

Development of Power Transmission Using Laser Light for Long Distance Power Supply on Tiltmeter Sensor

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ABSTRACT

This study aims to develop and test a Power over Fiber (PoF) system as a remote power supply for the operation of a tilt meter sensor used to detect ground inclination changes, which serve as early indicators of landslide potential in disaster-prone areas. Infrared laser diodes with wavelengths of 808 nm and 940 nm were employed as optical power sources, with light transmitted through multimode optical fiber to the AFBR-POC206L photovoltaic device for optical-to-electrical conversion. The results demonstrated that the photovoltaic device generated sufficient electrical power, achieving a maximum electrical output of 400.1 mW with an average conversion efficiency of 65.41%. The system successfully charged a 3.7 V, 5000 mAh lithium-polymer battery and supplied a stable voltage of 4.099 V to operate the tilt meter sensor continuously for four hours. These findings highlight the PoF system as a reliable and efficient alternative for remote geotechnical monitoring applications, with strong potential for broader implementation in environmental monitoring requiring long-distance and interference-free power transmission.

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I. INTRODUCTION

Remote monitoring technology has advanced significantly to meet the demands of various fields, including disaster mitigation, infrastructure monitoring, and environmental conservation. One of the developed remote monitoring systems is PoF—a method for transmitting power through optical fiber cables (Matsuura, 2021). PoF presents a promising solution to overcome the limitations of conventional methods, offering reliable power transmission with immunity to electromagnetic interference (Werthen et al., 2005). Furthermore, PoF enables power delivery to devices located in hard-to-reach areas, such as underwater environments, mountainous regions, or disaster sites.

Research on PoF has expanded across various applications, including subsea monitoring, telecommunication systems, and geotechnical monitoring systems (Diouf et al., 2020). In the geotechnical monitoring context, a commonly used sensor is the tiltmeter, which is designed to detect changes in ground inclination that may indicate potential landslide hazards (Qolbi, 2021). This type of monitoring plays a crucial role in identifying slope movements that can act as triggers for disasters such as landslides. However, implementing such technology in the field presents challenges, particularly in ensuring a stable and reliable power supply in remote or inaccessible locations.

The integration of PoF technology with tiltmeter sensors is therefore highly relevant and necessary. Advances in optical power transmission via PoF have opened new opportunities for applications in previously inaccessible areas. Previous studies have addressed the development and implementation of PoF in various contexts. For example, Matsuura (2021) identified the key components of PoF technology—high-power laser sources, optical fibers, and photovoltaic devices used to convert optical power into electrical power. The study also demonstrated the significant potential of PoF systems for applications such as sensing and communication. However, specific applications in geotechnical monitoring have not been explicitly explored.

The study conducted by Souza et al., focused on the application of PoF in the Industrial Internet of Things (IIoT), where PoF-powered wireless sensor nodes demonstrated good performance in challenging industrial environments. Using optical fiber as the power supply medium, the research successfully showed that PoF can replace conventional electrical cables, thereby improving system reliability in areas with high electromagnetic interference. However, this study did not explore how PoF systems could be applied beyond the industrial context, such as in ground movement monitoring, which requires continuous power supply and operates under more diverse environmental conditions (Souza et al., 2022).

The research by Setiono et al., developed and implemented an optical-based wire extensometer to measure and monitor translational landslides in hazard-prone areas. The results showed that the wire extensometer performed well and was capable of detecting ground displacement. In this study, solar panels were still used as the primary power source. Although this technology works well under certain conditions, its vulnerability to theft—particularly of the batteries—and the complexity of maintenance present significant challenges for field implementation. The application of PoF systems for geotechnical monitoring, particularly for monitoring ground inclination changes using a tilt meter sensor, has not yet been carried out. As an important factor in detecting inclination changes that can act as precursors to disasters such as landslides, tilt meter sensors require a stable and continuous power supply in remote and often inaccessible environments. PoF systems hold significant potential to address these issues, yet no in-depth studies have been conducted on how this technology could be integrated into geotechnical monitoring, especially for monitoring ground inclination changes (Setiono et al., 2023).

