Analysis of Voltage Sensor Based on Optical Fiber Macrobending Structure Using Piezoelectric for 1500 – 1600 nm Wavelength

Dwi Satriananda
School of Electrical Engineering, Telkom University
Bandung, Indonesia
dwisn@telkom.co.id

Erna Sri Sugesti[1] and A. Ali Muayyadi[2]
School of Electrical Engineering, Telkom University
Bandung, Indonesia
[1]ernasugesti@telkomuniversity.ac.id
[2]alimuayyadi@telkomuniversity.ac.id

***Abstract*—The integration of the optical fiber and piezoelectric macrobending structures can be utilized to create a voltage sensor. Both are arranged in such a way that optical fibers form a half or a circle whose position is between two piezoelectric. The piezo characteristic used is a one-way length dimension if applied voltage. So, when the piezo is given a certain voltage, then the optical fiber form, which was originally a half or a circle, will be shaped into an ellipse, because piezo length changes will push the cable from left and right. In addition to the changes in the shape of optical fiber, the distance between piezo, number of turn and cable characteristics used also affect the changes in macrobending loss.**

Keywords—Voltage Sensor; Macrobending; Piezoelectric; Ellipse

I. INTRODUCTION

In the industrial world has applied various kinds of sensors that function in accordance with the needs of the industry. For example light sensor, motion sensor, sound sensor, pressure sensor, temperature sensor, or voltage sensor. The voltage sensor serves to find out how much voltage applied to a device. If it does not match the input voltage, the device-forming components are not working properly which ultimately leads to damage. Therefore, immediate corrective action should be taken when the voltage is incompatible with the specification. The important thing in using the sensor is the extent of its sensitivity. There are several factors that affect the sensitivity of the sensor, one of which is the components used by the sensor.

The sensor using fiber optic cable has been discussed based on [1], optical fibers attached to both ends of piezo are formed to resemble a semicircle and give rise to an attenuation called macrobending loss. So, if the piezo is given a certain voltage, then the length dimension of piezo will increase, which resulted in the original shape of optical fiber is a half of circle to resemble a half of ellipse. Different with [1], [2] position the optical fiber is in a half of circle and clamped left-right with a slider tool in the form of travel single-axis translation stage, resulting macrobending [3, 4, 5]. The experimental results on [1, 2] are limited to the condition of a semi-circle only cable, so it is less likely to be sensitive to any change in loss. Sensitivity can be increased if the number of optical fiber turns added, so the value of loss will also increase, but note the value of loss should not be too large because it will cause the signal can not be transmitted. In [6], the attenuation value generated based on the experiment will increase if optical fiber turns increase.

This paper proposes a new method for enhancing sensitivity by using optical fiber turns and a modified piezoelectric [7, 8, 9] position. If given a certain voltage, piezoelectric dimension will change to be longer. Optical fibers that form a half or a circle and cause macrobending loss, positioned between two piezo, and will change its loss if a voltage change is applied to the piezoelectric. [10, 11].

II. MACROBENDING AND ELLIPSE

A. Macrobending in Optical Fiber

The attenuation occurring in the optical fiber [12,13,14,15], is caused by bending, as shown in Figure 1. Optical fibers bent at radius R, causing the input signal to experience gradation. The value due to attenuation, called macrobending loss. To calculate macrobending loss [5], can use mathematical formula as seen equations as follows:

$$L = AR^{-1/2} exp(-UR) \tag{1}$$

$$A \approx 30(\Delta)^{1/4} \lambda^{-1/2} \left(\frac{\lambda_{ce}}{\lambda}\right)^{3/2} Rexp(-UR) \tag{2}$$

$$U \approx 0.705 \frac{(\Delta)^{3/2}}{\lambda} \left(2.748 - 0.996 \frac{\lambda}{\lambda_{ce}}\right)^{3} \tag{3}$$

where L = macrobending loss (dB), Δ = relative difference of refractive index, λ = wavelength, λ_{ce} = cut-off wavelength and R = radius of turn.

