JoFRISE 1 (1) (2023)
Journal of Frontier Research in Science and Engineering
https://journal.riau-edutech.com/index.php/jofrise
Publisher :
Andester Riau Edutech
Pusat Inovasi Pendidikan dan Teknologi
ISSN : 0000-0000

Polarization Characteristics of Electromagnetic Wave in Optical Fibers

Muhammad Sahal[1], Ernidawati[1], Naila Fauza[1]

[1] *Department of Physics Education, PMIPA, FKIP Universitas Riau, Pekanbaru Indonesia*

*Corresponding author's email: Mhmmdsahal28@yahoo.com

Submitted: 16/10/2023
Revised: 27/10/2023
Accepted: 06/11/2023
Published: 22/12/2023
Vol. 1
No. 1

ABSTRACT

This article goes into the details of optical fiber technology, focusing on important things like wave polarization, light waves, and the innovative use of liquid crystal-based fiber optic sensors. We start with the basics of polarization and how light waves work. Then, we dive into the world of optical fiber technology, which is crucial for how we communicate today. We specially focus on wave polarization inside these fibers, explaining why it matters for sending signals smoothly. Imagine these fibers as tiny tunnels where light waves travel, and how they're oriented, or polarized, affects how well the signals go through. Next, we explore liquid crystal-based fiber optic sensors, which are a cool advancement. These sensors use special liquid crystals to notice changes in their surroundings. We look at how they're designed and where they're used, like in keeping an eye on the environment and helping with medical diagnostics. By mixing simple explanations with real-world examples, this article aims to help both curious readers and professionals understand the basics and practical applications of optical fiber technology in our everyday communication systems

Keywords: *Fiber optic, Wave Polarization, Light Waves, Liquid crystal-based sensor*

1 Introduction

Optical fiber is a technology of transmitting light through very fine glass or plastic fibers. Operating based on the legal principles of internal total reflection, optical fiber enables high-speed data transmission with high capacity, minimal interference, and energy efficiency. Its applications extend from telecommunications to medicine, providing effective solutions for long-distance data transfer and fast-paced communication (Nugraheny et al., 2018).

Examine crucial aspects in the understanding of electromagnetic wave physics and its application in modern technology. Waveguides, which are structures designed to direct electromagnetic waves, such as light or microwaves, play a central role in communication systems, remote sensing, and radar technology. Polarization, which refers to the direction of oscillations of electric and magnetic fields in a wave, affects directly how these waves interact with the matter and devices used for the control and transmission of those waves. The study of polarization in waveguides opens new horizons in the design and development of electromagnetic devices, offering the potential to improve efficiency, bandwidth, and data transmission capabilities. Therefore, a deep understanding of this phenomenon is not only theoretically important but also has far-reaching practical implications in telecommunications and electromagnetic engineering (Ayu, 2019).

This study becomes relevant to the development of fiber optic technology, where the polarization of light can affect the efficiency and capacity of data transmission. For example, an understanding of polarization helps address issues such as dispersion mode, which can reduce signal quality in fiber optic communication systems. In addition, polarization of light is used in a variety of sensor applications, such as in remote sensing technology and precision measuring instruments

How to Cite :
Sahal, M. *et al* (2023). Polarization of Electromagnetic Wave (Light) in Optical Fibers. *Journal of Frontier Research in Science and Engineering(JoFRISE)*, 1(1), 21-27.

2 Research Methodology

2.1 Polarization

The theory of polarization of light is a fundamental concept in physical optics, referring to the phenomenon in which light waves, which are intrinsically transverse, exhibit a certain orientation in the direction of their vibration. Polarization can be generated through various methods, such as reflection, refraction, or by using polarizing filters. This process is important in a wide range of applications, from photography to screen technology. Polarization not only enriches our understanding of the nature of light but also paves the way for innovations in science and technology (Wahyuni, 2018)(Putri Yuppe dkk, 2018).

