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Investigation of coupling loss caused by misalignment in optical fiber

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ABSTRACT

In a fiber optic communication system, optical fiber is used as a transmission medium consisting of a flexible filament that guides the optical signal to be transmitted from the transmitter to the receiver or vice versa. Like any other communication medium, the optical fiber cable faces some losses that can be caused by the material and length of the fiber. One of the main reasons for losses in optical communication systems is misalignment during the fiber to fiber joining process. This type of loss is also known as coupling loss, which is caused by an imperfect physical connection between two fibers. The coupling losses are most often caused by three misalignment issues: end gap displacement, lateral displacement, and angular displacement. The main goal of this article is to investigate coupling loss caused by misalignment in optical fiber using the Modicom 6 module. Before we can find a way to reduce the coupling losses in the fiber optic system, we need to have a concrete idea about the nature of coupling losses due to misalignment. An ideal fiber coupler should not lose light and should be insensitive to light dispersion.

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1. INTRODUCTION

An optical fiber coupler that transmits light from one fiber to the next. It is one of the essential segments of an optical fiber network. It also increases the number of terminal connections allowed in optical fiber communication system expansion. Optical fiber couplers can interface at least one fiber to permit the transmission of light waves in different paths. Inputs from multiple sources can be combined into a single output [1]. Fiber optic couplers are either active or passive. Active optical fiber couplers require an external power source to operate, whereas passive optical fiber couplers can operate and redistribute optical signals without requiring optical to electrical conversion. An active coupler is an electronic device that divides or joins the signal electrically and utilizes fiber optic sources and detectors for both the input and the output, whereas a passive optical fiber coupler reallocates the optical signal without any of the optical-to-electrical conversion [2]. One method for achieving low loss in fiber communication is to reduce the material's impurities [3]. Mass-production of optical fibers was possible with low optical propagation loss by the vapor phase axial deposition (VAD) method, which produced fibers with low hydroxyl content (low-OH) [4]. Some of the specialty fibers, optical fiber devices, and fiber lasers are manufactured using the VAD method and other technologies [5]. Polarization beam combiners (PBCs) were introduced for better performance and improved reliability than the usual PBCs [5], [6]. A grating coupler made of optical fiber [7] is known as an optical fiber grating coupler (FGC). It's a coupler with a refractive index modulated grating printed on the tapered section. It may be utilized with an optical switch since it has cross phase modulation inside its grating [8]. Nevertheless, the switch needs a high-power control light for the switching, hence it’s seldom used in reality [9]. Optical components with polarization-dependent characteristics typically degrade system performance. A system with a wide range of wavelengths (20–30 nm) suffers a lot. If the pump and signal wavelengths are approximately 1.48–1.55 µm, the polarization-dependent loss (PDL) is too low. A lower wavelength was not suitable for the application to wavelength-division multiplexer (WDM) systems [10]. WDM fiber optic networks require 1×N couplers, which are cheaper, smaller, and have less excess loss [11]. A new multi-core plastic optical fiber, commonly known as MC-POF, is introduced to provide a better splitting ratio and a smaller distinction in modal power distribution. MC-POF usually contains polymethyl methacrylate-based 19 cores with double clad layers. It has also been shown to be notably stable in the modal power distribution and to have a better splitting ratio compared to a conventional optical coupler [12].

