

The Handout of ELE432 Presentation

Topic: Fiber-Optic

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1. Introduction

An **optical fiber** (or **fibre**) is a glass or plastic fiber designed to guide light along its length. **Fiber optics** is the overlap of applied science and engineering concerned with the design and application of optical fibers. Optical fibers are widely used in fiber-optic communication, which permits transmission over longer distances and at higher data rates than other forms of communications.

The fine glass fiber is relatively flexible and can be used to guide optical signals over distances of kilometers without the necessity of perfect alignment between source and detector. This significantly increases the applications of optical communication in areas such as telephone and data transmission.

Compared with electrical cable, light propagates through the fiber with little attenuation compared to electrical cables and the light signals propagating in the fiber can be modulated at rates as high as 40 Gb/s. Additionally, fiber saves space in cable ducts because a single fiber can carry much more data than a single electrical cable. Fiber is also immune to electrical interference, which prevents cross-talk between signals in different cables and pickup of environmental noise. Also, wiretapping is more difficult compared to electrical connections. Moreover, fibers are non-electrical, fiber cables can bridge very high electrical potential differences and can be used in environments where explosive fumes are present, without danger of ignition.



Figure1.Fiber-Optic

2. History

In 1965, Charles K. Kao and George A. Hockham of the British company Standard Telephones and Cables were the first to suggest that attenuation of contemporary fibers was caused by impurities, which could be removed. They speculated that optical fiber could be a practical medium for communication, if the attenuation could be reduced below 20 dB per kilometer.^[2]

In 1970, Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar demonstrated a fiber with 17 dB optic attenuation per kilometer by doping silica glass with titanium.

A few years later they produced a fiber with only 4 dB/km using germanium oxide as the core dopant. Nowadays, attenuations in optical cables are far less than those in electrical copper cables, leading to long-haul fiber connections with repeater distances of 500–800 km.

The erbium-doped fiber amplifier, which reduced the cost of long-distance fiber systems was co-developed by teams led by David Payne of the University of Southampton, and Emmanuel Desurvire at Bell Laboratories in 1986.

The more robust optical fiber commonly using glass for both core and sheath was invented by Gerhard Bernsee in 1973 by Schott Glass in Germany.

In 1991, the emerging field of photonic crystals led to the development of photonic crystal fiber (*Science* (2003), vol 299, page 358), which guides light by means of diffraction from a periodic structure, rather than total internal reflection. The first photonic crystal fibers became commercially available in 1996.

3. Principle of Operation

An optical fiber is a cylindrical dielectric waveguide that transmits light along its axis, by the process of total internal reflection. Light is kept in the "core" of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide.

The fiber consists of a core surrounded by a cladding layer. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt, in step-index fiber, or gradual, in graded-index fiber.

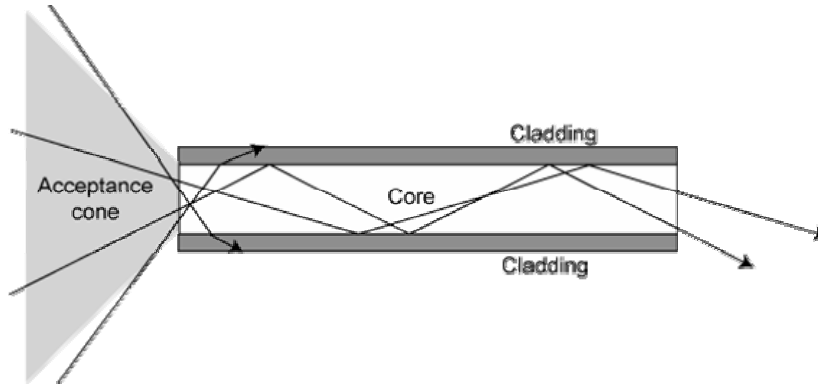


Figure 2. The propagation of light through a multi-mode optical fiber.

4. Types of Optical Fiber

4.1 Multi-Mode

Fiber with large (greater than $10\ \mu\text{m}$) core diameter may be analyzed by geometric optics. Such fiber is called multimode fiber (MMF), and multimode fibers support many propagation paths or transverse modes.

4.1.1 step-index multimode fiber

In a step-index multimode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle (measured relative to a line normal to the boundary), greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber. A low numerical aperture may therefore be desirable.

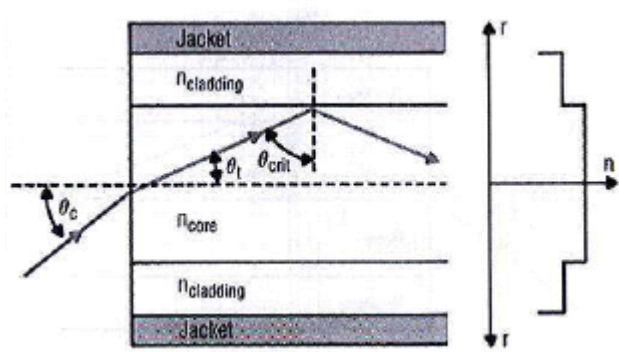


Figure 3 step-index multimode fiber

4.1.2 graded-index fiber

In graded-index fiber, the index of refraction in the core decreases continuously between the axis and the cladding. This causes light rays to bend smoothly as they approach the cladding, rather than reflecting abruptly from the core-cladding boundary. The resulting curved paths reduce multi-path dispersion because high angle rays pass more through the lower-index periphery of the core, rather than the high-index center. The index profile is chosen to minimize the difference in axial propagation speeds of the various rays in the fiber. This ideal index profile is very close to a parabolic relationship between the index and the distance from the axis.