In this study, the PoF system is implemented using commercially available optical fibers that are commonly used. The implementation aims to supply power to the tilt meter system for slope inclination monitoring. A High Power Laser Source (HPLS) is used as the power source, along with a photovoltaic device to convert optical energy into electrical power. This research aims to evaluate the performance of the system in transmitting power efficiently and stably, as well as the sustainability of long-distance monitoring operations. Additionally, tests are conducted to determine the extent to which the PoF system can support sensor operation.

II. METHOD

2.1 Power over Fiber (PoF) System Design

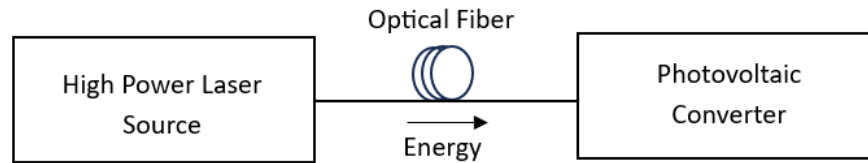


Figure 1 Schematic Diagram of the PoF System

Figure 1 presents the schematic diagram of the PoF system, which consists of three main components: the HPLS, optical fiber, and photovoltaic converter. The HPLS serves as the optical light source for supplying energy, which is subsequently transmitted through the optical fiber. In this study, laser diodes with 808 nm and 940 nm of wavelength are utilized as the optical sources. The HPLS is equipped with a laser driver that regulates the driving current to maintain stable light intensity.

The optical fiber as the transmission medium, delivering the optical power from the HPLS to the photovoltaic converter. The photovoltaic converter converts the received optical energy into electrical energy. This electrical energy is used to power the tiltmeter sensor. The schematic diagram in Figure 1 summarizes the energy flow within the PoF system, starting from optical power generation in the HPLS, transmission through the optical fiber, and subsequent conversion into electrical power by the photovoltaic converter. These three components work in an integrated manner to create an efficient and reliable system for powering applications such as tilt meter sensors.

2.2 Measurement Setup Scheme

The measurement setup in this study was designed to evaluate the performance of the PoF system in transmitting power using a laser and converting it into electrical power through a photovoltaic device. The system also supports power supply to a tilt meter sensor. The measurement arrangement was carried out in several integrated stages to ensure that all aspects of the system were thoroughly tested. The process begins with the laser source, to generate the optical power. A laser driver is employed to control the current supplied to the laser diode. The laser driver ensures a stable input current to the laser diode, enabling precise control of the generated optical power according to the experimental requirements.

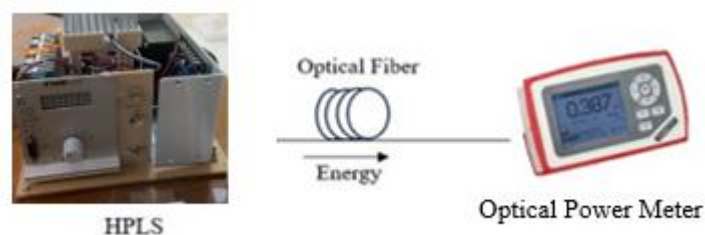


Figure 2 Optical Power Measurement Setup

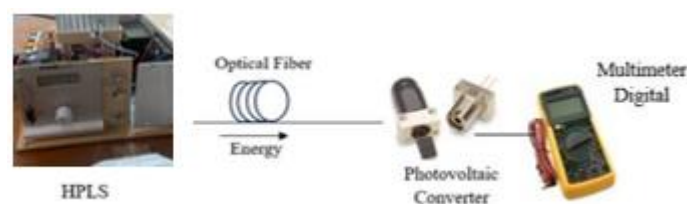


Figure 3 Optical Power Conversion Measurement Setup

In this setup, HPLS is directly connected to the optical fiber to transmit optical power. At the receiving point, the transmitted optical power is measured using a power meter, and records the

remaining power after transmission. After the power transmission process through the optical fiber, the optical power is received by the photovoltaic device and converted into electrical power. The photovoltaic device, AFBR-POC206L is responsible for capturing the optical energy and converting it into electrical energy. At this phase, the output voltage and current from the photovoltaic device are measured using a digital multimeter. These measurements are conducted to determine the generated electrical power as well as the efficiency of the optical-to-electrical power conversion process.