An analysis has been conducted on a six-port coupler that contains three even-matching long-period fiber gratings. The performance of this coupler is investigated in connection with variables such as coupling coefficient, evanescent field, and comparable fibers. This novel coupler can also be used for broadband filtering, signal processing, and add/drop multiplexing [13]. It is possible to avoid the cost of optic-electronic-optic (OEO) conversion by interconnecting all-optical and all-fiber interconnection devices. It ensures excellent transmission capacity and data rate. Especially in the dense metro area, it is required to convert the wavelengths of both the signal and the medium where they spread within a dense wavelength division multiplexing (DWDM) system and local area network (LAN). Wavelength and mode selective couplers (WMSC) were robust, compact, had higher efficiency in mode conversion, lower insertion loss, and were suited for optical interconnections [14]. Photonic crystal fiber (PCF) contains even air holes going through the fiber cladding. The PCF core has a hole in the fiber center. Its characteristics were largely studied after its initial invention in 1996 [15]. It has a wider range of wavelengths [16], a controllable dispersal property [17], and a larger mode for field diameter [18]. An optical fiber coupler can function as an optical switch, a WDM, and a power splitter. It is also commonly employed in optical communications due to the increased use of PCFs. Two types of PCFs were fused into an optical coupler with the fused biconical tapered (FBT) method [19]. SMF-28 fiber’s efficiency was one of the obstacles to its commercialization. Several methods have been taken, including couplings in silicon-on-insulator (SOI) layer 220 nm c-Si, with single or multiple tip tapers or tridents [20]-[22]. Edge couplers have been designed, manufactured, and tested to target industry-standard SMF-28 silicon photonic fibers. These couplers are fabricated on a SOI platform using a SiN reverse taper and include a process for removing the etch-based substrate that prevents silicone substrate leakage [23]. Numerous studies on the polarization of the fiber (PMF) coupler with novel transmission properties have been conducted [24]. With the input light polarized in circular and elliptic directions, the novel coupler is evolved into an inline polarizer and a conventional PMF coupler. When linearly polarized light is applied, the coupler behaves identically to a 3 dB PMF coupler. These unique joints have a wide range of applications in optical sensor systems, including fiber optical hydrophones, optical fiber current sensors, and optical fiber gyroscopes [25], [26]. The output power of a single-mode fiber-optic coupler affects the length of the coupling zone. A spiral micrometer can precisely measure the characteristics of a fiber-optic coupler [27]. The fiber coupler is commonly used in integration optics. It collects light in a specific direction, making it a polarimeter, filter, or splitter. Due to small cubage, corrosion resistance, and easy demodulation, coupling zone distortion can affect output light ratio, low cost, and anti-EMI [28], [29]. Semiconductor quantum dots (QDs) have become an alternative material in light-emitting diodes, wavelength conversions, or even optical amplifiers [30]. In the hypothetical study, the authors estimated the performance of a quantum dot fiber amplifier (SQDFA) constructed with a fiber coupler coated with PbS QDs film. QDs have many features, such as broader bandwidth, faster gain, higher saturation power, and less noise [31]. Fiber lasers doped with Yb have higher efficiency, higher power scalability, and exceptional beam quality, making them suitable for optical communications, military applications, material processing, and medical laser therapies [32]-[34]. Researchers employed a pair of serially cascaded fused tapered couplers to adjust the power of a highly efficient, long-pulse fiber laser. To explore photoelastic effects and linear shifts in transmission spectra, torsional stress is applied to a few coupling zones [35]. Optical vortex beams (OVBs), also known as broadband selective couplers, are used in orbital angular momentum beams [36], optical tweezers [37], quantum computation [38], and data transmission [39] to supply a femtosecond optic vortex pulse of OAM ±1, ±2 [40] topological loads. With WDM couplers and fiber Bragg gratings for wavelength separation, a wavelength multiplexing network addresses various frequencies using fiber optic sensors. The concept of network multiplexing is implemented, sensors are placed in the network, and self-referencing properties are introduced. The performance of such a network was assessed by investigating the measurement characteristics like crosstalk, power budget and resolution of the sensing setup [41].

An investigation and analysis of coupling loss due to the misalignment between two optical fibers have been performed using the Modicom 6 module. The rest of the paper has been organized as follows: all the experimental setup, including a brief introduction to Modicum 6, has been discussed in section 2. Section 3 presents the measured results and analysis. Finally, a conclusion has been incorporated at section 4.