2.2 Light Waves

One of the most prominent physicists who contributed significantly to the wave theory of light was James Clerk Maxwell. Maxwell's contributions to electromagnetism, particularly through Maxwell's Equations, revolutionized the understanding of light waves. This equation, developed in the mid-19th century, shows that light is a form of electromagnetic waves. Maxwell successfully demonstrated that electric and magnetic fields propagate through space in the form of waves, and the speed of this propagation corresponds to the known speed of light. This discovery not only corroborated the wave theory of light but also became the foundation for modern electromagnetic theory, which influenced the development of communication technology and our understanding of the electromagnetic spectrum. Maxwell effectively unified light, electricity, and magnetism into one comprehensive theoretical framework, providing a more holistic and unified view of physical phenomena (Iqbal & Trinugroho, 2008)(Cahyaningsih, 2021).

2.3 Fiber Optics

Optical fiber according to David N. Payne, who is a leading researcher in this field, is a technology that utilizes the physical principles of light to transmit information. Payne, whose contribution was significant in the development of optical fibers, described how these fibers utilize total internal reflection to guide light through a very pure fiber core. This process allows high-speed data transmission and minimal signal loss, revolutionary in telecommunications. Payne's inventions and innovations in fiber optics have paved the way for the modern communications era, offering much greater efficiency and capacity compared to traditional transmission methods (Laming & Payne, 1989).

3 Results and Discussion

3.1 Wave Polarization in Optical Fiber

Brewster Angle Method Polarization

This method emphasizes the merging of several basic theories about the polarization of reflected light. Brewster's experiment therefore obtained the equation:

$$tan\theta : \frac{n1}{n2} \tag{1}$$

Light polarization combined with the Brewster method can be applied to determine the refractive index value of a material. In experiments conducted by Nugraheni et al, 2018 researchers involved light polarization to determine the refractive index in an optical device which in this study used clear resin.

This experiment uses a polarizer to adjust the angles of TE and TM. In TE mode the polarizer sets the angle at 0 and in TM mode the angle is 90. Therefore, light will tend to have an electric field component rather than a magnetic field, so the intensity value in TE mode will be greater than TM mode.

This experiment shows that we can adjust the angles of TE and TM to bring out the desired intensity by setting this intensity can get the reflectance value of light with the equation:

$$R: \frac{I_v}{I} \quad (2)$$

With R refectancy, I light intensity using a He-Ne laser (with wavelengths (642.5293 ± 0.3112 nm) and light intensity at specific positions (with an angle range of 10, 20, 30, 40, 50, 60, 70, 80, and 90). This experiment obtained a Brewster angle value of 52.5 and a refractive index value (1.303 ± 0.055) with an accuracy of 89% I_v°(Nugraheny et al., 2018).

Polarization of TE and TM Waves

The mode of electromagnetic waves in two dimensions is divided into two, namely TE polarization and TM polarization. Transverse electric polarization or te is a mode of electromagnetic waves that has magnetic properties for the z-axis component and an electric field for the y-axis and x-axis components. Transverse magnetic polarization or TM has an electric field component located on the z axis and on the x and y axes is the magnetic field(Firdausi et al., 2017).

In 1873 the phenomena of electricity and magnetism at the macroscopic level were capitalized by Maxwell's equations discovered by Maxwell. The conclusions of Maxwell's equations from electromagnetic science at that time and the hypothesis of the kinetic theory of electric current discovered by Marconi and Hardwell on empirical basis and gaus amper faraday And other scientists developed theoretically (Pozar, 2009).

A method that is useful for solving problems related to electromagnetics and is one of the numerical simulation techniques is the FDTD method (Namiki, 1999). The FDTD method has been widely used in various problems and was first proposed by Yee (Bérenger, 2007). We can observe propagation by considering the geometry and materials used in electromagnetic waveguide structures inside the structure using the FDTD method (Negara et al., 2015).

The FDTD method has been widely used in various problems and was first proposed by Yee[16] [17]. The numerical approximation of differential forms of Maxwell's equations is used as a very simple algorithm in this technique. By calculating the Field equation as a function of the previous field related in the dimensions of space and time y can perform a calculation using the available electric and magnetic field grids. The expansion of squared tailors in the dimensions of space and time is the basic approximation of the Yee algorithm. The provision of appropriate spatial grids at each wavelength is used to minimize errors due to cluttered grids and numerical scattering (Turner & Christodoulou, 1999).