2.3 Power Tiltmeter Sensor for Application

In the subsequent experiment, the electrical power generated by the photovoltaic device was utilized to charge a battery and supply power to the tiltmeter sensor. In this configuration, the laser produces optical power that is transmitted through an optical fiber cable. The optical power arriving at the end of the cable is then converted into electrical power by the AFBR-POC206L photovoltaic converter. This process provides stable voltage and current for the operation of the tiltmeter sensor. In addition to powering the tiltmeter sensor, the PoF system also charges the battery. The battery serves as a backup power source to maintain the operation of the tiltmeter sensor when the PoF system is inactive, such as during laser shutdown or other disruptions in optical power transmission.

III. DISCUSSION

3.1 Laser Source Characterization

The light source used for power transmission in this study was a laser diode with wavelengths of 808 nm and 940 nm. The laser characterization was conducted to evaluate its performance and efficiency under different operating conditions and to confirm its suitability for the requirements of this research. Understanding the relationship between the supplied current and the output power is essential for determining overall performance and efficiency, ensuring reliable operation for long-distance power delivery. The output power (mW) was measured against variations in input current (mA) using an optical power meter, and the results are presented as a graph showing the current–power relationship for both wavelengths.

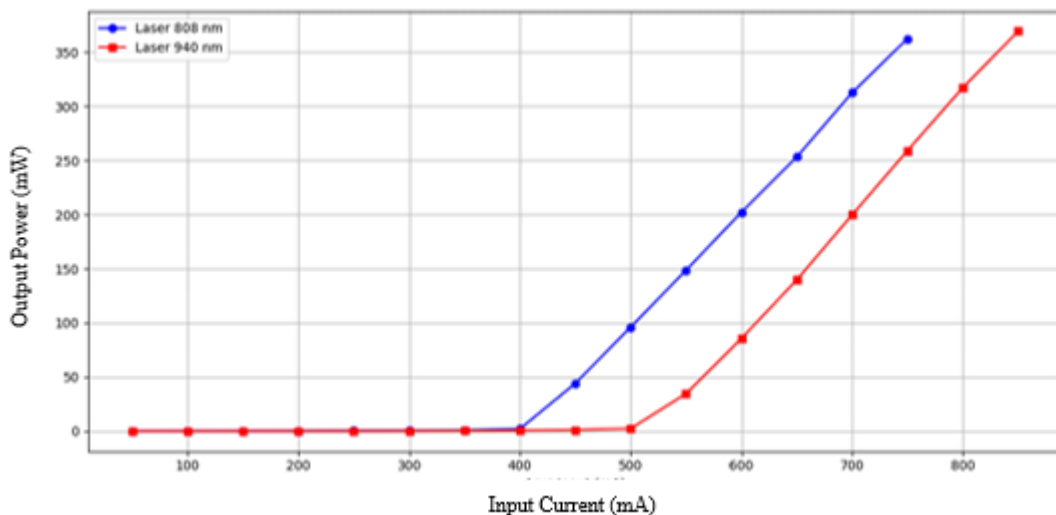


Figure 4 Laser Source Characterization

After processing the data and generating the graph of the relationship between input current and output power for both lasers, as shown in Figure 4, it was found that the laser with a wavelength of 808 nm exhibited an increasingly rapid rise in output power after reaching its threshold current of 400 mA. This occurs because the photon energy at 808 nm is well matched to the bandgap of the GaAs-based active material, leading to more efficient electron–hole recombination and an earlier onset of stimulated emission compared to the 940 nm laser.

At a current of approximately 400 mA, or after reaching the threshold current, the output power increased sharply from 2 mW to 44 mW with a current change of only 50 mA. The laser power continued

to increase with increasing injection current, reaching 400 mW at an injection current of 800 mA. This laser has a maximum output of 2500 mW at an injection current of 2000 mA (2 A).

