total collapse on the system.

In this research, we try to provide a better solution to mitigate a bandwidth and failure issue in ring topology which many of international carmaker using this network for their infotainment system. By utilizing a WDM-POF system in star topology, we believe that a total breakdown issue in data entertainment distribution system inside the vehicle will be solved.

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II. METHODOLOGY

A. *WDM-POF System Design*

POF links are becoming increasingly popular for applications such as home networking, automotive field, board interconnects and even domestic hi-fi systems. Unlike GOF, POF remains flexible while having a large core and higher numerical aperture [1], lead to a high capacity they can bring along the fiber. Among the passive components for POF applications, optical splitter/coupler plays an important role that is borne out by the availability of a complete line of products. There have been many techniques of produce a POF coupler. These techniques include; thermal deformation, twisting and fusion, side polishing, grinding, chemical etching, molding, reflective body and biconical body [4].

Our recent communication system over POF able to increase a bandwidth in a form of wavelength division multiplexing (WDM) system in start topology allows the transmission of information over more than just a single wavelength (color). WDM is a technique that multiple signals are carried together as separate wavelengths (color) of light in a multiplexed signal. As shown is Fig. 2, 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. What so special about the network is when one of the signal (audio, video, Ethernet, etc) is breakdown it will not affect the others, unless failure occur in the main transmission line.

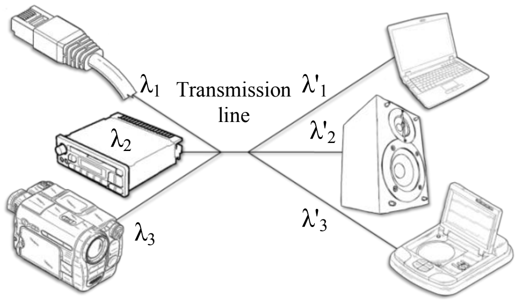

Figure 2. Proposed design for WDM-POF network in star topology able to transmit three different signal; ethernet (λ_1), audio (λ_2) and video (λ_3) at the same time through one transmission medium.

In WDM-POF system, many transmitters with different lights color to carry single information. For example, red light with 665nm wavelength modulated with Ethernet signal while blue (λ_1), green (λ_2), and yellow (λ_3) lights carry image information, radio frequency (RF), and television signal, respectively [8]. The light has to be combined by the Multiplexer (MUX) and split by means of the Demultiplexer (DEMUX).

For more than 15 years, WDM widely expanded the overall transmission bit rate in GOF-long-range systems, because of its easy expandable system approach: adding one new source with different transmission wavelength in combination with a MUX/DEMUX-element expands the usable transmission rate directly by this source. Due to the attenuation of POF, the wavelengths from 400nm to 700nm are used for the WDM, as shown in Fig. 3.

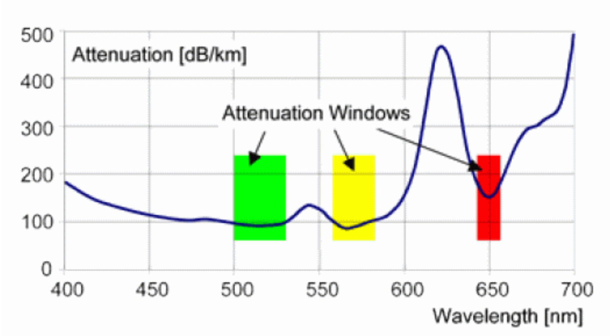

Figure 3. Attenuation behavior of a POF in the area of the visible spectrum.

Theoretically, 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. Conceptually, POF splitter has a same function, operates to couple or combine several optical data pulse as a single coupled signal. Therefore, the development of wavelength division multiplexer based on POF splitter is possible. A low-cost solution for POF-WDM system application will be presented.

Wavelength division multiplexing has several advantages over the other presented approaches to increase the capacity of a link:

- Works with low speed equipment [5].
- Works with existing single mode communication fiber [5].
- *Is transparent*: Doesn't depend on the protocol that has to be transmitted [5, 6].
- It is easy for network providers to add additional capacity in a few days if customers need it. This gives companies using WDM an economical advantage. Parts of a fiber can be leased to a customer who then gets fast network access without having to share the connection with others. The telecommunication company on the other hand still has an independent part of the fiber available for other customers [5, 7].
- *Is scalable*: Instead of switching to a new technology, a new channel can easily be added to existing channels. Companies only have to pay for the bandwidth they actually need [5, 6].

A novel fused POF splitter has been fabricated by a fusion technique, as an effective transmission media to split and recombine a number of different wavelengths which represents different signals. Three different wavelengths will be fully utilized to transmit three different sources of systems; LAN connection Network, radio (audio) and video transmission system. Red LED which in 665nm 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, and blue LED with 470nm wavelength represents an audio transmission system inside the house.