2. METHOD

2.1. Introduction to Modicom 6

Modicom 6, designed for single-board applications, is a fiber-optic transmitter/receiver module that provides two independent fiber-optic communications links. Alternatively, it can be used as a stand-alone system, allowing the user to compare different methods of modulating a light source with an analog or digital signal, as well as different methods of demodulating the received output from the fiber-optic cable. A Modicom 6 module may also be used to establish a fiber-optic communications link between a pair of Modicom transmitter/receiver boards, and two Modicom 6 modules may be used to establish a full two-way serial fiber-optic communications link between two microcomputers. This module allows an analog signal to be used to modulate a light source by frequency modulation. The on-board function generator block provides an adjustable-amplitude 1 kHz sine wave and a 1 kHz square wave to use as a modulating signal. The module can be used as a stand-alone device to test alternative modulation methods, transmitting a light signal through fiber-optic cable and recovering the original signal at the receiver. Both analog and digital signal sources provided on the board may be used to modulate (amplitude) a light source directly as well as to illustrate the advantages of digital modulation as far as recovery of the original signal is concerned. Both available fiber-optic links are utilized to make a direct comparison between the different modulation methods. Figure 1 depicts the Modicom 6 module's circuit diagram.

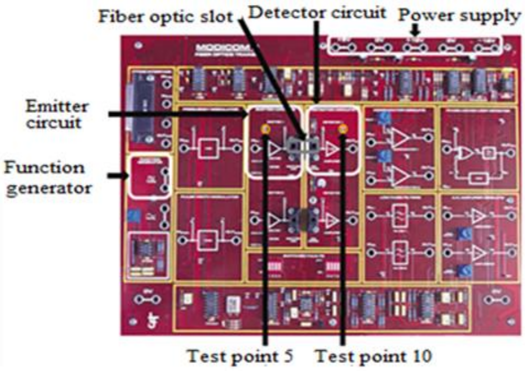

Figure 1. Fiber optic module (Modicom 6)

2.2. Investigation of coupling loss

The investigation of coupling loss is carried out with the aid of Modicom 6, a fiber optic transmitter/receiver module that is used to study coupling losses in fiber optic communications. The main goal of the experiment is to measure coupling losses for three different misalignment issues: end gap displacement, lateral displacement, and angular displacement. The Modicom 6 requires +5 V at 100 mA and ±12 V at 200 mA. First, we need to connect the emitter 1 input to the 1 kHz square wave output of the function generator block. To send data over a fiber optic link, a circuit must first generate input signals. Both a variable-amplitude sinusoidal signal and a fixed-amplitude square wave signal are available as outputs.

Furthermore, two 0.5-meter-long fiber optic cables are used to make connections among the emitter circuit, optical fiber alignment module, and detector circuit. Figure 2 shows a block diagram representation of the optical fiber misalignment experiment. The test and measurement of coupling loss have been carried out by adjusting the optical fiber alignment module for three parameters: end gap displacement, lateral displacement, and angular displacement. The result of Vpk-pk is obtained by connecting the oscilloscope to the test point 10 of Modicom 6. The whole connection setup is presented in the following Figure 3 and the fiber optic alignment module has also been depicted in Figure 4.

