OPTICAL FIBERS

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Summary

Optical fiber is an excellent physical medium for high-speed transmissions. An optical fiber provides extremely low-attenuation transmission over a huge frequency range, which allows signals to be transmitted over long distances at high speeds without being amplified or regenerated. Due to these properties, optical fiber is favored over traditional transmission media, such as copper or free space, and widely deployed in today's communication systems. An optical fiber has two main building sections: a cylindrical *core* of glass or plastic and a surrounding section called the *cladding*. In addition to the cladding (a plastic shell), an optical fiber is usually covered by integrated strain relief boot, which protects the fiber from damage, strain, and the rigors of daily use. Both the core and the cladding are typically made of silica. However, the refractive index of the core is set lower than the cladding to make sure the light is guided through the core.

This chapter gives a brief introduction of optical fibers. It explains basic features of optical fibers including fiber structures, types, materials, and also communication characteristics. A basic optical fiber transmission link and a basic wavelength division multiplexing (WDM) transmission system are also introduced.

1. Introduction

Optical fibers have become a major data-transmission component for today's telecommunication systems due to their many advantages over conventional copper twisted-pair cables. Some of their advantages are the following:

- Optical fibers are able to carry data in either analog or digital form in very high bit rates. For instance, digital information could be transferred at Terabit rates over a single fiber.
- Fibers with very low transmission losses and attenuation are commercially available. This allows communication lines to be extended longer without the need to be amplified or regenerated (refreshed). As a result, amplifiers (or repeaters) are spaced further from each other and also the system installation expenses are reduced.
- Fiber optics could be deployed in full-duplex (data is simultaneously transmitted in two opposite directions over a single fiber) and half-duplex (data is transmitted in each direction over separate fibers).
- Both glass and plastic types of optical fibers are insulators. This means that no electric current could flow through them, either owing to the transmitted signal or due to external radiation striking the fiber. In addition, optical waves do not interfere with other communication channels since they are trapped within the fiber.
- As the basic fiber is made of glass, it will not corrode and is unaffected by most chemicals. It can be buried directly in most kinds of soil or exposed to most corrosive atmospheres in chemical plants without significant concern.
- A fiber optic cable, even one that contains many fibers, is usually much smaller and lighter in weight than a wire or coaxial cable with similar information carrying capacity. It is easier to handle and install, and uses less duct space. (It can frequently be installed without ducts.)
- Fiber optic cable is ideal for secure communications systems because it is very difficult to tap but very easy to monitor. In addition, there is absolutely no electrical radiation from a fiber.
- Optical fibers are not affected by electromagnetic pluses.
- Fibers and fiber cables are surprisingly flexible, bendable, and reliable.
- The basic material for optical fibers is silicon dioxide, which is inexpensive, accessible, and plentiful.
- Various types of protected fiber cables, resistant to flame, moisture, rodent, chemical reaction, and crush, are commercially available.

A wide section of optical fibers (cables) exist in today’s market. The differences among fibers involve in their features including constructing material, structural design, attenuation, dispersion, and propagation characteristics. Their performance differences are related to several factors, such as modulation format, multiplexing technique, and transmission mode. In the following sections, we discuss these topics in brief.

2. Nature of Light

In order to attain a good understanding of the physical structure and wave-guiding properties of optical fibers, it is important to go through some of the related theories to light. Light is often described in two ways to explain different experiments and observations: sometimes light acts as a wave (*Maxwell theory*); sometimes it behaves as a particle (*Particle theory*).

Fresnel showed that light is a wave motion in 1815. Latter, the work of Maxwell in 1864 theorized that light waves must be electromagnetic in nature. Also, wave motion is perpendicular to the direction in which the wave travels. This view introduces two kinds of *wave fronts* (*phase fronts*): *plane and spherical*. If the wavelength of the light is much smaller than the source of light, it seems that the wave fronts traverse in straight lines (plane wave fronts). If electromagnetic waves are generated by a point source, the wave fronts appear as a series of spherical wave fronts with the source at the center (spherical wave fronts).

Light behaviors can be explained if light is considered as an electromagnetic wave, which has a very high oscillation frequency and a very short wavelength. The term optic (as well as the term light) is referred to frequencies in the *infrared* (extended from 0.2 to 0.4 µm), *visible* (extended from 0.4 to 0.7 µm), and *ultraviolet* (extended from 0.7 to 2 µm) portions of the spectrum. The wavelength (λ) of a light beam is calculated by,

$$\lambda = c / f$$

where c is the light speed, and f is its frequency.