For the laser with a wavelength of 940 nm, the graph shows a similar pattern; however, the laser efficiency transition point occurs at a higher current compared to the 808 nm laser. At an input current of 450 mA, the output power increased significantly from 1 mW to more than 34 mW. According to the datasheet, the maximum output power of this laser is 4000 mW (4 W) at an injection current of 3500 mA (3.5 A).

Both lasers demonstrated optimal performance within a specific current range, with a similar pattern of output power increase but at different current parameters. The 808 nm laser tends to reach its efficiency point faster than the 940 nm laser. This characterization provides essential guidance for setting the operating parameters of the power transmission system, including determining the most suitable drive current to optimize output power without causing damage to the laser.

3.2 Optical-to-Electrical Power Conversion

At this phase, the focus is on verifying the capability of the Power over Fiber system to convert the optical energy generated by the laser into usable electrical power. This process is critical because the success of the overall system depends on whether the converted power is sufficient and stable to operate the sensor and its associated devices. To achieve this, a Power Photodetector is employed as the key component for converting optical power into electrical energy, and its performance is analyzed in detail to evaluate the efficiency of the conversion process.

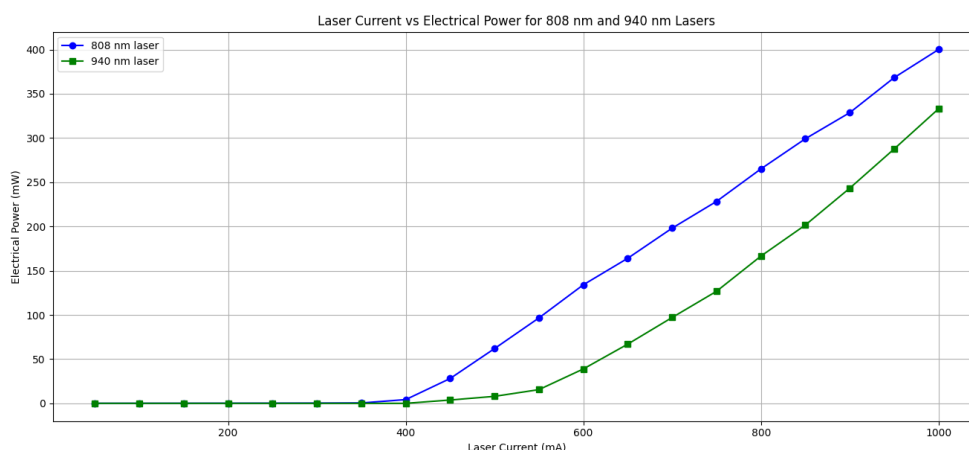


Figure 5 Correlation Between Laser Drive Current and Electrical Power Output

When comparing the two lasers, it is evident that the 808 nm laser outperforms in generating electrical power at low drive currents. This is shown in the figure, where the electrical power output of this laser is already detectable at currents as low as 50 mA, whereas for the 940 nm laser, no electrical power is detected until the current reaches 450 mA. At higher currents, the performance of both lasers exhibits a similar trend. Nevertheless, the 808 nm laser still delivers a higher maximum power output compared to the 940 nm laser at the maximum drive current of 1000 mA, namely 400.1 mW for the 808 nm laser versus 333.064 mW for the 940 nm laser.

3.3 Laser Performance Characteristics

This laser-based power characterization was analyzed using measurement data that encompass the relationships among voltage, current, and output power of the AFBR-POC206L photovoltaic device. The measured data were used to evaluate the performance of optical-to-electrical power conversion in the implemented laser system. The analysis focused on the Current-Voltage (I-V) characteristics, Volt-Power (V-P) characteristics, and the optical-to-electrical conversion efficiency. Measurements were performed using a laser driver to control the drive current supplied to the laser source. The laser was operated with input currents varying from 50 mA to 1000 mA. The photovoltaic output voltage was measured with a digital multimeter. Electrical power was calculated as the product of measured voltage and current, while the input optical power was measured with a power meter.

