Electric Current and Magnetic Field Sensor Based on Plastic Optical Fiber and Magnetic Fluid

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Abstract. This study aims to test of sensor based plastic optical fiber for measuring electric current and magnetic field using amacrobending technique. Sensor testing is done by using length of peel variation of with cladding and without cladding sensortype which is covered by magnetic fluid in a plastic tube. The measurement is done by putting the sensor near the magnetic field source produced by a wire coil that is electric current flowed. The magnetic field interact with the magnetic fluid that is on the sensor result in the refractive index of fiber optic sensor increases. This causes the power losses to increase and the light intensity transmitted from the LED to the phototransistor decreases so that the resulting of output voltage also decreases. The best results obtained on the with cladding sensor type with 3 cm length of peel for measuring electric current produce a sensitivity value of 0.008 V/A and a resolution of 0.121 A, while for measuring magnetic field produce a sensitivity value of 0.738 V/T and a resolution of 1.345 T. Testing of sensor based on plastic optical fiber suitable for measuring electric current and magnetic field with advantages such as having high sensitivity, easy fabrication, low cost, real time, as well as has a simple measurement and accurate system.

1. Introductions
Measurement of electrical quantities for commercial purposes needed in the operation and maintenance of distribution networks in the ability to use measuring devices. Measurement of electrical quantities has a very broad review such as measuring electric current and magnetic field. Electric current and magnetic field are related, that is electric current generate a magnetic field in the wire coil and vice versa the electric current can be generated from a magnet driven near the wire coil. Along with the rapid development of electrical and electronic technology, the presence of magnetic fields derived from electric current can be measured by using optical fiber. Optical fiber technology has become a significant user of various measurement parameters in its application as a sensor [1].

Sensor based on optical fiber is the right choice with the advantages it has compared to conventional electronic sensor. The advantages of sensor based on optical fiber include being unaffected by electromagnetic interference, easily integrated in variety of structures, small size, light weight, high sensitivity, remote sensing capability and multiplexing capability to form a sensing network [2,3,4]. By paying attention to the advantages that exist in optical fiber as sensor, many theoretical and experimental results have discussed or conducted research on fiber optic sensor which was applied for the measurement of electric current and magnetic field. Among them was measured the electric current using a fiber optic current sensor (FOCS) with the bending method [5,6], as well as the utilization of the intrinsic magnetic field sensitivity effects for measurement of electric current based FOCS [7]. In addition, measurement of electric current using fiber optic sensor can also be
carried out based on the birefringence characteristics [8], interferometric multiplexing sensor [9], Fabry-Perot interferometer fiber [10], and the Fiber Bragg Grating sensor using mechanical transducers [11]. Similarly, sensor based on optical fiber can be applied to the measurement of magnetic field using magnetic fluid and microfiber interferometer modes [12]. Another development is the measurement of magnetic field based on optical fiber using magnetic fluid as cladding [13]. However, some of methods of measuring electric current above require complex systems and expensive equipment [14].

Based on the measurement method performed above, an electric current sensor based on plastic optical fiber with bending configuration will be designed. In this study, optical fiber sensor will be developed by utilizing the effects of magnetic field arising from an electric current flowing on a wire coil. The magnetic field interacts with the magnetic fluid on the sensor. The existence of this, its interaction will affect the refractive index accurs in the optical fiber to affect change in response to the output voltage and light intensity, from the light passed in the optical fiber. The sensor testing is expected to produce high sensitivity in a simple measurement process, easy fabrication, low cost, and can be connected to the Arduino Uno microcontroller and computer.

2. Method
This research begins with the manufacture of ± 12V and 5 V power supply and differential amplifier. Electric current and magnetic field sensor based on plastic optical fiber connected to LED light source and phototransistor. The light source used is an IF-E91A infrared LED with a wavelength of 950 nm received by IF-D92 phototransistor. Plastic optical fiber made of polymethylmetacrylate (PMMA) material with diameters of coat, cladding, and core are 2.2 mm, 1 mm, 0.98mm respectively. The plastic optical fiber has refractive index of core and cladding is $n_{\text{core}} = 1.492$ and $n_{\text{cladding}} = 1.402$ with a numerical aperture value $NA = 0.5$.

