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Angular displacement and SOP speeds in aerial and buried single mode and polarisation maintaining fibers

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ABSTRACT

Optical fiber transmission suffers significant penalty from dispersion related effects. In this study, we experimentally investigate angular displacement and speed of state of polarization in single mode fibers (SMF) and polarization maintaining fibers in two states, i.e. aerial and buried state. The results show that a buried single mode fiber incurs minimal change of state of polarization (implying lower polarization mode dispersion) as compared to a buried polarization maintaining fiber, with a slight difference of 0.000464 standard deviation (spread). This is a good finding, since, most of the telecom companies use single mode fibers for their transmission, so reinstallation might be so costly, time wasting and unnecessary as well as the costs that would be incurred in purchasing PMF which are more expensive compared to the single mode fiber, as per 'THORLABS'. i.e $33.75–$40.0 per meter of PMF compared to $7.0–$14.0 per meter of a single mode fiber. However in cases where aerial transmissions are un-avoidable, Polarization maintaining fibers are highly recommended as compared to single mode fibers.

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1. Introduction

The continuous growth of internet traffic is driving transmission system engineers to use higher data rates in all segments of 10 Gbps and above. Such high data transmission rates impose very strict requirements on optical fiber plants as well as transmission systems deployed out there in the field [1]. Most deployed transmission systems are using traditional modulation techniques such as On-Off Keying and their replacement with the advanced modulation formats/techniques such as Differential Phase Shift Keying (DPSK) and Polarization Shift Keying (PolSK) is quite expensive and complex. Therefore, Polarization Mode Dispersion (PMD) still remains a challenge in such systems that still use traditional modulation techniques.

Polarization Mode Dispersion (PMD) is a serious limitation, since light is an electromagnetic wave, it is characterized with polarization (In classical physics, light is modeled as a sinusoidal electromagnetic wave in which an oscillating electric field and an oscillating magnetic field propagate through space). Polarization is defined in terms of the pattern traced out in the transverse plane by the electric field vector as a function of time and its optical power is a scalar quantity that is proportional to the mean square of the electric field amplitude.

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If we let z be the direction of propagation, then, the polarization vector is in the x-y plane. By superposition of the x- and y-vector components at time t at any location, the polarization vector is expressed as; $E(t) = E_x(t) + E_y(t)$ where, $E_x(t)$ and $E_y(t)$ are the amplitudes of the x and y components of the electric field.

Polarized light takes three forms, linearly polarized, circularly polarized and elliptically polarized light. Linearly polarized light has no phase difference between the x and y electric field components. Circularly polarized light has a fixed phase difference of 90°, and the amplitudes of the two electric field components are the same. The polarization state is elliptical for all other phase differences and amplitudes. The Poincaré sphere is used to describe the polarization and changes in polarization of a propagating electromagnetic wave [2]. It provides a convenient way of representing polarized light, and of predicting how retarder will change the polarization form. Any given polarization state corresponds to a unique point on the sphere therefore; the two poles of the sphere represent left- and right-hand circularly polarized light. Points on the equator indicate linear polarizations. All other points on the sphere represent elliptical polarization states.

We show, the angular displacements and SOP speeds and relate them to polarization mode dispersion in both single mode fiber and polarization maintaining fiber, under similar conditions, that is buried and aerial optical fibers.

2. Research design

For aerial transmission, the single mode fiber is used when both scramblers are switched on. By doing this, it changes the state of polarization of ray of light traveling through the optical fiber randomly over time. A sampling frequency of 10 kHz was used and the received light was analyzed using a polarization analyzer. For the case of Polarization maintaining fiber, it is physically shaken randomly (in place of scramblers) over time.

For transmission in buried fibers, the single mode fiber and polarization maintaining fiber are tapped on the table (to avoid any sight movements of the optical fiber) and the scramblers are switched off (for the case of SMF).

The experiments were carried out under laboratory conditions (constant room temperature) thus the change in SOPs and the corresponding PMDs considered were as result of external stress birefringence inserted on the fiber from bending and twisting the fibers.

Experimental set up

3. Theory

While discussing polarization mode dispersion, terms like birefringence cannot be avoided. It is used to describe a phenomenon that occurs in certain types of materials in which light is split into two different paths [3]. This phenomenon occurs because these materials have different indices of refraction, depending on the polarization direction of light. Birefringence is also observed in an optical fiber, due to the slight asymmetry in the fiber core cross-section along the length and due to external stresses applied on the fiber such as bending [4]. In general, the stress-induced birefringence dominates the geometry-induced one. A specialty fiber called the Polarization Maintaining (PM) Fiber intentionally creates consistent birefringence pattern along its length, prohibiting coupling between the two orthogonal polarization directions [5]. In any design, the geometry of the fiber and the materials used create a large amount of stress in one direction, and thus create high birefringence compared to that generated by the random birefringence.

The Stokes parameters have a simple physical interpretation related to Poincaré sphere representation. They also have a physical interpretation related to intensity measurement.

In a given 0xyz reference system (0z being the direction of propagation of light), the Stokes vector can be expressed as:

$$S = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} I_0 \\ I_x - I_y \\ I_{+45} - I_{-45} \\ I_L - I_R \end{bmatrix} \tag{1}$$

Where I_0 is the total power of the light, I_x, I_y are the x and y linearly polarized light intensities, I_{+45}, I_{-45} are the 45° and -45° linearly polarized light intensities, and, I_L, I_R are the left and right hand circularly polarized light intensities.

Normalizing $[S_1, S_2, S_3]$ by S_0, we will get the SOP $[[S_1, S_2, S_3]]$, which are the coordinates of one point on the Poincaré sphere; S_1, S_2 *and* S_3 being the states of polarization.

In order to obtain the angular displacement of SOPs, let us assume two vector points $\vec{A}$ and $\vec{B}$ in 3-D (on a Poincare sphere) with $A(S_{A1}, S_{A2}, S_{A3})$ and $B(S_{B1}, S_{B2}, S_{B3})$.

The angle (θ) between these points can be obtained using the dot product i.e.

$$\vec{A} \cdot \vec{B} = \left|\vec{A}\right| \left|\vec{B}\right| \cos \Delta\theta \tag{2}$$

Where $\left|\vec{A}\right| = \sqrt{S_{A1}^2 + S_{A2}^2 + S_{A3}^2}\ \sqrt{S_{A1}^2 + S_{A2}^2 + S_{A3}^2}$ and $\left|\vec{B}\right| = \sqrt{S_{B1}^2 + S_{B2}^2 + S_{B3}^2}\ \sqrt{S_{B1}^2 + S_{B2}^2 + S_{B3}^2}$

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