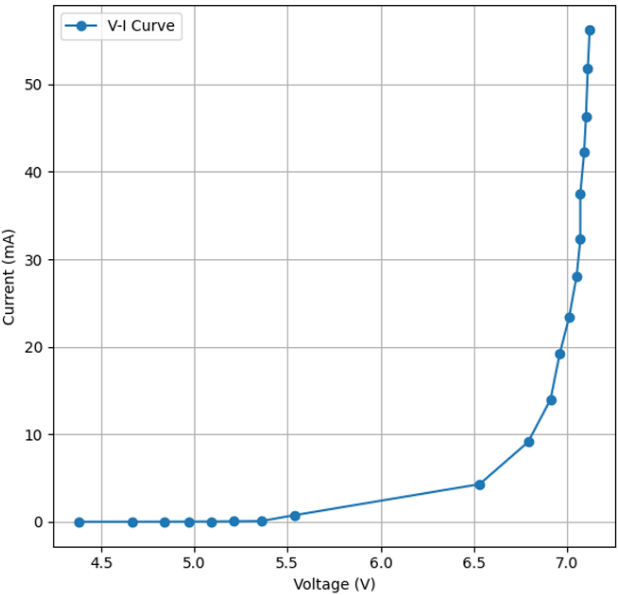


Figure 6 Current-Voltage (I-V)

Figure 6 illustrates the relationship between voltage (V) and current (I) at the output of the photovoltaic device. At the initial stage of measurement, the output current increases gradually with the rise in voltage, indicating that the system is in its early operational phase where the received optical power is still low. A more noticeable increase in output current is observed when the voltage reaches 5.5 V, at which point the photovoltaic begins to demonstrate more effective optical-to-electrical power conversion. Once the voltage exceeds 6.5 V, the current rises rapidly until it peaks at approximately 7.12 V. This indicates that the photovoltaic operates at its peak efficiency in converting optical power into electrical power.

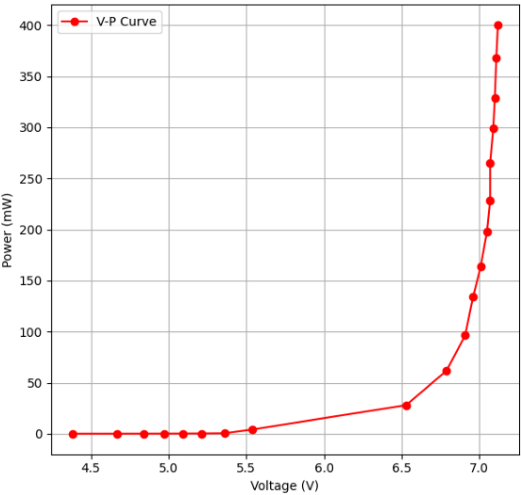


Figure 7 Voltage-Electrical Power Relationship (V-P)

Figure 7 shows the relationship between voltage (V) and the electrical power (P) generated by the photovoltaic device. At the initial stage of measurement, the electrical power increases gradually with rising voltage. This reflects the early operating phase of the photovoltaic, where the energy conversion efficiency is still low due to the suboptimal amount of optical power received. As the voltage increases, the electrical power rises significantly until it reaches its maximum value. The power peak is recorded at 7.12 V, where the electrical power reaches 400.1 mW. This point marks the optimal operating condition of the photovoltaic, in which the combination of voltage and current yields the highest power output. Based on the measured electrical and optical power data, the average conversion

efficiency is calculated. This average efficiency indicates that the AFBR-POC206L photovoltaic device used in this system is capable of converting approximately 65.41% of the optical power into electrical power. This value is considered favorable for an optical-to-electrical system, particularly for low-power applications. Such an average efficiency implies that the photovoltaic operates with a satisfactory performance level, making the system reliable for powering small devices such as sensors or monitoring instruments. Based on the analysis, the laser system employed in this study is capable of achieving an average efficiency of approximately 65.41%. Furthermore, the analysis of the Voltage–Current and Voltage–Power characteristics demonstrates that the photovoltaic device exhibits stable performance for low- to medium-power applications.