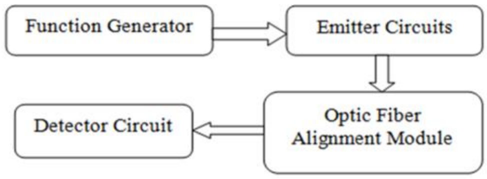

Figure 2. Block diagram of optical fiber misalignment experiment

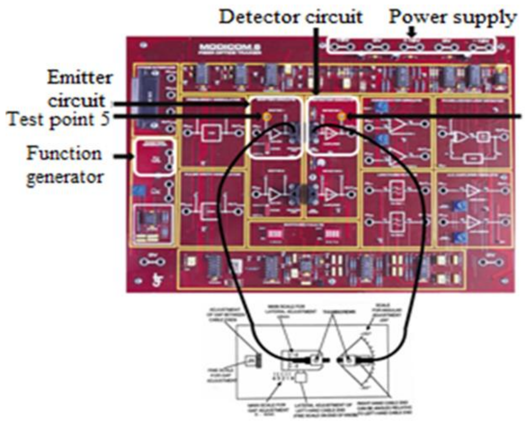

Figure 3. Circuit setup for investigation of coupling loss

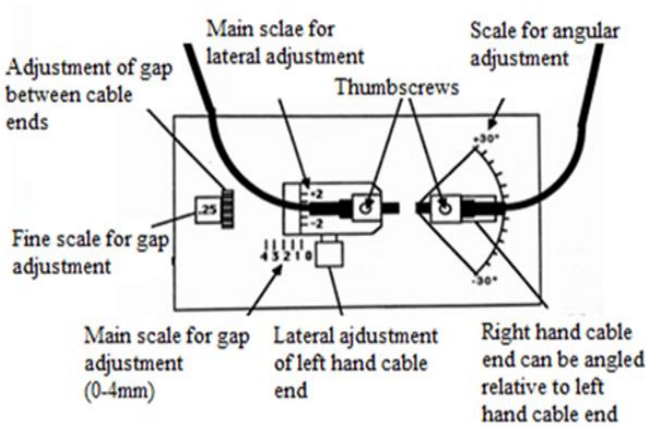

Figure 4. Fiber optic alignment module

3. RESULTS AND DISCUSSION
3.1. End gap displacement (G)
Coupling loss due to end gap displacement is shown in Figure 5. This misalignment issue often happens when splices are made in optical fibers. After splices are made, the two fibers should touch and connect with each other. The loss of propagating light increases as the distance between the connecting fibers grows. Two fibers connected by a connector should not have their ends in contact with each other because the fibers could be damaged if the ends of the fibers rub against each other within the connector.

For this experiment, data for end gap displacement (G) has been taken from G=0.00 mm and slowly increased the end gap displacement up to 4.00 mm with an increment of 0.25 mm. During this experiment, angular displacement (A) and lateral displacement (L) were kept constant at 0° and 0.00 mm, respectively. Table 1 presents the raw data of voltage peak-peak readings obtained from the oscilloscope for this experiment. This experiment was performed three times to ensure the accuracy of the estimated values. The average reading is obtained based on three attempts at conducting the experiment. Figure 6 presents the graph of the average value for voltage peak-to-peak versus the end gap displacement. From the graph, it can be concluded that the average value of voltage (peak-to-peak) decreases as there is an increment in the end gap displacement between the two fiber cables. The obtained value of voltage (peak-to-peak) is the highest when the end gap displacement is 0.00 mm, i.e., when two optic cables are fully connected without any spaces between them.

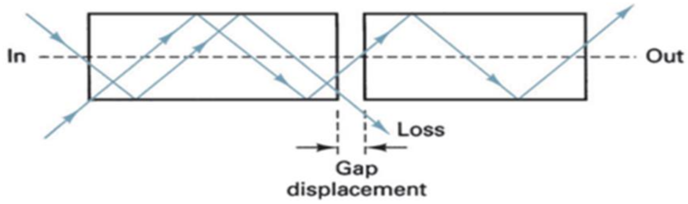

Figure 5. Coupling loss due to end gap displacement

Table 1. Voltage (peak-peak) for end gap displacement

End gap displacement (mm)	1st reading Vpk-pk (mV)	2nd Vpk-pk (mV)	3rd Vpk-pk (mV)	Average reading (mV)
0.00	157	157	165	159.67
0.25	157	153	141	150.33
0.50	157	145	137	146.33
0.75	157	145	137	146.33
1.00	157	145	137	146.33
1.25	153	141	133	142.33
1.50	149	137	133	139.67
1.75	149	137	133	139.67
2.00	145	133	133	137.00
2.25	145	129	137	137.00
2.50	141	125	137	135.67
2.75	141	129	137	135.67
3.00	137	133	133	134.33
3.25	137	129	133	133.00
3.50	133	125	129	129.00
3.75	133	125	125	127.67
4.00	137	121	125	127.67