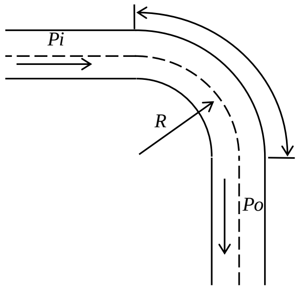

Fig. 1. The diagram of macrobending loss [5]

B. Ellipse

When viewed, the ellipse is like a circle pressed from both sides, making it oval-shaped, and collection of points from several circle with different radius, as seen Fig. 2.a [16].

The value of the radius of each circle within the ellipse, Fig. 2.b, can be obtained according to the following formula [16].

$$\frac{1}{r} = ab\frac{\left(b^2-\left(b^2-a^2\right)\cos^2\varphi\right)^{\frac{3}{2}}}{\left(b^4-\left(b^4-a^4\right)\cos^2\varphi\right)^{\frac{3}{2}}} \tag{4}$$

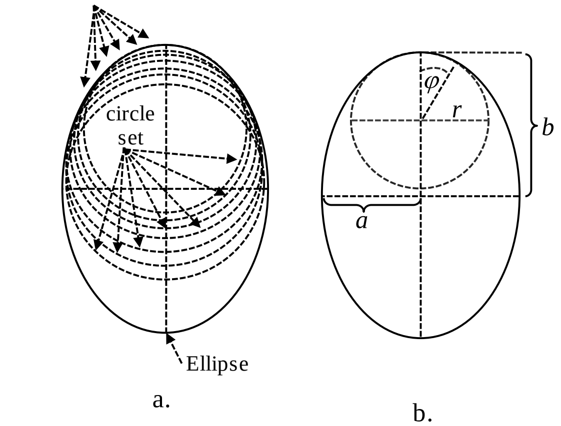

Fig. 2. (a). Circle set inside an ellipse, (b). Circle with radius r in ellipse.

III. SENSOR DESIGN AND SIMULATION

Materials used in this paper are piezoelectric and optical fiber. Piezoelectric type N10 Actuator AE0505D44H40 NEC / TOKIN, has a characteristic that can change its dimension in length if applied voltage and used in this paper only under increasing or decreasing voltage conditions only [8]. Optical fiber used is type 1060XP [17] and SM1250G80 Thorlabs [18], with specification as seen in TABLE I.

A. Sensor Design

In this paper, the wavelength used is 1500 - 1600 nm. The sensor modeling consists of a half or a circular structure of optical fiber. The schematic design in Fig. 4, shows that the diameter of half or one optical fiber circle changes depending on the piezoelectric length change. Piezoelectric base attached to wall or platform.

TABLE I. OPTICAL FIBER SPECIFICATIONS

Parameter of fiber	1060XP	SM1250G80 Thorlabs
λce	920nm	1150nm
Core Refractive Index	1.46313	1.45094
Cladding Refractive Index	1.45642	1.44680
Core diameter	5.3µm	4.5µm
Cladding diameter	125µm	80µm
Δ	0.004576	0.002849
λ	980 - 1600nm	1310 - 1550nm

Measurement of loss due to bending on optical fiber, formulated into mathematical equations that are resulted to vary depending on the parameter changes, including changes in the distance between the ends of the Piezoelectric.

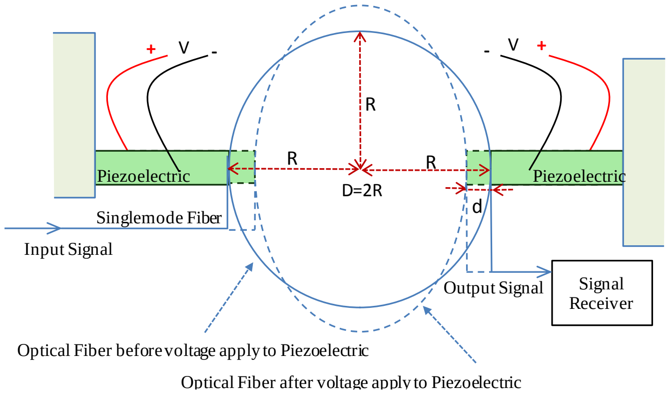

Fig. 4. Scheme Design

When voltage applied, there will be current movement on the Piezoelectric, which results in a change in Piezo dimension. The distance change (D) between one Piezo and the other Piezo, will change the diameter value of the optical fiber bending. Result of simulation analysis based on the obtained mathematical formula, can be used as reference of a voltage sensor modeling.