The light from the LED passes and it will be modulated by an optical fiber sensor that is given a magnetic fluid. Magnetic fluid is made from Magnetic Ink Character Recognition (MICR) and cooking oil with concentration ratio for both materials that is 50%:50%. The magnetic fluid will interact with the magnetic field generated from the solenoid wire coil which is electrically flowed. Increasing the electric current in the wire coil causes the magnetic field to be generated increases. The magnetic field will cause the magnetic fluid to move towards the tip of the optical fiber sensor and affect the refractive index of the optical fiber sensor. This causes a greater power loss in the sensor, so that the light intensity received by the phototransistor gets smaller and the output voltage decreases.

Schematic circuit and design electric current and magnetic field sensor based on plastic optical fiber using a macrobending technique shown in Figure 1 and Figure 2. The basic principle of this sensor is utilize the effect of the magnetic field produced by electric current in the wire coil which affects the change in response to the output voltage and the light intensity passed in the optical fiber.

![Figure 1](image-url)
3. Result and Discussion

Optical fiber sensor used to measure electric current and magnetic field with a reading result in the form of output voltage. Some of the supporting devices used in the manufacture of sensor are the power supply circuit, differential amplifier circuit, infrared LED and phototransistor. The infrared LED emitting light will be transmitted to the phototransistor to converted be an electrical signal, then it will be amplified by the differential amplifier and the result will be read on the microcontroller and computer.

Furthermore, the data obtained from the testing of sensor based on plastic optical fiber for measuring electric current and magnetic field used to analyze sensor characteristics. Sensor characteristics include range values of changes in output voltage, sensitivity, and resolution. The output voltage range value on the sensor calculated using the following equation (1) [15,16]:

$$\Delta V = V_{\text{max}} - V_{\text{min}}$$  \hspace{1cm} (1)

Where, $V_{\text{max}}$ is the maximum output voltage and $V_{\text{min}}$ is the minimum output voltage. Sensor sensitivity is a measurement to determine the sensitivity of the sensor to the measured amount. Sensitivity of the sensor can be measured using the following equations (2a) and (2b) [15,16]:

$$S = \frac{V_{\text{max}} - V_{\text{min}}}{I_{\text{max}} - I_{\text{min}}}$$  \hspace{1cm} (2a)

$$S = \frac{V_{\text{max}} - V_{\text{min}}}{B_{\text{max}} - B_{\text{min}}}$$  \hspace{1cm} (2b)

Where, $I_{\text{max}}$ is the maximum electric current and $I_{\text{min}}$ is the minimum electric current. While $B_{\text{max}}$ is the maximum magnetic field and $B_{\text{min}}$ is the minimum magnetic field. Furthermore, it calculates the sensor resolution to determine the smallest value that can be measured by the sensor. Sensor resolution can be determined using the following equation (3) [15,16]:

$$R = \frac{N}{S}$$  \hspace{1cm} (3)

Where, $N$ is the smallest scale of the microcontroller used is 0.001 V and $S$ is the sensitivity value of the sensor.

Testing of sensor based on plastic optical fiber for measuring electric current made using length of peel sensor variation 1 cm, 2 cm, and 3 cm. This test uses a type of sensor with cladding and without cladding formed into amacro bending configuration, then the plastic optical fiber covered with a tube that has been injected with magnetic fluid. The sensor testing process do in the range of electric current 0 A to 5.2 A with an interval of 0.2 A. The results of sensor testing for measuring electric current in the length of peel sensor variation are shown in Figure 3 below:

![Figure 2. Design of electric current and magnet field sensor based on plastic optical fiber.](image-url)
The graph in Figure 3 shows that the output voltage decreases with increasing electric current. The greater of the magnetic field causes the output voltage to decrease. The output voltage value varies according to the variation of the length of peel sensor. Characteristics of electric current sensor based on plastic optical fiber were determined using equations (1), (2a), (3) shown in the following Table 1:

| Sensor Type          | Length of Peel (cm) | Range (V) | Sensitivity (V/A) | Resolution (A) |
|----------------------|---------------------|-----------|-------------------|----------------|
| With Cladding        | 1                   | 0.020     | 0.004             | 0.260          |
|                      | 2                   | 0.031     | 0.006             | 0.168          |
|                      | 3                   | 0.043     | 0.008             | 0.121          |
| Without cladding     | 1                   | 0.004     | 0.001             | 1.209          |
|                      | 2                   | 0.017     | 0.003             | 0.308          |
|                      | 3                   | 0.019     | 0.004             | 0.275          |

The data in Table 1 shows data of sensor characteristics for measuring electric current in the length of peel with cladding and without cladding sensor type. Based on the data in the table, it shows that the longer of the sensor, the better of the sensor characteristics. The best sensor characteristics were obtained on the 3 cm length of peel with cladding sensor type show sensitivity and resolution values of 0.008 V/A and 0.121 A respectively.

