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POLARIZATION PROFILE IN SINGLE MODE OPTICAL FIBER AND ITS APPLICATION IN OPTICAL COMMUNICATION

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Abstract-The development of communication technology in the digital era encourages the use of optical fiber as a reliable high-speed data transmission medium. Single-mode optical fiber offers advantages in terms of distance and transmission capacity, but still has challenges related to the phenomenon of light polarization. Polarization is the orientation of the electric field of light that can change during propagation due to pressure, bending, temperature, and birefringence. These changes can reduce signal quality, cause power loss, and trigger polarization mode dispersion (PMD), the highest DoP (97%) is obtained when the fiber is straight and free of interference, indicating that almost all light remains polarized. In long-distance transmission (50 meters), the DoP decreases to 72%, indicating the effect of polarization mode dispersion (PMD) or cumulative interference during propagation. This study was conducted using a literature study method to understand the characteristics of polarization in single-mode optical fiber and its impact on the performance of the optical Extinction communication system. Parameters such as Degree of Polarization (DoP) and Polarization Ratio (PER) are used to measure polarization stability. The results show that the physical and environmental conditions of optical fibers greatly affect the degree of light polarization, where the DoP decreases drastically when the fiber is disturbed. Technologies such as polarization-maintaining fiber, polarization controllers, and polarization-division multiplexing (PDM) techniques have been developed to manage polarization and maintain transmission quality. Understanding and controlling polarization are key to optimizing modern optical communication systems.

Keywords: *Polarization, single optical fiber, DoP, birefringence, optical communication*

I. Introduction

In Indonesia, with its large population, there is an increasingly urgent demand for technology that can support communication and internet access, especially for long distances such as between islands that require Wi-Fi signals or internet quotas (Fadila et al., nd). Signal quality, coverage area, access speed, data security, and affordable costs are key factors in the development of this technology (Asmara et al., 2019). The internet itself is a global network that combines millions of computers from all over the world, enabling the exchange of information, communication, and access to various online services. To meet these needs, a stable signal is needed for fiber optic technology to act as an effective and efficient transmission medium. Optical glass fiber is a fiber optic cable that uses light to transmit data (Dwiputra et al., 2025). This technology is known for its high speed in data transmission. The development of optical technology is inseparable from the change of old theories to new theories, starting from prehistoric times to the modern optical era, which can be divided into several periods: Prehistoric Times to 1500 AD, Period 1550-1800 AD, Short Period 1800-1890 AD, and Period 1887-1925 (Deswita & Saputri, 2021). In the field of telecommunications, fiber optics work by converting analog signals into digital signals which are then converted into light waves and transmitted through optical fiber to the receiver. This process involves light modulation to convert electrical signals into light and vice versa (Fadila et al., nd).

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With the rapid development of computer and internet networks, the quality of information transmission through fiber optics has become very important. Increasing internet demand and different distances can reduce the quality of network connections. Fiber optics play a major role in industry due to its widespread use in various economic and commercial activities.

Optical fiber has become one of the mature transmission media, because it has advantages such as high bandwidth capacity (25 THz), low attenuation, small size, and resistance to electromagnetic interference (Asmara et al., 2019). This makes fiber optic ideal for improving the performance of the community's internet network with high speed, large capacity, and high reliability. Based on the number of modes, there are two types, namely single-mode and multi-mode. As the name implies, the type of single-mode fiber optic cable is only capable of transmitting one mode of light or can only transport one wavelength of light at a time with a wavelength ranging from 1310 nm to 1550 nm. (MochammadAfrieAdam & YuliarmanSaragih, 2022). Single-mode fiber has a core diameter of between 8 and 9 microns, which only allows one light path or mode. Multimode fiber has a core size of 50 or 62.5 microns (sometimes even larger) which allows multiple light paths or modes (Nasir, 2018). This single fiber is also far superior to multimode fiber because it has a larger bandwidth, so there is no need to doubt it and has fewer disadvantages compared to multimode fiber levels. In addition, the losses that occur are less than multimode because single-mode light moves linearly and can be utilized in applications that require long-distance connectivity. The disadvantage of this unusual mode is that it is more complicated to install. (Mochammad Afrie Adam & Yuliarman Saragih, 2022).