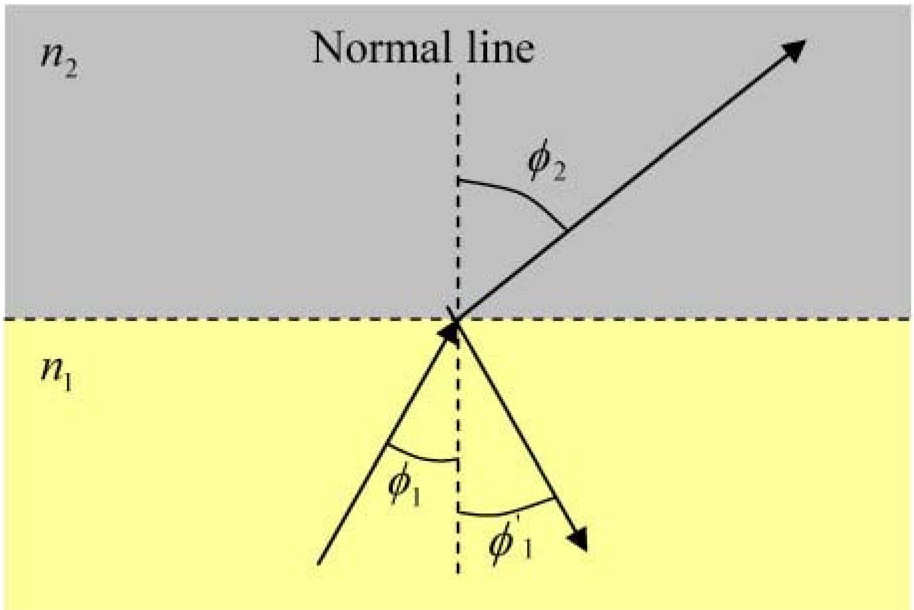

Figure 1: The angle of incident (ϕ_1), the angle of refraction (ϕ_2), and the angle of reflection ($\phi_1^{'}$)

Note that in free space, electromagnetic waves travel at the speed of 3×10^{8} m/s but in optical fibers, the light speed is usually considered $2c/3$ or 2×10^{8} m/s. The electromagnetic nature of light is used to analyze how optical waves traverse through fibers. The results of related analyses show the conditions necessary for light to be guided by a fiber.

We can also look at light as a pool of very small particles. The particle nature arises from the observation that light energy is always emitted or absorbed in discrete units called *quanta* or *photons*. The energy of a single photon W_p is computed by

$$W_p = hf$$

where h is Planck's constant, $h = 6.626 \times 10^{-34}$ Js. By means of Particle theory, the generation of light sources, such as semiconductor lasers, light-emitting diodes, and laser diodes could be explained. The detection of light by conversion of optical radiation to electrical current is also justified by this theory [1].

Trapping light in the fiber and guiding it through glass can be easily explained by considering the behavior of light rays associated with plane wave fronts which travel in straight lines, the so-called *ray theory* or *geometrical optics* approach. When a lightwave traversing a material encounters a different material, part of the ray is reflected back into the first material and the reminder is bent (refracted) to the second material. The bending or refraction of the light ray at the interface is a result of the difference in the speed of light in two materials that have different refractive indices. The relationship between two refractive indices at the boundary is known as Snell's law and is given by

$$n_1 \sin\phi_1 = n_2 \sin\phi_2$$

where the angle ϕ_1 is the angle between the incident ray (or reflected ray) that strikes the boundary line and the normal line (the perpendicular line to the boundary line as it has been illustrated in Figure 1), and the angle ϕ_2 is the angle between the refracted line and the normal line. More details on this subject are found in [1-2].

3. Fiber Materials

An optical fiber consists of two main sections: a cylindrical *core* of glass or plastic and a solid dielectric surrounding section called the *cladding*. The cladding is not necessary for light to propagate along the core, it serves several purposes. The cladding reduces scattering loss that results from dielectric discontinuities at the core surface; increases flexibility by adding strengthening elements to the fiber; protects the core from absorbing contaminations with which it could come in contact. In addition to the cladding, most fibers are covered by an elastic, abrasion-resistant plastic material known as *outer jacket*. The outer jacket adds further strength to the fiber and mechanically isolates or buffers from small geometrical irregularities, distortions, or roughness of adjacent surfaces [2]. Both the core and the cladding are typically made of silica, which has a refractive index of approximately 1.45 [3]. The refractive index of a material is the ratio of the speed of light in free space to the speed of light in that material. During the manufacturing of the fiber, certain impurities (dopants) are inserted in the core and/or the cladding to slightly increase the refractive index of the core over the cladding.

Increasing the refractive index of the core enables light to be guided by the core and thus propagate through the fiber as it has been illustrated in Figure 2.

Fibers are fabricated by a number of methods. In [1] two direct producing methods,

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Biographical Sketches

Atousa Vali Sichani received the B.Sc. degree in electrical and computer engineering from the Isfahan University of Technology, Isfahan, Iran, in 1993, the M.Sc. degree in electrical and computer engineering from Queen’s University, Kingston, ON, Canada, in 2002, and the Ph.D. degree in electrical and computer engineering at the University of Ottawa, Ottawa, ON, Canada in 2006. Her research interests include optical networks, routing protocols, network survivability, and network management.

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