The use of analytical methods that cover surfaces resembling the finite element method became the basis for the FDTD method. Absorbent limits are installed around the analysis area to avoid unwanted wave reflection on the wall is something to note when using the FDTD method. Wether (Merewether, 1971), Engquist and Majda (Engquist & Majda, 1977)Nut (Mur, 1981), Lindman (Lindman, 1975), Higdon, and Berenger (Berenger, 1994) represents some usable absorption limit.

Dispersion Mode Polarization Using HP 8509B

Frequency is important in obtaining the speed of the waveguide and the size and wavelength are the base points of a waveguide (Hecht, 2015).

The phenomenon of pulse wave dilation that occurs due to delay differences is a form of dispersion mode polarization(Khare, 2004). Polarization of dispersion modes becomes a case of modal dispersion in which case of modal dispersion is a distortion mechanism involved in many mode optical fibers and other waveguides. The optical signal propagation speed that is not the same as all modes causes the signal to propagate over time. Dispersion mode polarization occurs when both waves move at speeds that resemble the shape of fiber nuclei and stress symmetry propagates at varying speeds and resulting imperfections will damage symmetry.

The input signal that enters the fiber that is directly polarized into a circular polarization or elliptical polarization circle and the output signal comes back out in straight form in another position is referred to as optical fiber in dispersion mode polarization. A delay (WCD) will appear when the input signal reaches the output. WCC makes a first-order or second-order input signal because the fiber experiences slow delay and short delay throughout the fiber. There are two groups of noise in single-mode fibers: internal and external. The permanent characteristics of fibers due to errors in the manufacturing process are internal characteristics. As for external noise, it is noise that arises due to external pressure that provides noise to optical fibers during the wiring process. Imperfections in these conditions cause birefringence in the fibers.(Poole & Nagel, 1997).

PMDs in many systems change over time and are best characterized by statistical representations to explain the details of those changes.

The nature of PMD can be characterized by three magnitudes depending on the wavelength or optical frequency.

1. Main pairs of polarization states
2. Three-dimensional polarization dispersion vector
3. Jones Matrix

We can see the polarization of light waves using the HP 8509B. The measurement menu offers a range of integrated measurement solutions that address modal polarization dispersion (PMD), polarization loss, Jones matrix and optical optimization (Puja Negara et al., 2019).

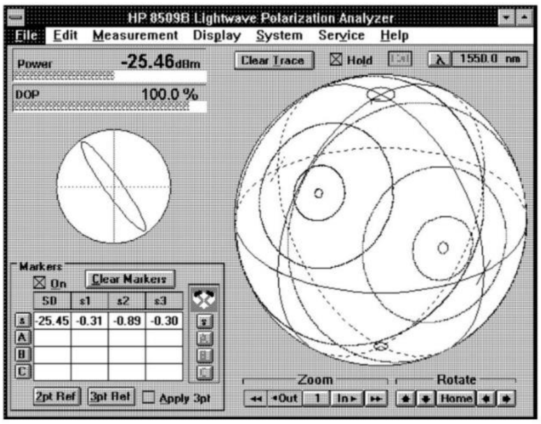

Figure 1. The Main measurement window of the HP 8509B light wave polarization analyzer

Fluorescent Polarization for Cooking Oil Quality Evaluation

Florescence that is not linear with respect to the polarization of incident light causes a change in polarization, and the maximum polarization value obtained when = 0°. Changes in fluorescence polarization in olive and palm oil increase with the mass of unusable oils. One of the main causes is similar as in the case of transmission misalignment, namely the addition of saturated fatty acids to oil that is barely suitable for use. This method of polarization of fluorescence has similarities to transmission polarization, but the difference lies in that the average Alpha value for florence is always greater than the Beta value. Indirectly, this method complements the photoelectric method and can also be used as an initial test on the feasibility of cooking oil for use.θ