Furthermore, testing of sensor based on plastic optical fiber for measuring magnetic field using the same method as testing of the electric current sensor that is using a type of sensor peel with cladding and without cladding on the variation of sensor lengths of 1 cm, 2 cm and 3 cm, respectively. Each sensor covered with a tube that has been injected with magnetic fluid. The sensor testing process is carried out in a magnetic field range of 0 mT to 65 mT at 2.5 mT intervals. The changes response in sensor output voltage to the magnetic field is shown in Figure 4 below:
Figure 4. Graph of response to changes in output voltage to the magnetic field in variations in the length of the sensor peel (a) with cladding and (b) without cladding.

The graph in Figure 4 shows that increasing the magnetic field causes the output voltage to decrease, both on the with cladding sensor type and the without cladding sensor type. Data from the graph used to determine sensor characteristics using equations (1), (2b), and (3) shown in the following Table 2:

| Sensor Type       | Length of Peel (cm) | Range (V) | Sensitivity (V/T) | Resolution (T) |
|-------------------|---------------------|-----------|-------------------|----------------|
| With Cladding     | 1                   | 0.028     | 0.431             | 2.321          |
|                   | 2                   | 0.036     | 0.554             | 1.806          |
|                   | 3                   | 0.048     | 0.738             | 1.354          |
| Without Cladding  | 1                   | 0.025     | 0.392             | 2.550          |
|                   | 2                   | 0.028     | 0.441             | 2.267          |
|                   | 3                   | 0.031     | 0.458             | 2.186          |

Based on the data in Table 2 shows that the length of peel sensor, both the with cladding and without cladding sensor types affect the value of the sensor characteristics. The longer of the sensor peel, the better of the sensor characteristics. The best sensor characteristics for magnetic field measurement were obtained at 3 cm length of peel with cladding sensor type show sensitivity and resolution values of 0.738 V/T and 1.354 T respectively. When an electric current flows in a wire coil raises a magnetic field around in the coil. The increase in the electric current flowing in the wire coil causes the resulting magnetic field to increase. The magnetic field causes the magnetic fluid in the tube to move and gather around the fiber optic sensor, thus affecting the refractive index of the optical fiber. The existence of these things causes the power losses in the sensor to increase, so that the light intensity received by the phototransistor will be smaller. Thus the output voltage generated by the phototransistor will decrease. Changes in electric current are proportional to changes in magnetic fields but inversely proportional to changes in output voltage. The greater the electric current flowing in the wire coil causes the magnetic field to increase, the output voltage on the sensor to decrease. The small output voltage causes the output power to decrease. This study has suitability with previous studies of magnetic field sensor by utilizing intensity modulation on optical fiber gratings using magnetic fluids in measure reflected optical power toward magnetic field. This study states that the greater the magnetic field cause the output power decreases [17]. Plastic
optical fiber applications are suitable for use as electric current and magnetic field sensor with advantages such as high sensitivity and simple measurement techniques.

4. Conclusion
The results showed that plastic fiber optic as a sensor can be used to measure electric current and magnetic field. Increased electric current and magnetic fields cause the output voltage to decrease. The best electric current measurement results were obtained on the with cladding sensor type of 3 cm length of peel show a sensitivity value of 0.008 V/A and a resolution of 0.121 A. While the best magnetic field measurement results were obtained on the with cladding sensor type of 3 cm length of peel show a sensitivity value of 0.738 V/T and a resolution of 1.354 T. Measurement of electric current and magnetic field can be done using a plastic optical fiber sensor because it produces high sensitivity values.

Acknowledgements
This research was supported by “PDUPT-UNHAS 2018” Contract No. 1634/UN-4.21/PL.00.00/2018.

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