However, the performance of data transmission through optical fibers depends not only on the type of fiber and optical devices used, but also on the physical phenomena of light in the optical fiber itself. One phenomenon that greatly affects the quality of transmission in single-mode optical fibers is light polarization. Polarization is the absorption of the direction of the wave vibration plane. Polarization symptoms can only be experienced by transverse waves (Simbolon & Firdausi, 2018). In the context of optical transmission, changes or fluctuations in polarization can cause signal distortion, optical power fluctuations, and degradation of communication quality, especially in high-speed and long-distance systems. Some factors that affect changes in polarization include: Birefringence, birefringence is a phenomenon in which two components of light polarization propagate at different speeds in an optical fiber, causing changes in polarization along the fiber. Pressure, external pressure can change the refractive index of the fiber through elasto-optic effects, affecting the polarization of light. Research by Wati and Kuswanto found that increasing pressure on plastic optical fibers increases the intensity of light output, indicating changes in polarization characteristics. Curvature, the bend that occurs in a fiber optic cable is very risky to cause significant power loss and can even cause the fiber optic to break. Therefore, it is important to measure the impact of fiber optic bending on the power loss that occurs when the fiber optic is bent (Sembiring, 2022). Optical fibers experience signal degradation/loss when bent at certain radii. (Harsono, 2010). Sembiring in his research showed that the smaller the radius of curvature, the greater the power loss that occurs in single-mode optical fibers. Therefore, understanding the characteristics of polarization in single-mode optical fibers, as well as polarization control and compensation techniques, is very important to ensure the reliability of optical communication systems. In addition, the development of polarization-based devices, such as Polarization Beam Splitter (PBS), Polarization Controller, and Polarization Maintaining Fiber (PMF), has become an integral part of the design of modern optical communication systems. By understanding and managing polarization phenomena, fiber optic systems can be optimized to support increasingly complex current and future communication needs.

Based on this understanding, this study was conducted to examine the characteristics of light polarization in single-mode optical fibers and analyze their impact on the performance of optical communication systems, especially in terms of interference such as polarization mode dispersion (PMD) and data transmission stability. The research method is a literature study method to collect and analyze theories and previous research results related to polarization in optical fibers.

II. Formulation of the problem

1. What is the mechanism for polarization changes in single-mode optical fibers?
2. What factors affect polarization stability in single-mode optical fibers?
3. How do polarization changes impact the performance of optical communication systems?
4. What are the methods or technologies used to control or maintain polarization in fiber optic communication systems?
5. In modern optical communication applications, how does polarization control improve the efficiency and quality of data transmission?

III. Research purposes

1. To analyze the causes and mechanisms of polarization changes during optical signal transmission.
2. To identify factors that affect polarization stability in optical fibers.
3. To evaluate the effect of polarization changes on the performance of optical communication systems.
4. To review the technologies and methods used to control or maintain polarization in optical fibers.
5. To review the important role of polarization control in improving the efficiency and reliability of modern optical communication systems.

IV. Research methodology

This study applies a descriptive and analytical literature review method that aims to understand the polarization phenomenon in single-mode optical fibers and their application in communication systems through a review of various scientific and technical sources. The literature study method, often referred to as a library study, is a way of collecting data and information by reviewing written sources such as scientific journals, reference books, encyclopedias, and other reliable sources both in written and digital formats that are relevant and related to the object being studied (Sabrina, 2021). The research was conducted with a qualitative approach, where data was obtained from reference books, scientific journals, conference proceedings, and technical documents relevant to the field of optics and fiber optic communications.

A beam of light can be considered to be composed of two orthogonal electric vector field components that vary in amplitude and frequency (Muslimin, 2010). Polarized light occurs when these two components differ in phase or amplitude. The process that changes unpolarized light to polarized light is known as polarization (Yuliara, 2016). Polarization can be divided into linear, elliptical, or circular polarization (Permatasari, 2015).