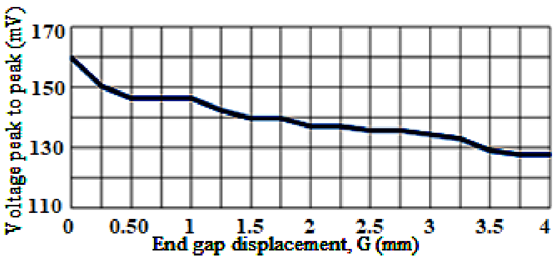

Figure 6. Average voltage (peak-to-peak) versus end gap displacement

3.2. Lateral displacement (L)

The concept of lateral or axial displacement between two adjacent fiber cables is presented in Figure 7. The loss varies from a few tenths to several decibels. This loss is negligible if the fiber axis is less than 5% of the diameter of smaller fibers.

The angular displacement (A) and end gap displacement (G) were kept constant throughout the experiment at 0° and 1.00 mm, respectively, to prevent damage to the fiber ends. Lateral displacement started at -2.00 mm and slowly moved towards +2.00 mm with a step size of 0.25 mm. Table 2 presents the raw data of V peak-peak obtained from the oscilloscope. This experiment is also performed three times to ensure the accuracy of the obtained value. The average value is obtained from 3 attempts at conducting the experiment. Figure 8 shows the graph of the average voltage peak-to-peak values versus the lateral displacement. The graph shows that the estimated average voltage peak-to-peak decreases as the lateral distance between the two fiber cables increases. The measured value of voltage (peak-to-peak) is the highest when the lateral displacement is 0.00 mm. This is because when the lateral displacement is 0.00 mm, i.e., the two optic cables are fully connected without any misalignment.

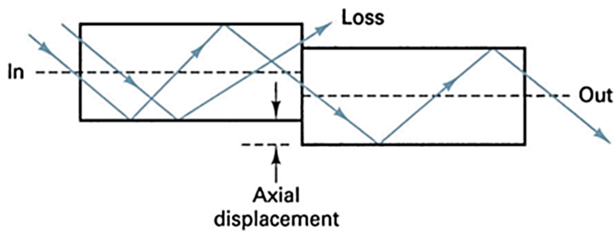

Figure 7. Coupling loss due to lateral displacement

Table 2. Voltage (peak-peak) for lateral displacement

Lateral displacement (mm)	1st reading Vpk-pk (mV)	2nd Vpk-pk (mV)	3rd Vpk-pk (mV)	Average reading (mV)
-2.00	143	143	123	136.33
-1.75	145	145	121	137.00
-1.50	145	141	129	138.33
-1.25	145	149	137	143.67
-1.00	145	147	129	140.33
-0.75	145	145	141	143.67
-0.50	145	149	139	144.33
-0.25	149	149	141	146.33
0.00	169	149	137	151.67
0.25	165	153	135	151.00
0.50	173	145	133	150.33
0.75	165	145	129	146.33
1.00	169	147	123	146.33
1.25	165	146	122	144.33
1.50	167	145	129	147.00
1.75	165	147	125	145.67
2.00	169	147	119	145.00