3.4 Application of The PoF System In A Tilt Meter Sensor

The Power over Fiber (PoF) system is implemented on a tilt meter sensor as part of a trial to support remote power requirements. This sensor is used to monitor changes in ground inclination, making a stable power supply a crucial factor in maintaining monitoring accuracy. By using the PoF system, power can be supplied to the sensor without relying on conventional cabling, thereby enhancing the reliability and efficiency of the monitoring system in hard-to-reach locations. The test results include the performance of battery charging and power supply to the tilt meter system.

The battery used is a Lithium Polymer (Li-Po) type with a capacity of 3.7 V, 5000 mAh (18.5 Wh). This battery is employed to store energy from the photovoltaic device, enabling it to support the sensor during periods without optical power transmission.

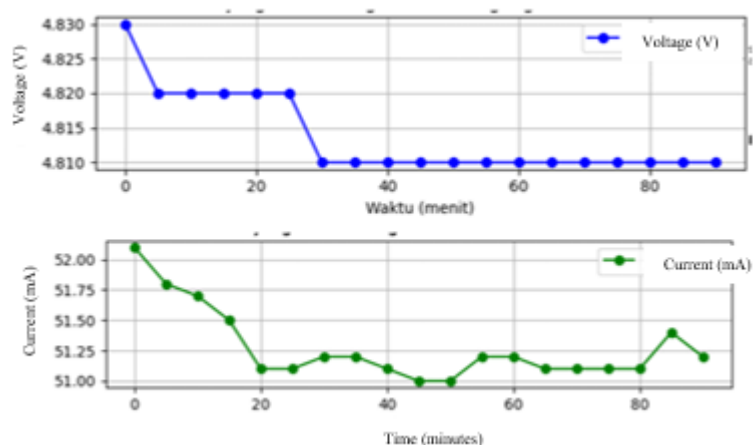


Figure 8 Time Relationship with Voltage and Current in Battery Charging

Figure 8 shows that the voltage remains stable in the range of 4.81 V to 4.83 V, while the charging current gradually decreases from 52.1 mA at the start of charging to 51.0 mA after 45 minutes. At the end of the charging process (90 minutes), the current slightly increases to 51.2 mA. This charging pattern indicates that the battery is approaching full capacity, with the initial charging power recorded at 251.643 mW and gradually decreasing to 245.791 mW. The decrease in charging power is attributed to the increase in the battery's internal resistance as the charging process progresses. Despite the slight reduction in charging power, the battery voltage remains stable, indicating that the PoF system is capable of maintaining a stable power supply throughout the charging process. The battery used has a capacity of 5000 mAh, which allows for a more efficient charging process at a stable charging voltage. This large capacity also means that the battery can store sufficient energy for extended device operation periods. With the input power generated by the PoF system, the battery can be consistently charged without experiencing significant voltage fluctuations. Based on the figure 8, although the charging current decreases, the voltage remains stable, indicating that the PoF system can provide a consistent power supply during charging.

After the battery was fully charged, the power supply to the tilt meter sensor was tested to ensure the stability of the PoF system in supporting sensor operation. Figure 9 shows during four hours of testing, the supply voltage remained stable at 4.099 V, while the supply current fluctuated slightly in the range of 74.6 to 75.2 mA. These minor fluctuations indicate the capability of the PoF system to adjust to the sensor's power demands without compromising operational stability. The test results demonstrate

that the PoF system can deliver reliable performance to support the implementation of the tilt meter sensor. The stable voltage observed during both the battery charging process and the power supply operation reflects the system's efficiency in transmitting and converting optical power into electrical power. The gradual decrease in current during battery charging is a common phenomenon caused by the increase in the battery's internal resistance as the charge capacity approaches full. Meanwhile, the minor fluctuations in the power supplied to the tilt meter did not affect voltage stability, allowing the sensor to operate effectively without interruption. With its maintained stability, this system is suitable for sensor applications requiring a reliable remote power supply.