Special interference filters will be placed between the splitter and receiver-end to make sure the entire WDM system can select a single signal as desired. This interference filters solutions are well-known in the infrared range but also available for the visible spectrum.

For the filter design which able to eliminate unwanted signal and select the wavelength of the system as desired. Some parameters, such as optical output power, power losses, optical noise to ratio and crosstalk of the devices will be observed, and not mentioning about the effect of filter placement and the efficiency of the WDM-POF system itself.

B. A Novel Fused Splitter

Two key components of the WDM-POF system have been produced in this paper are the novel fused splitter and the special filter as a very sophisticated prototype in WDM-POF network application. In this research, we propose a novel fusion technique that is low-cost and simple using Bunsen burner and metal tube to perform indirect heating process for the fabrication of POF-based splitter with minimal structural imperfection, low in excess loss and better homogeneity in splitting ratio.

In general, the term of '*fusion*' defines the act or procedure of liquefying or melting by the application of heat. The fabrication method is particularly different from the conventional biconical technique. Since the fabrication of polymer fiber does not need to be exposed to very high temperature, POFs are liquefied by indirect heat exposure of Bunsen burner with yellow flame (1000 ºC), instead of oxyhydrogen burner (heating temperature T= 2660 ºC) that was applied in conventional method to produce GOF based splitter [8, 9].

In order to perform indirect heating process, metal tube is used to preserve POF structure from direct heating during fiber fusion process. Heating a bundle of POFs directly to the burner flame causes POFs vulnerable to serious damage in its core.

In novel fusion method as shown in Fig. 4, the controllable parameters are fusion length L_f, number of twist T, fusion time t_f, pulling length L_p and other parameters. The multimode step-indexed POF having a polymethyl methacrylate (PMMA) core diameter of 1 mm was used as material fabrication for second-generation splitters. PMMA is one of the most commonly used optical materials. Its intrinsic absorption loss is mainly contributed by carbon–hydrogen stretching vibration in PMMA core [8]. In addition, polyvinyl chloride (PVC) is another material that was used as jacket for insulating the POF ports.

According to Kagami in Toyota R&D review report in 2006 [10]**,** high cost of commercial splitter/coupler was raised as critical challenge for the development of wavelength division multiplexing (WDM).

The fabrication method using expensive BFT machine is considered as factor of high production cost**.** Through conventional BFT fabrication method, the diameter of the fused taper region is extremely small, in which stress is concentrated and result in low survivability of structure.

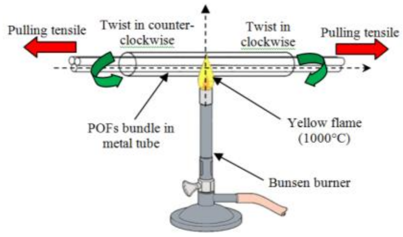

Figure 4. The procedure of novel fusion technique with Bunsen burner and metal tube.

In fabrication of POF-based fused 1 × N splitter or N × N coupler, the tapered fiber structure is given high priority as the structure give major impact on optical loss in device. In theoretical consideration, the loss of device is mainly caused by extrinsic factor due to structural fiber imperfection. Along fused tapered section, many structural imperfections are accompanied in fused splitting/coupling device such as twisting-effect, elongation, diameter change and polymer degradation [11-13].

Fibers with imperfection or defection cause light scattering in fibers as the light transferred to cladding medium and leak to atmosphere and result in optical loss. In novel fusion technique, four main processes have to be gone through for producing splitting/coupling device with minimal fiber imperfection to provide low-loss optical data transmission (less than 3 dB). The process includes fiber bundle configuration, spiral fiber fabrication, twisting-effect removal and fiber tapering process. In twisting-effect removal process, particular twisting and pulling procedures are practiced to fabricate a highly fused fiber which ensures that the optical data signal can be distri*but*ed into N division with better homogeneity in splitting ratio (reach 1/N of input power, where N is number of output power) may be carried to other output fibers) to provide effective multiplexing solution for WDM application.

C. Characterization Process

In our research project, the study is divided into three stages; fabrication parameter optimization, device fabrication and performance characterization. For optimization, a comparative study is undertaken to determine the tolerance between the analytic and the experimental result. For second stages, before a novel fusion technique is practiced, the thermal behavior of Bunsen burner on POF bundle is studied. The temperature of Bunsen burner is tuned and optimized to obtain yellow flame (minimum heating temperature T = 1000 ºC). The proposed fusion technique is formed and formulated using optimal fabrication parameters. The method includes four processes; fiber bundle configuration, spiral fiber fabrication, twisting-effect removal and fiber tapering process.

III. RESULTS AND DISCUSSION

From the design of 1 × N splitter, the fused taper-twisted part, where every N number 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 [12, 14, 15].

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

A. Bidirectional test

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 [16].

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. 5.