B. Simulation

The simulation starts from determining the radius of each circle or semicircle that tangent to the ellipse. Fiber optic cable originally in the form of a half or a circle in the initial position, to be ellipse-shaped, this is due to a push from the left side and right side Piezoelectric. Piezoelectric when given a certain voltage, would change its length according to the voltage applied based on the characteristic Piezo type used. The length of the radius of each circle within the ellipse would serve as the basis for the calculation of attenuation on the side of the circle tangent ellipse. The accumulation of attenuation of each side of the circle (angle φ) in contact with the ellipse side is the attenuation of only one side of a circle, so that if the two sides of the circle are intersecting with an ellipse-shaped optical fiber cable, the total attenuation value must be at two times.

IV. ANALYSIS AND DISCUSSION

From some input parameters generated, it can be analyzed several things about the modeling of voltage sensor. The analysis is based on several differences, among which, wavelength different, the distance between piezoelectric, optical fiber turns, as well as the voltage applied to the Piezoelectric.

Equation (1) - (3) consists of several variables used. For optical fiber (table 1), the relative differences of refractive index, wavelength and cut-off wavelength are used. As for equation (4) it is used to obtain the radius value of the circle that forms the ellipse. From the obtained radius, we can determine the macrobending loss that occurs by using equation (1) - (3).

Fig. 5 and Fig. 6 are comparison of macrobending loss results, in the simulation with previous work as in [1]. Although different parameters are used that cause different loss values, the figures show that there is a tendency of the same graph pattern, ie the greater the wavelength of the operation being used, the macrobending loss will increase. So there is a correlation between wavelength and macrobending loss. In previous work [1], with wavelength 1540 nm and 1550 nm there is a significant increase of loss compared to the pattern of loss from simulation. This happens because the simulation is only ideal conditions based on shape change curvature of optical fiber and mathematical approach, does not take into environmental factors, such as noise [19].

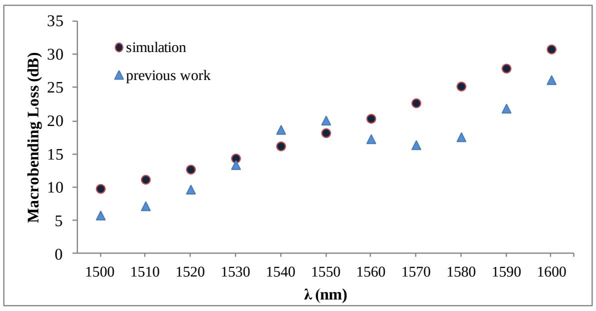

Fig. 5. Comparison between simulation result of macrobending loss at 50 V (FO 1060XP; Piezo distance = 10 mm; Optical fiber turns = 0.5) with previous work.

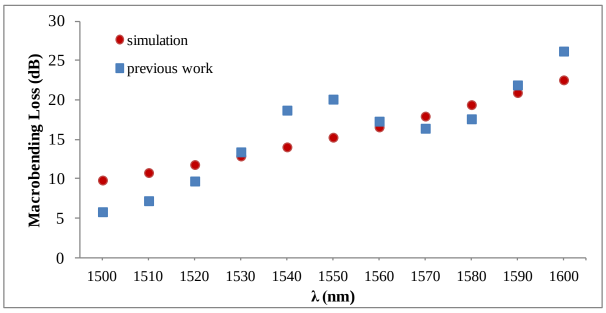

Fig. 6. Comparison between simulation result of macrobending loss at 50 V (FO SM1250G80 Thorlabs; Piezo distance = 10 mm; Optical fiber turns = 0.5) with previous work

According to Fig. 5, that the macrobending loss is more than 20 dB between the operating wavelengths of 1550 nm and 1560 nm. While in Fig. 6, the macrobending loss is worth more than 20 dB, between the wavelengths of 1580 nm and 1590 nm. Large losses will make the received signal will be smaller so that the quality of data sent will decrease.