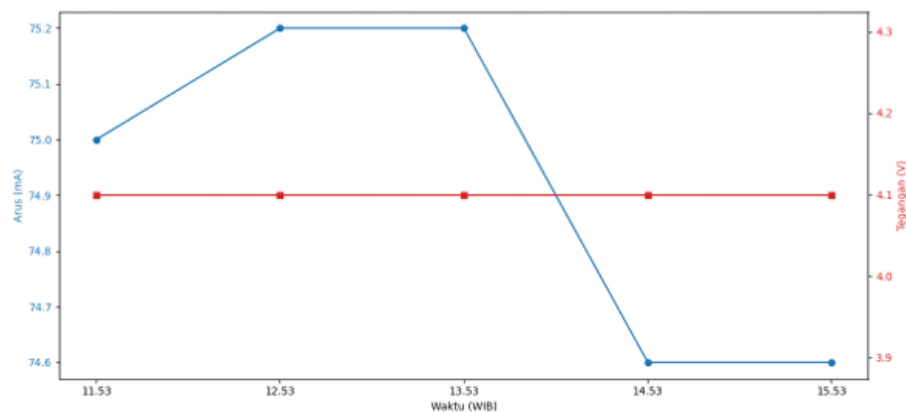


Figure 9 Charging Current and Voltage to the System

IV. CONCLUSION

This research successfully developed a Power over Fiber (PoF) system as an innovative solution for long-distance power supply, specifically to support a tilt meter sensor for monitoring ground inclination changes. The results show that the PoF system can transmit optical power using a laser diode through optical fiber with relatively high power conversion efficiency. The photovoltaic device used, AFBR-POC206L, is capable of converting optical power into electrical power with efficiency suitable for supporting low-power devices. Testing with the tilt meter sensor demonstrated that the power supply from the PoF system remained stable at 4.099 V during sensor operation. The system was also able to charge a lithium-polymer battery with good voltage and current stability, proving its capability to provide backup power for the sensor during periods without direct transmission. This research demonstrates that the PoF system can replace conventional electrical cables with higher reliability and efficiency, particularly in addressing challenges such as electromagnetic interference, vulnerability to theft, and intensive maintenance requirements. The PoF system developed at the laboratory scale has proven its stability and reliability, indicating strong potential for real-world application.

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REFERENCES

- H Aldi, W., Abil, H., 2024, Rancang Bangun Buck-Boost Converter sebagai Charger Baterai Controller Berbasis PWM dengan Sumber Photovoltaic, *Jurnal Elektronika Borneo (JEB)*, Vol. 10, No. 1.
- Arroyave, M.A., Behera, B., Cavanna, F., Feld, A., dkk, 2024, Characterization and Novel Application of Power Over Fiber for Electronics in a Harsh Environment, *arXiv*.
- Broadcom Inc, *Datasheet AFBR-POC206L*, from Broadcom Website.
- Deri, S., Belangi, H. A. P., Gading, A. R., 2022, Analisa Keamanan Jaringan Pada Sistem Monitoring Keandalan Struktur Jembatan Suramadu di Lingkungan Kementerian Pekerjaan Umum dan Perumahan Rakyat, *UPN Veteran Jawa Timur*.