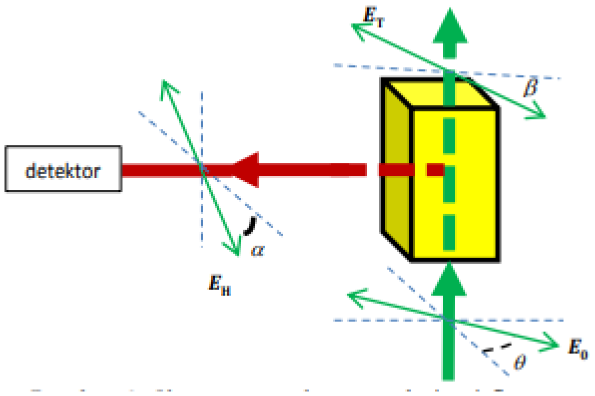

Figure 2. Fluorescence Polarization Design

Research on measuring changes in polarization angle has not been done by many other researchers, this is because the equipment used is less complicated than oil testing in general.(Yesiana et al., 2015).

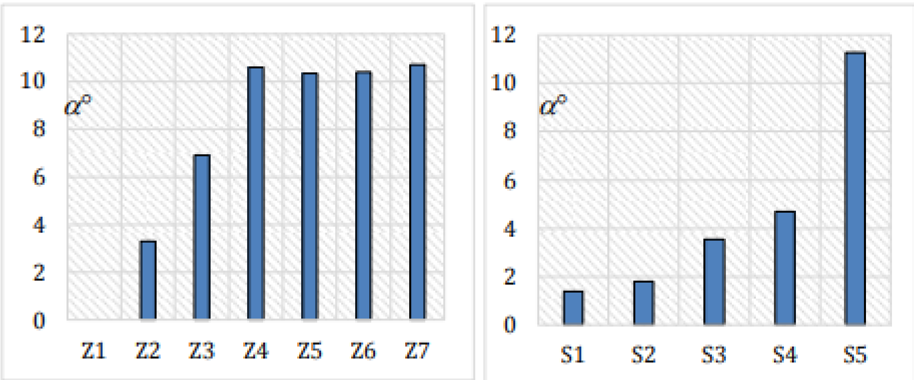

Figure 3 EH Scattering Polarization Profile

Figure 3. EH scattering polarization profile with polarization angle α relative to the Z1 sample and its comparison to the palm oil sample. Angle of polarization of incident light $\theta = 0°$. Olive oil data taken from references (Firdausi et al., 2014).

Polarization Maintining Fibre (PMF)

PMF is a type of fiber optic cable with a single mode that has the ability to maintain the polarization of a light. In maintaining the polarization of light requires the addition of stress rods located on both sides of the core. The characteristics of this stress rod must have a different material from the material imposed on the core, for example on the core we use silica base material in other words on the stress rod we use materials other than silica in its manufacture. The electric field propagating in the trajectory contained in this study will experience collisions after experiencing a wave phase change of π/β, but in a direction that is counter-directional, in other words, the phase shift sigma that occurs in the configuration is π. Therefore, a standing wave resonance will form at $(\pi+m\pi)$, where odd m values will cause interference to increase or increase each other, then for even number m values will cause wave interference that eliminates each other.

3.2 Characteristic of Liquid Crystal-Based Fiber Optic Sensor

PMF fiber optic cable is a single-mode fiber optic cable that has the ability to maintain the polarization of light waves. As discussed in the previous section, the materials used on stress bars are materials that are in addition to the materials used on the core. This research uses a device consisting of nematic liquid crystals (LC) and several other optical components that have the ability to operate under light depending on the intensity of polarization present. The high and low polarization and cost of nematic liquid crystals, with relatively low power consumption depend on the electrical signal to be generated by the liquid crystal, which in turn will determine the pattern of polarized light. To the 90° polarization grid (PBS) splits the two optical rays into two orthogonal polarizations that have a deflection angle of 90°. To focus the output light from PBS, this study used a 90/10 POF input output lens; 10% of the output port will be used to see the output power, and 90% of it is used to connect the switch to the fiber link.