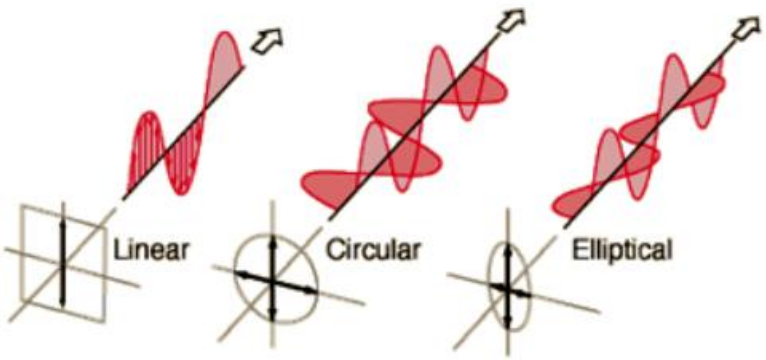

Figure 1: Linear, Circular and Elliptical Polarization

Source: https://images.app.goo.gl/bF3X8PkSpTCuxZtB7

Light that forms a plane wave in space is called linearly polarized (Sirait, 2020). Light is considered an electromagnetic wave, which is the result of a combination of electric and magnetic fields that vibrate and spread through space while transporting energy from one location to another (Lestari et al., 2025). Naturally, this light is not/not yet polarized like light from the sun, classroom lights, or candle flames, but it can be polarized with an optical device called a polarizer/polarizer (Yuliara, 2016). If both have different magnitudes, the phase-time difference between them must not be 0° or a multiple of 180° (because it will be linear), if the light consists of two identical plane waves but with different amplitudes and a phase difference of 90°, then the light is said to be circularly polarized (circle) (Rahmadhy, 2009). If two plane waves have different amplitudes and a phase of 90°, or a relative phase other than 90°, then the light is considered elliptically polarized. Any polarization is an issue in fiber optic transmission.

Optical fiber components continue to develop in the telecommunications industry in various variations to support efficient and stable communication. However, the output signal from the optical fiber is still affected by interference, power loss due to bending and dispersion, such as birefringence (Veriyanti & Saktioto, 2020). Birefringence refers to a phenomenon that occurs in certain types of materials, where light is split into two different paths. This phenomenon occurs because the material has a different refractive index, depending on the direction of the light polarization. Birefringence is also observed in optical fibers, due to slight asymmetry in the cross-section of the fiber core along the fiber and due to external pressure applied to the fiber such as bending. In general, birefringence caused by pressure dominates that caused by geometry. Changes in the refractive index cause changes in the light propagation path. Microbending loss is a loss that occurs due to microscopic effects due to defects at the core and cladding boundaries. Microbending is more difficult to detect because the radius of curvature is close to the radius of the optical fiber core, which causes power coupling between modes (Kahfi, 2017). The damage is caused by inadequate cable manufacturing, errors in the wiring process, low temperatures, and the presence of fiber parts that are pressed by an object. To anticipate fiber loss, the optical signal must be kept constant (continuous)**(Yuniarti & S, 2013).**

Optical fiber is a transmission channel made of high-quality glass material, thus offering reliability and advantages over transmission media made of metal such as copper cables, coaxial cables, and striplines (R, 2006). Basically, optical fiber reflects and bends some of the light flowing through it. Optical fiber offers wide bandwidth, allowing for more and faster data transmission processes, making it suitable for use in telecommunications system applications (Wiley & Sons, 2022). Based on the number of modes, there are two types, namely single-mode and multi-mode. Single-mode optical fiber is a type of optical fiber that only allows one path or mode of light to propagate in the fiber core. This reduces modal dispersion and allows for long-distance data transmission at high speeds. The core diameter of single-mode fiber is usually around 8–10 μm.

Light is one of the topics that has long been studied by physicists. One phenomenon that is still being studied is the phenomenon of light polarization (Nugraheny et al., 2018). Polarization is the orientation of the electric field direction of an electromagnetic wave (light). In single-mode optical fibers, light has two orthogonal polarization components that can change during propagation due to external influences such as pressure, bending, and temperature variations. Although called "single mode," optical fibers still allow two orthogonal polarization modes. Changes in polarization can occur due to birefringence, the difference in refractive index for different polarization directions. Polarized light can also be produced from the difference in refractive index of two rays from anisotropic minerals (Sutarto et al., 2019). This birefringence can be fixed (intrinsic birefringence) or change randomly due to external interference (random birefringence). In fiber optic communication systems, loss management plays an important role in the success of a telecommunications connection (Naufal et al., 2024). Polarization changes can cause polarization mode dispersion (PMD) and polarization dependent loss (PDL), which affect signal integrity, especially in high-speed and coherent-based systems. In modern optical communication systems, control of polarization is essential to maintain signal quality. To overcome the negative impact of polarization, devices such as polarization controllers, polarization-maintaining fiber (PMF) are used, PMF is a type of single-mode fiber optic cable that has the ability to maintain light polarization (Sahal et al., 2023) and polarization scramblers. In addition, the polarization-division multiplexing (PDM) technique is used to increase transmission capacity by utilizing two different polarization states simultaneously (Anggraini, 2017).

To measure the percentage of polarized waves in an optical fiber, we can use the Degree of Polarization (DoP) parameter. DoP is a measure of how much of the polarized component of light is compared to the total light. When a wave is perfectly polarized, its DOP is 100%, while an unpolarized wave has a DOP of 0%. If the wave is partially polarized, meaning that it is a mixture of polarized and unpolarized parts, its DOP will be between 0% and 100%. DOP is calculated by finding the fraction of the total wave power carried by the polarized part. Scientists can use DOP to study how materials strain by looking at the DOP of the light they emit. The polarization of the emitted light is related to the strain in the material through something called the photoelasticity tensor. To visualize DOP, a common representation called the Poincaré sphere is used. In this representation, the DOP is indicated by the length of a vector measured from the center of the sphere.

