Introduction to Polarization

Abstract: The interaction of polarized light with matter can lead to a host of effects, some of which are very useful for certain applications. However, in many other applications, polarization effects can degrade or limit the performance of an optical system.

Light can be described as an electromagnetic wave that, like radio waves, propagates via a sinusoidal oscillation of an electric field. The direction in which the electric field oscillates as it propagates is known as the *polarization*. The simplest type is *linear* or *plane* polarization, illustrated in Fig. 1 for an optical signal traveling through free space, in which the field of the optical signal oscillates only in a single fixed plane. The vector along which the light travels must also lie in this plane, but this restriction still allows an infinite number of planes of polarization to be defined, each of which describes a separate linear state of polarization (SOP).

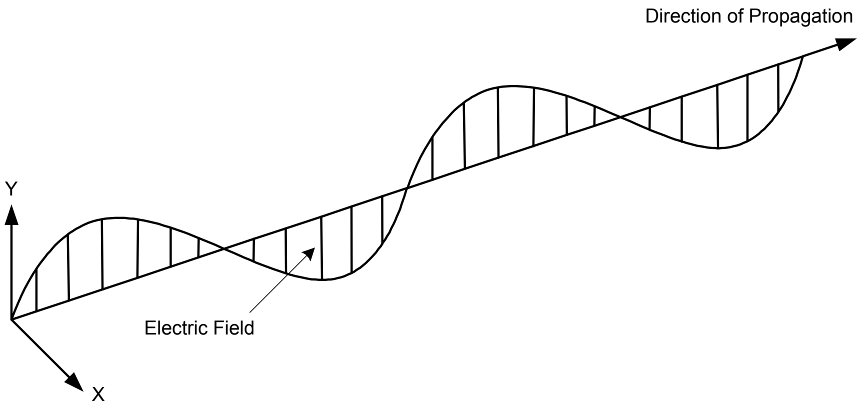

Fig. 1. Plane-polarized lightwave

In order to meaningfully specify the polarization of an optical signal, we must first define some physical reference. This might be one of the crystalline axes in the laser diode chip that serves as a source of light, or possibly a reference line on one of the components in an optical system. Whatever reference we choose will then define a set of axes, which provides a basis for specifying every possible SOP. Figure 2 shows a bulk optical crystal with a laser beam incident on one face. We've decided to choose the horizontal crystal axis as a reference, since it coincides with one of the *Principal States of Polarization* (PSP) for the crystal -- those SOP's which are invariant for slight changes in launched signal wavelength. We label the horizontal axis "**x**", and the orthogonal vertical crystal axis, "**y**". As in the figure, the polarization of the incident laser beam is linear and oriented at 45° to the **x-** and **y**-axes. In our reference frame, this polarization state equivalently resolves into two linear polarization states, each of which lies along one of the crystal axes.

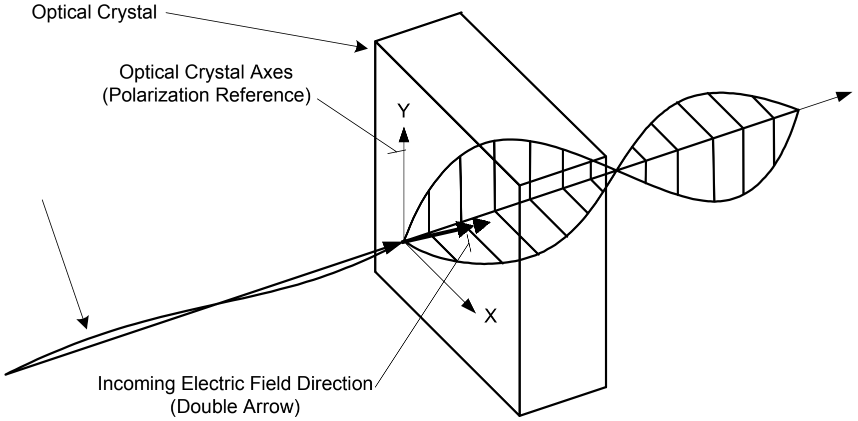

Fig. 2. Plane polarized light wave resolved into two new linear states of polarization.

Birefringence is a property of optical materials for which light that is polarized along the **x** axis experiences a different index of refraction, and therefore travels at a different speed than does light polarized along the **y** axis. If the length of an optical crystal is just such that, with the difference in speed of propagation, the **x**-polarized light arrives one-quarter wavelength ahead of (or behind!) the **y**-polarized light, the crystal is known as a quarter wave plate. An interesting thing happens when we pass linearly-polarized light through a quarter wave plate at 45° to its axes, as seen in Fig. 3. If we track the electric field of the propagating wave, it appears that the field is rotating in a circle as the wave propagates. For this reason, this type of field configuration is described as *circularly polarized*. In fact, depending on the relative magnitude of the **x**- and **y**-polarized components and the phase difference between them, we can see a continuum of different states varying from linear to circular, with intermediate states being described as having *elliptical polarization* (Fig. 4). Furthermore, with elliptical or circular polarization, the field can rotate either to the left or to the right as the light propagates.