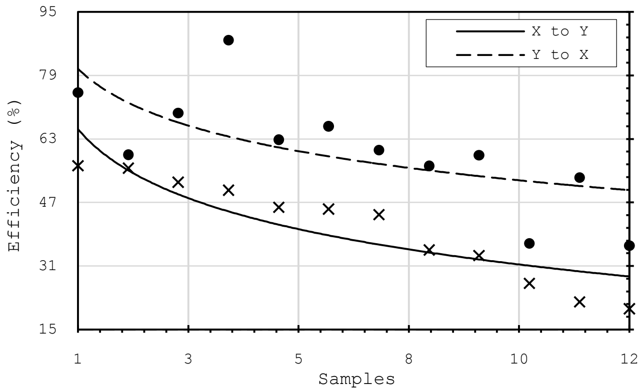

Figure 5. Efficiency for fused bundle fibers from best to worst sample in both directions and the linear function of the 1 × N.

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 [17].

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, 18]. 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.

B. Coupling Process Testing

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 splitter and the receiver section. In this research, two different LED was utilized; red LED (665 nm) transmit an ethernet line through LAN connection and green LED (520 nm) 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 POF splitter, and optical power meter was placed in the output port right before the receiver port, as shown in Fig. 6. It shows that red LED has 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.

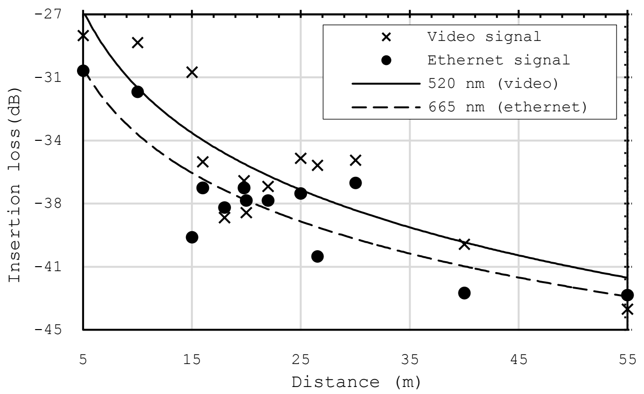

Figure 6. Power loss comparison between 520nm and 665nm signals, green LED represent the video quality of the system while red LED represent the rate of download and upload through ethernet line.

The deviation between both signals was reach 3 dB, 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. 7 (*next page*).

(a)

(b)

Figure 7. Video quality of WDM-POF system of (a) 10m and (b) 50m of optical transmission line trough 2-channels of WDM-POF in star topology.

IV. Conclusion

In conclusion, before the concept of WDM is applied, single channel or single wavelength is used for POF transmission and this leads to bandwidth limitation [19, 20]. WDM system solves this problem by increasing the bandwidth of POF system. The concept of WDM shows performance that has become the alternative in in-vehicle optical networks, not to mention about their advantages both visibility and workability.

A fabrication technique has been used applied to produce an optical splitter based on POFs using PMMA SI-POF. Fabrication and characterization stages have been conducted to optimize the functionality of the low cost optical devices such as splitter, coupler, filter, etc to be integrated into in-vehicle infotainment system. This experiment shows the transmission of a number of signals with different wavelengths carried along the (single) fiber. The concept of multiplexer and demultiplexer are the basic of this system. The system only utilizes two colors for the transmitters and also the filters for the demultiplexer which are green (λ = 520 nm) and red (λ = 665 nm). Light source from the red and green transmitters are coupled and pass through multiplexer and separated using demultiplexer.

Color filters also played their role increasing the insertion loss from the WDM-POF system, but the quality of both output ports are not radically destroyed due to the color band gap from the filter itself, speed rate of the Ethernet signal 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 handmade 1 × N splitter itself.

Red LED with a 665 nm wavelength has been injected to different color filters for the purpose of characterization test in order to analyze the level of power efficiency of the demultiplexer. Analysis shows that efficiency maintains for filter of the same wavelength as the transmitter while other range of wavelengths will mostly be filtered out or blocked. This main idea is fully utilized for the designing of demultiplexer for in-vehicle infotainment system. Final analysis shows that efficiency of the filter can reach up to 70%.

The WDM-POF has a great potential to be employed as an economical network to be applied in automotive field due to it advantages which are low optical loss and low cost. Star topology in-vehicle infotainment system seems to be a huge competitors for current technology in automotive field which still using a traditional ring network. Bandwidth and failure issue can simply solve through their independent data transmission lines.

An intensive study suggested in order to enhance the homogeneity and efficiency of the network. Although fusion technique facing a great constraint regarding the consistency of producing splitter as it was almost not possible to fabricate POF splitter with better and consistent performance. This WDM-POF network can be improved progressively through experiences and practices. These optical devices are highly recommended for in-vehicle infotainment system as the network is quite cheap compared with other commercial devices. Furthermore, both fabrication and installation technique are easy, simple and suitable to be used for short-haul communication application.

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