PER (Polarization Extinction Ratio) is a power ratio measurement used to describe the power exchange between the polarization states in an optical fiber and the components used in an optical communication system (Stevens, 2022). PER tells us the ratio of the power in the desired polarization direction to the power in the perpendicular direction after passing through the device or system. PER is usually expressed in decibels (dB). PER is affected by various factors such as the characteristics of the light source (whether the light is fully polarized or not), misalignments at fiber splices or joints, and the fiber or device itself. PER is also an important factor to consider in systems or devices that require the light to remain linearly polarized and aligned to a particular axis. In these cases, a higher PER is preferred. The actual PER value can vary depending on the device. For example, passive components typically have a PER value of around 18-20 dB, while polarizers or polarizing waveguides can have values of 50-60 dB or even higher. PER can also be used to estimate the DOP of a depolarizer or low-polarization light source. In such cases, the PER will be close to 0 because the light is distributed evenly across the different polarizations. There are various methods available to measure the PER, and the choice of method depends on the specific application. For coherent transmitters and receivers, the PER is a key parameter, because the X-polarization and Y-polarization are encoded by different signals.

V. Results and Discussion

In fiber optic communication systems, understanding the characteristics of light polarization is very important, especially in systems that use technologies such as polarization-division multiplexing (PDM) or optical-based sensors. One important parameter for measuring and understanding polarization characteristics is the Degree of Polarization (DoP). DoP measures how much of the proportion of light waves is polarized compared to the total light intensity. Degree of Polarization (DoP) is a parameter that describes the percentage of light components that have a certain polarization. The DoP value ranges from 0 to 1 (or 0% to 100%), with:

- DoP = 1 (100%) indicates fully polarized light.
- DoP = 0 (0%) indicates unpolarized light.
- 0 < DoP < 1 indicates partially polarized light.

In the case of fully polarized light, the relationship given byequality

$$S_0{}^2 = S_1{}^2 + S_2{}^2 + S_3{}^2 \tag{1}$$

Another important parameter, namely the degree of polarization (DOP) of light, is defined by:

$$DoP = \frac{\sqrt{S_1{}^2+S_2{}^2+S_3{}^2}}{S_0} \tag{2}$$

Where:

- S_0 = Total light intensity (lm)
- S_1= Linear light intensity (cd)
- S_2= Linear light intensity 45^0 (cd)
- S_3= Circular orientation light intensity (cd)

DoP measurement is done by analyzing the Stokes parameters of light produced by optical fiber using a tool called a polarimeter or other optical detection system. A polarimeter is a tool for analysis based on measuring the rotation angle of linearly polarized monochromatic light by transparent materials that have active optical properties (BA Wibowo et al., 2016). In fiber optic communication systems, DoP is an important indicator for assessing system stability against changes in polarization, identifying depolarization effects due to birefringence or polarization mode spread (PMD) and monitoring the performance of optical sensor systems, especially in optical fibers used to detect voltage, temperature, or magnetic fields.
Example of measurement results of the percentage of polarized light waves after passing through an optical fiber, using the Degree of Polarization (DoP) parameter.
The measurement method is carried out with an automatic polarimeter, which records the Stokes parameters and calculates the DoP using the formula:S_0, S_1, S_2, S_3

$$DoP = \frac{\sqrt{S_1{}^2+S_2{}^2+S_3{}^2}}{S_0} \tag{3}$$

Table 1: Results of measuring the percentage of polarized light waves after passing through the optical fiber.

Fiber Optic Conditions	$S^0(a.u)lm$	S_1(CD)	S_2(CD)	S^3(CD)	DoP (0-1)	DoP (%)
Straight, without interruption	1,000	0.950	0.100	0.150	0.97	97.0%
Lightly bent	1,000	0.800	0.120	0.100	0.82	82.0%
Pressed/stressed	1,000	0.600	0.150	0.100	0.64	64.0%
Heated (40°C)	1,000	0.400	0.180	0.120	0.47	47.0%
Heated (60°C)	1,000	0.250	0.130	0.090	0.31	31.0%

After 50 m of transmission	1,000	0.680	0.120	0.150	0.72	72.0%

Source: (Agrawal, GP (2012).