CONCLUSION

The change of voltage on piezoelectric, will cause changes in macrobending loss on optical fiber, that is utilized as a voltage sensor. Parameters that affect the characteristic of the sensor include the type and optical fiber turns of optical fiber and also the distance between piezo.

The deviation of macrobending loss due to the change of voltage will be more significant if longer wavelength used, and more sensitive as a voltage sensor.

REFERENCES

[1] Pengfei Wang, Semenova, Y., Wu, Q., and Farrell, G., "A fiber-optic voltage sensor based on macrobending structure. Optics and laser technology", Optics and Laser Technology, vol. 43, no. 5, pp. 922-924, January 2011.

[2] Pengfei Wang, Semenova, Y., Wu, Q., and Farrell, G., "A bend loss based singlemode fiber micro-displacement sensor", Microwave and Optical Technology Letters, vol. 52, no. 10, pp. 2231-2235, October 2010.

[3] International Baccalaureate Extended Essay, "Macrobending Attenuation in a Single Mode Optical Fiber", March 2013.

[4] Dorcas Nhiwatiwa, "Comparison of macrobend losses in single mode fibre (SMF) and multimode fibre (MMF)", University of Zimbabwe, January 2012.

[5] Jianchun Qiu, Dongjian Zheng, Kai Zhu, Bin Fang, and Lin Cheng, "Optical fiber sensor experimental research based on the theory of bending loss applied to monitoring differential settlement at the earth-rock junction", Journal of Sensors, Hindawi Publishing Corporation, Article ID 346807, 2015.

[6] Okfarima Mandasari, Erna Sri Sugesti, and Bambang Setia Nugroho, "Analisis daya hilang pada serat optik melengkung menggunakan metode Geometris dan FDTD", Jurnal Penelitian dan Pengembangan Telekomunikasi, Kendali, Komputer, Elektrik, dan Elektronika (TEKTRIKA), Telkom University, vol.01, no. 01, January 2016.

[7] NEC/TOKIN, "Multilayer Piezoelectric Actuators", vol. 08, July 2015.

[8] NEC/TOKIN, "Piezoelectric Ceramics", vol. 05, October 2013.

[9] Andy Noven Krisdianto SB, "Study characteristics of generated energy with piezoelectric vibration energy Harvesting mechanism method for frontal and lateral loading", Sepuluh Nopember Institute of Technology Surabaya, July 2011.

[10] Pengfei Wang, "Development of fiber bend loss edge filter", Dublin Institute of Technology, Ireland, January 2008.

[11] Pengfei Wang, Semenova, Y., Wu, Q., and Farrell, G., Ti, Y., Zheng, J, "A macrobending singlemode fiber based Refractometer", vol. 48, issue no. 31, pp.6044-6049, January 2009.

[12] Jesus Castrellon-Uribe, "Optical fiber sensors: An overview", Center for Research in Engineering and Applied Sciences, CIICAp, Autonomous University of Morelos State, UAEM, Mexico.

[13] Ginu Rajan, "Optical Fiber Sensor : Advanced Techniques and Applications", CRC Press, University of New South Wales, Australia, 2015.

[14] Ray Tricker, "Optoelectronic and Fiber Optic Technology", Newnes, 2002.

[15] _, "Bab II Serat optik - USU Repository", http://repository.usu.ac.id/bitstream/123456789/31342/4/Chapter%20II.pdf, March 29, 2015.

[16] _, "Geometry - A circle inside an ellipse",

https://math.stackexchange.com/questions/1972994/a-circle-inside-an-ellipse, May 4, 2017.

[17] Pengfei Wang, Gerald Farrell, Qian Wang, and Ginu Rajan, "An optimized macrobending-fiber-based edge filter", IEEE Photonics Technology Letters, vol. 19, no. 15, August 2007.

[18] _, "Thorlabs.com - single mode fiber", https://www.thorlabs.com/NewGroupPage9_PF.cfm?ObjectGroup_ID=949, January 15, 2015.

[19] Leanna Vidya, Ali Muayyadi, and Erna Sri Sugesti, "Studi penerapan DWDM-ROF untuk transmisi sinyal multi teknologi akses nirkabel", Thesis, Institut Teknologi Telkom, DOI: 10.13140/2.1.1261.5363, June 2011.