4 Conclusion

Based on the description of the paper, it can be concluded as follows The polarization of light waves in optical fibers can be affected by the direction of vibration of their electric field. Single optical fibers typically support single polarization, which means light waves propagate with a specific electric field orientation. However, in multimode fiber optics, the polarization of light can be more complex because different path variations can support various polarizations. It is necessary to take into account polarization characteristics in the design and operation of fiber optic systems. Some renewable research methods on polarization in optical fibers are Brewster Angle polarization, TE and TM wave polarization, dispersion mode polarization using HP 8509B, Fluorescence polarization for cooking oil quality evaluation and Polarisation Mainting Fiber (PMF).

5 Acknowledgement

We would to thanks to Department of Physics Education, PMIPA, FKIP Universitas Riau for great support in this research.

Reference

Ananto, B. (2011). Simulasi Perambatan Cahaya Pada Serat Optik. *Jurnal Teknik Elektro Fakultas Teknik Universitas Diponegoro*, 1–9.

Ayu, D. F. (2019). *Gelombang Optik Polarisasi*.

Berenger, J.-P. (1994). A perfectly matched layer for the absorption of electromagnetic waves. *Journal of Computational Physics*, *114*(2), 185–200. https://doi.org/https://doi.org/10.1006/jcph.1994.1159

Bérenger, J.-P. (2007). *Perfectly Matched Layer (PML) for Computational Electromagnetics*. Springer International Publishing. https://doi.org/10.1007/978-3-031-01696-7

Cahyaningsih, T. (2021). Rancang Bangun Alat Peraga Polarisasi Cahaya Dalam Pembelajaran Fisika Di Sekolah Menengah Kejuruan. *CSRID Journal*, *13*(3), 306–315. https://doi.org/http://dx.doi.org/10.22303/csrid.13.3a.2021.306-315

Deswita, P., & Saputri, R. H. (2021). Revolusi Saintifik dalam Perkembangan Ilmu Optika. *Natural Science: Jurnal Penelitian Bidang IPA Dan Pendidikan IPA*, *7*(2), 138–150. https://doi.org/10.15548/nsc.v7i2.3028

Engquist, B., & Majda, A. (1977). Absorbing Boundary Conditions for the Numerical Simulation of Waves. *Mathematics of Computation*, *31*(139), 629. https://doi.org/10.2307/2005997

Firdausi, K. S., Simbolon, N., & Sugito, H. (2017). Polarisasi Fluoresens Untuk Evaluasi Mutu Minyak Goreng. *Jurnal Ilmiah Teknosains*, *3*(1).

Firdausi, K. S., Suryono, H. S., Amitasari, R., Murni, S., & Putranto, A. B. (2014). A Study of Natural Polarization on Saturated Fatty Acid as most Responsible Parameter for Investigation of Oil Quality Level. *Proceedings of International Seminar on New Paradigm and Innovation on Natural Sciences and Its Application (4th Isnpinsa), 28th October*, 49–52.

Hecht, J. (2015). *Understanding Fiber Optics* (Fifth Edit). Lase Light Press.

Iqbal, M., & Trinugroho, A. (2008). Perkembangan Riset Aplikasi Polarization Imaging By Reflection Untuk Objek Transparan Dalam Bidang Computer Vision. *Seminar Nasional Aplikasi Teknologi Informasi*, *2008*(Snati), 21–2008.

Khare, R. P. (2004). *Fiber optics and optoelectronics*. Oxford University Press.

Laming, R. I., & Payne, D. N. (1989). Electric Current Sensors Employing Spun Highly Birefringent Optical Fibers. *Journal of Lightwave Technology*, *7*(12), 2084.