Based on Table 1: The results of measuring the percentage of polarized light waves after passing through the optical fiber, the highest DoP (97%) was obtained when the fiber was straight and free of interference, indicating that almost all light remained polarized. When the fiber is bent or pressed, the DoP decreases significantly, indicating depolarization due to birefringence or mechanical stress. Increasing temperature also causes a fairly sharp decrease in DoP, because temperature changes disrupt the optical structure in the fiber. In long-distance transmission (50 meters), the DoP decreased to 72%, indicating the effect of polarization mode dispersion (PMD) or cumulative interference during propagation. The Degree of Polarization value quantitatively indicates what percentage of light waves are still polarized after leaving the optical fiber. Under ideal conditions, the DoP can approach 100%, but this value decreases with physical interference, temperature, or the length of the fiber passed through. DoP monitoring is very important for optical systems that depend on polarization stability, such as in coherent communications and interference-based sensor systems.

In line with technological advances, the demand for high-speed internet is increasing, and fiber optics are the main choice because they use light to transmit signals. The history of fiber optics began in period IV (1887-1925) with the discovery of photoelectric and fiber optics in the field of optics (Deswita & Saputri, 2021). In the 1930s, German researcher Heinrich Lamm studied the transmission of light through fiber optics (Deswita & Saputri, 2021). Fiber optics began to be practically applied for long-distance communication in 1966 using laser technology, which was discovered in 1961 (Ballato & Dragic, 2020). The development of fiber optics continues to this day, making it the main device in long-distance telecommunications. In a fiber optic communication system, an input signal (audio, video or other digital data) is used to modulate light from a source such as an LED or semiconductor LASER and transmitted through an optical fiber (A. Wibowo, 2022). At the receiving end, the signal is demodulated to reproduce the input signal. If data transfer occurs only between two devices, then it is called point-to-point communication.

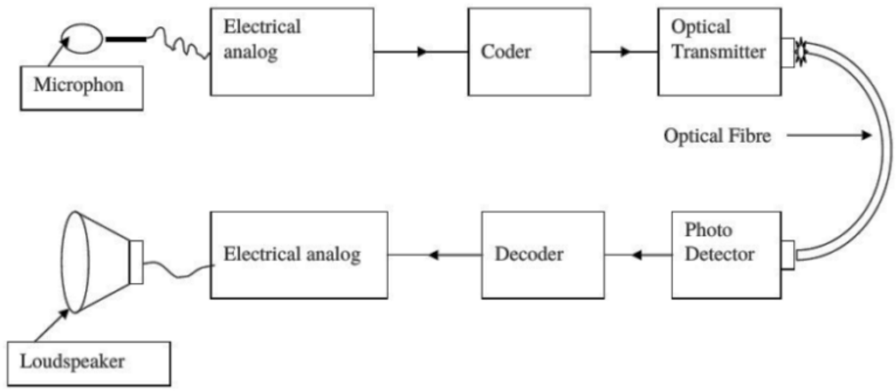

Figure 2: Point-to-point fiber optic communication system

Source :(Wibowo, 2022)

Based on Figure 2, the fiber optic communication process, communication using fiber optics is as follows: The first sound is converted into an electrical signal using a transducer. The sound is digitized using a Coder. The digital signal, which carries sound information, is fed to an optical transmitter. There are two types of light sources that are usually used, the selection of these two types of optical sources depends on the data transmission bit rate and the distance to be achieved, these two types of light sources are: 1. LED (Light emitting diode) 2. LASER (Light Amplification through Stimulated Emission of Radiation) (Jambola, 2016). At the other end, the modulated light signal is detected by a photo detector and decoded using a decoder. Finally, the information is converted into an analog electrical signal and fed to a loudspeaker, which converts the signal into sound.

VI. Conclusion

The polarization of light in single-mode optical fiber plays an important role in determining the performance of optical communication systems, especially in high-speed and long-distance data transmission. Polarization changes caused by factors such as birefringence, mechanical stress, fiber curvature, and temperature variations can reduce signal stability, cause power loss, and cause polarization mode dispersion (PMD). The Degree of Polarization (DoP) parameter is used to measure the extent to which light remains polarized after passing through an optical fiber, and the measurement results show that physical and environmental interference significantly reduce the DoP value. To overcome this problem and maintain transmission quality, various technologies are used such as polarization-maintaining fiber (PMF), polarization controllers, and polarization-division multiplexing (PDM) techniques. Polarization management is not only important in communication systems, but also in optical sensor applications that require high signal stability. With a good understanding of the characteristics and effects of polarization, as well as the application of appropriate control technology, fiber-optic communication systems can be optimized to support modern communication needs that are increasingly complex and require high reliability.

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