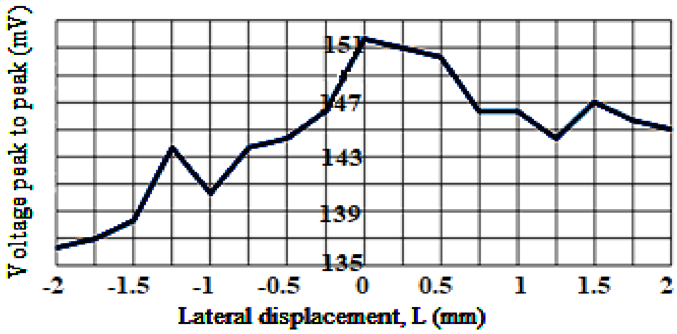

Figure 8. Average voltage (peak-to-peak) versus the lateral displacement

3.3. Angular displacement (A)

The scenario of coupling loss for angular displacement of two adjacent fiber cables is depicted in Figure 9. Coupling loss is usually less than 0.5 dB for angular displacements under 2°. In this case, the lateral displacement (L) and end gap displacement (G) are kept constant at 0.00 mm and 1.00 mm, respectively (to prevent damage to the fiber ends). During the experiment, the first angular displacement is considered to be -30° and slowly moves towards +30° with an increment of 5°. Table 3 presents the measured raw data for voltage peak-peak. As before, this experiment is also performed three times to ensure the accuracy of the measured value. The average voltage is calculated from three measured values, and then the average voltages are plotted with respect to angular displacement as shown in Figure 10. With increasing angular displacement between the two fiber cables, the average voltage (peak to peak) decreases.

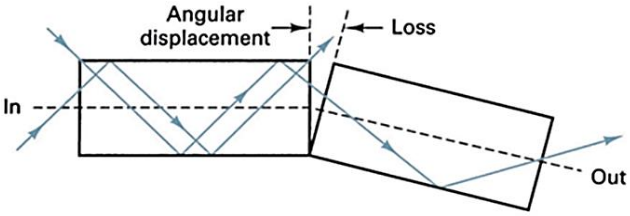

Figure 9. Coupling loss for angular displacement

Table 3. Voltage (peak-peak) for angular displacement

Angular displacement (Degree)	1st reading Vpk-pk (mV)	2nd reading Vpk-pk (mV)	3rd reading Vpk-pk (mV)	Average reading (mV)
-30	137	137	133	135.67
-25	145	133	137	138.33
-20	149	137	141	142.33
-15	145	137	141	141.00
-10	145	133	145	141.00
-5	145	141	145	143.67
0	141	141	145	142.33
5	145	137	145	142.33
10	141	137	145	141.00
15	141	137	141	139.67
20	137	137	141	138.33
25	141	137	141	139.67
30	145	133	133	137.00

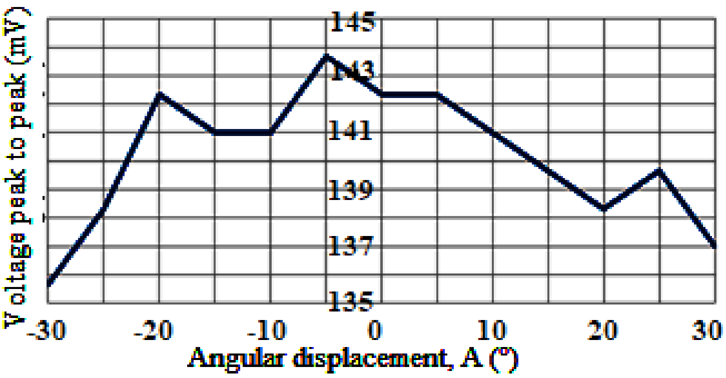

Figure 10. Average voltage (peak-to-peak) versus angular displacement

4. CONCLUSION

This investigation shows that there is a significant coupling loss due to three misalignment issues: end gap displacement, lateral displacement, and angular displacement between the two ends of fiber cables that are needed to be connected. Modicom 6 is used to conduct the investigation at the fiber optic lab of Universiti Teknologi PETRONAS (UTP), Malaysia. The total investigation has been performed in three phases: in the first phase, coupling loss has been measured and analyzed for end gap displacement while keeping the other two displacements constant. Similarly, in the 2nd and 3rd phases of the investigation, the coupling loss has been measured for lateral displacement and angular displacement. From the investigation, it is obvious that the coupling loss increases with increasing displacement. Therefore, during the deployment of any optical network, we need to deal with all three misalignment issues carefully to reduce coupling loss.

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