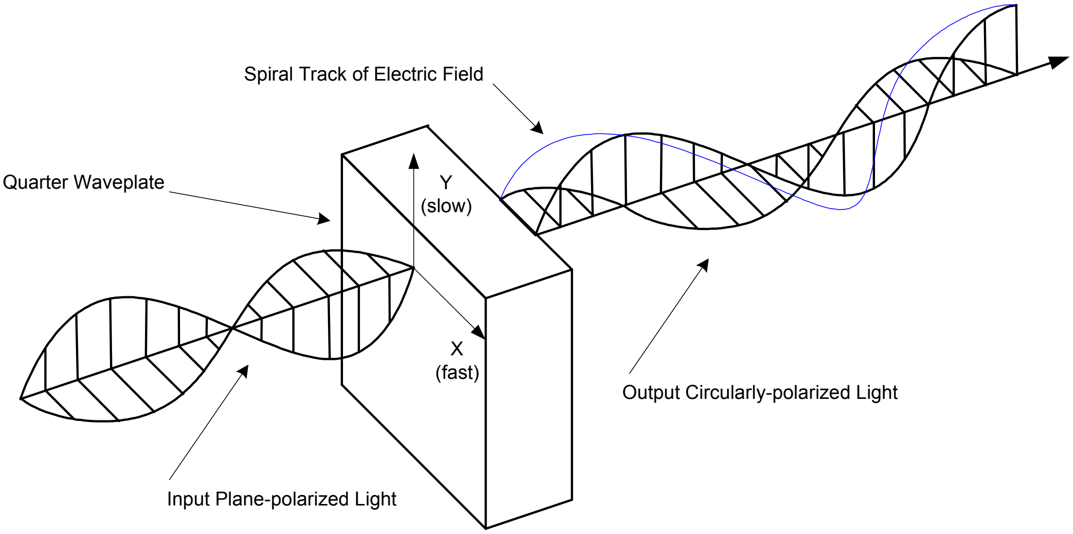

Fig. 3. Transformation of plane-polarized to circular-polarized light by a quarter wave plate.

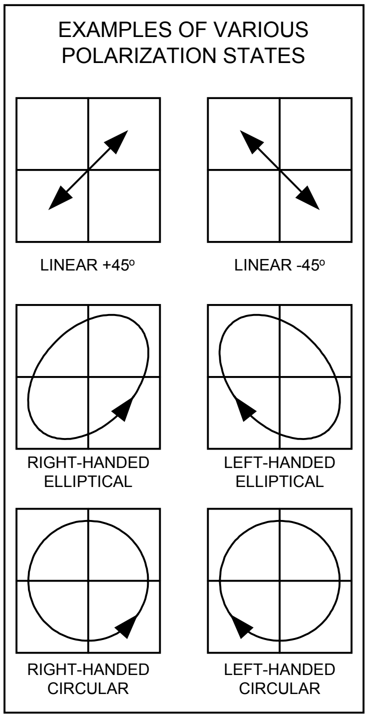

Fig. 4. Examples of different polarization states, which depend upon relative magnitude and phase between the two principal polarization components.

For light launched with a fixed SOP into free space, polarization remains constant as the light propagates, as long as the frame of reference doesn't change. In an optical fiber, however, the situation is not as simple. Stresses in the glass fiber caused by natural bending, twisting, and pinching of the fiber that result from handling and routing, combined with residual stresses and imperfect geometry created during its manufacture, produce small amounts of birefringence that can have a large effect on the output polarization. Worse, as the ambient temperature changes or the fiber is moved, the effect of the fiber on the polarization of a signal traveling through can change rapidly in a way that is nearly impossible to predict.

In our discussion so far, we have tacitly assumed that our optical sources produce signals that remain in a perfectly fixed SOP. This is a reasonable assumption for light produced by many telecommunications laser sources. However, the polarization of light from many natural sources such as the sun varies very rapidly, randomly visiting all possible polarization states. Such light is termed *unpolarized*. In reality, light signals are neither completely polarized nor completely unpolarized, and a signal can be characterized by its *Degree of Polarization* (DOP), a value that specifies the ratio of optical power that is polarized to the total power in the signal.

Though the topic of polarization is interesting to study in its own right, it is also important to understand the mechanisms through which polarization affects device and system performance. In some cases, we can incorporate polarization effects into a design to achieve a particular goal. For example, liquid crystals are employed for control of polarization in individual segments of an LCD display to make those segments appear bright or dark. Birefringence can be utilized in the design and construction of optical filters. In many situations, however, polarization effects are uninvited and undesirable. In long optical fiber spans, for example, the propagating optical signal can suffer polarization dependent loss (PDL) or polarization mode dispersion (PMD) [1]. These loss and dispersion mechanisms limit the distance that a fiber can span before the optical signal that it carries must be amplified or regenerated.

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[1] Refer to Luna Technologies articles "Introduction to PMD" and "Introduction to Insertion Loss and PDL" for further information.