- Diouf, C., Quintard, V., Ghisa, L., Guegan, M., Perennou, A., Gautier, L., 2020, Design, characterization, and test of a versatile single-mode power-over-fiber and communication system for seafloor observatories, *IEEE Journal of Oceanic Engineering*, Vol. 45, hal. 656-664, DOI: 10.1109/JOE.2018.2876049.
- Ekawati, R., 2021, Mengenal Fiber Optik, *Media Sains Indonesia*, Bandung.
- Fardani, A.S., Neforawati, I., 2019, Instalasi Kabel Fiber Optik dan Perangkat Switch untuk Layanan Internet Menggunakan Metode CWDM oleh PT XYZ, *Jurnal Multinetics*, Vol. 5, No. 1, DOI: <https://doi.org/10.32722/multinetics.v5i1.2787>.
- Fauziah, N., Irwanto., 2024, Analisis Gangguan Kabel Fiber Optik Menggunakan OTDR pada OTB Serang-Cilegon, *Jurnal Informatika dan Teknik Elektro Terapan*, Vol. 12, No. 3S1, DOI: <http://dx.doi.org/10.23960/jitet.v12i3S1.5295>
- Hartanto, O., Haryanti, M., 2018, Sistem Pemantauan Rumah Jarak Jauh dengan Komunikasi Wireless, *Jurnal Universitas Suryadarma*, Vol. 7, DOI: <https://doi.org/10.35968/jti.v7i0.306>.
- Hasanah, 2009, Revolusi Dunia Telekomunikasi Dengan Serat Optik, *JETC*, Vol. 4, No. 1.
- Luczak, S., Zams, M., Dabrowski, B., Kuszniereicz, Z., 2022, Tilt Sensor with Recalibration Feature Based on MEMS Accelerometer, *Sensors*, Vol. 22, DOI: <https://doi.org/10.3390/s22041504>.
- Matsuura, M., 2021, Recent Advancement in Power-over-Fiber Technologies, *Photonics*, Vol. 8, hal. 335, DOI: 10.3390/photonics8080335.
- Prasetya, D., 2009, Pengenalan Serat Optik Sebagai Salah Satu Solusi Pembangunan Jaringan Kabel, Universitas Sriwijaya, Palembang.
- Pujangga, D.A., 2013, Perancangan Teknologi Hybrid Fiber Coaxial (HFC) Untuk Apartemen, Laporan Kuliah Kerja Industri, STT Atlas Nusantara, Malang.
- Purbawanto, S., 2020, Media Transmisi Telekomunikasi, Deepublish, Yogyakarta.
- Putri, A. M., Fauziah, A., Syamsul., 2023, Analisis Rugi-Rugi Pelengkungan Pada Kabel Serat Optik Single Mode Berdasarkan Variasi Diameter dan Jumlah Lilitan, *Jurnal Tektro*, Vol. 7, No. 1.
- Qolbi, A.S., 2021, Estimasi Lokasi Sumber Tekanan dan Volume Suplai Magma Gunung Merapi Berdasarkan Data Tiltmeter Menggunakan Model Mogi, Skripsi, Jurusan Fisika, Universitas Islam Negeri Maulana Malik Ibrahim, Indonesia.
- Rahmania., 2019, Analisis Power Budget Jaringan Komunikasi Serat Optik di PT. Telkom Akses Makassar, *Vertex Elektro*, Vol. 01, No. 02.
- Rosolem, J. B., 2017, Power over Fiber Applications for Telecommunications and for Electric Utilities, *Optical Fiber and Wireless Communications*, DOI: <http://dx.doi.org/10.5772/68088>.
- Saputro, A. E., Darwis, M., 2020, Rancang Bangun Mesin Laser Engraver and Cutter Untuk Membuat Kemasan Modul Praktikum Berbahan Akrilik, *Jurnal Pengelolaan Laboratorium Pendidikan*, Vol. 2, No. 1.
- Setiono, A., Qomaruddin., Afandi, M.I., Adinanta, H., Rofianingrum, M.Y., Suryadi., Mulyanto, I., Bayuwati, D., Anwar, A., Widiyatmoko, B., 2023, Wire Extensometer Based on Optical Encoder for Translational Landslide Measurement, *Advanced Science Engineering Information Technology*, Vol. 13, No. 1, DOI: <https://doi.org/10.18517/ijaseit.13.1.15636>.
- Souza, L.C., Neto, E.R., Lima, E.S., Junior, A.C.S., 2022, Optically-Powered Wireless Sensor Nodes towards Industrial Internet of Things, *Sensors*, Vol. 22, DOI: <https://doi.org/10.3390/s22010057>.
- Sugiarto, I. T., Setiono, A., Hanto, D., 2013, Karakterisasi Dioda Laser untuk Pengujian Stabilitas Daya dan Frekuensi, *Proceeding Seminar Ilmu Pengetahuan Teknik*.
- Werthen, J-G., Widjaja, S., Wu, T-C., Liu, J., 2005, Power over Fiber: a review of replacing copper by fiber in critical applications, *Optical Technologies for Arming, Safing, Fuzing, and Firing*, DOI: 10.1117/12.619753.