Lindman, E. L. (1975). "Free-space" boundary conditions for the time dependent wave equation. *Journal of Computational Physics*, *18*(1), 66–78. https://doi.org/https://doi.org/10.1016/0021-9991(75)90102-3

Merewether, D. E. (1971). Transient Currents Induced on a Metallic Body of Revolution by an Electromagnetic Pulse. *IEEE Transactions on Electromagnetic Compatibility*, *EMC-13*(2), 41–44. https://doi.org/10.1109/TEMC.1971.303117

Mur, G. (1981). Absorbing Boundary Conditions for the Finite-Difference Approximation of the Time-Domain Electromagnetic-Field Equations. *IEEE Transactions on Electromagnetic Compatibility*, *EMC-23*(4), 377–382. https://doi.org/10.1109/TEMC.1981.303970

Musa. (2017). *Perfectly Matched Layer Pada Elektromagnetik*. Institut Teknologi.

Namiki, T. (1999). A new FDTD algorithm based on alternating-direction implicit method. *IEEE Transactions on Microwave Theory and Techniques*, *47*(10), 2003–2007. https://doi.org/10.1109/22.795075

Negara, T. P., Yuliawati, L., Garnadi, A. D., Nurdiati, S., & Alatas, H. (2015). Effect of filling-factor and angle of incident on transmittance of a dielectric slab waveguide with metallic grating. *AIP Conf. Proc. 1656*, 060003. https://doi.org/10.1063/1.4917134

Nugraheny, I., Nurfauzi, W., Fausta, D. E., Supurwoko, & Pambuka, R. N. (2018). Polarisasi Cahaya dan Penentuan Nilai Indeks Bias dengan Metode Sudut Brewster. *Jurnal Fisika Dan Aplikasinya*, *14*(3), 59–62. https://doi.org/10.12962/j24604682.v14i3.3867

Poole, C. D., & Nagel, J. (1997). Polarization Effects in Lightwave Systems. In *Optical Fiber Telecommunications IIIA* (pp. 114–161). Elsevier. https://doi.org/10.1016/B978-0-08-051316-4.50010-2

Pozar, D. M. (2009). *Microwave Engineering, 3Rd Ed* (J. W. & Sons (ed.)).

Puja Negara, T., Erniyanti, & Ismangil, A. (2019). Simulasi Gelombang Elektromagnetik Pada Waveguide Menggunakan Metode Finite Difference Time Domain Untuk Aplikasi Radar. *Seminar Nasional Sains Teknologi Dan Inovasi Indonesia (SENASTINDO AAU)*, *1*(1), 147–154.

Putra, M., Amir, D., & Syamsul, S. (2020). Rancang Bangun Antena Biquad dengan Reflektor Grid Parabolik untuk Mengoptimalkan Gain Antena Pada Frekuensi 450 Mhz. *Jurnal TEKTRO*, *4*(2), 105–112.

Putri Yuppe dkk. (2018). *Polarisasi Gelombang Cahaya*.

Rivaldo, R., Wijanto, H., & Wahyu, Y. (2018). Rectenna (Rectifier Antenna) 800 MHz-2500 MHz. *EProceedings of Engineering*, *5*(2).

Turner, G. M., & Christodoulou, C. (1999). FDTD analysis of phased array antennas. *IEEE Transactions on Antennas and Propagation*, *47*(4), 661–667. https://doi.org/10.1109/8.768805

Wahyuni, A. S. A. (2018). Konsepsi dan Miskonsepsi Siswa, Mahasiswa Calon Guru, dan Guru pada Topik Cahaya dalam Pembelajaran Fisika. *Jurnal Pendidikan Fisika*, *6*(3), 235–250. https://doi.org/10.26618/jpf.v6i3.1503

Wikara, B. (2012). Konsekuensi Hasil Penelitian Tim Icarus Tentang Kelajuan Neutrino Terhadap Teori Relativitas. *Jurnal Penelitian Fisika Dan Aplikasinya (JPFA)*, *2*(1), 15. https://doi.org/10.26740/jpfa.v2n1.p15-19

Yesiana, Y., Hambali, A., & Rahardjo, S. (2015). Analisis Karakteristik Ring Resonator Tunggal Dengan Menggunakan PMF (Polarization Maintaining Fiber) Untuk Diaplikasikan Sebagai Filter Optik. *E-Proceeding of Engineering*, *2*(2), 2315–2320