4.2 Single-Mode

As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called single-mode

The waveguide analysis shows that the light energy in the fiber is not completely confined in the core. Instead, especially in single-mode fibers, a significant fraction of the energy in the bound mode travels in the cladding as an evanescent wave.

The most common type of single-mode fiber has a core diameter of 8 to 10 μm and is designed for use in the near infrared. The mode structure depends on the wavelength of the light used, so that this fiber actually supports a small number of additional modes at visible wavelengths. Multi-mode fiber, by comparison, is manufactured with core diameters as small as 50 micrometres and as large as hundreds of micrometres.

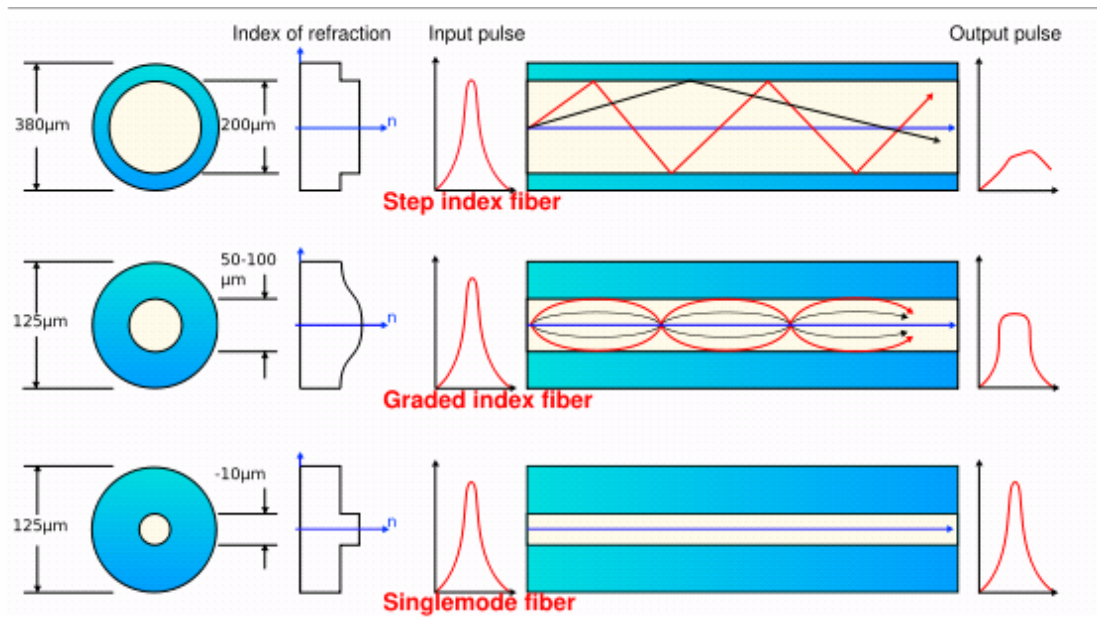


Figure 4 Optical fiber types

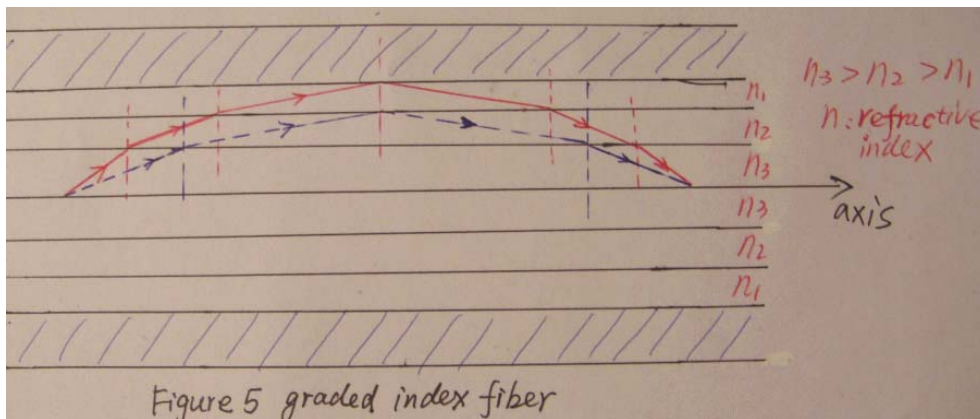


Figure 5 graded index fiber

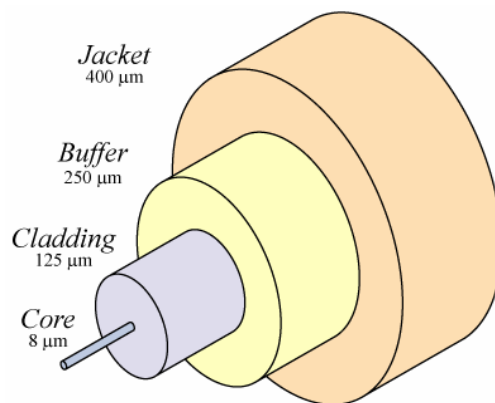


Figure 6. A typical single-mode optical fiber, showing diameters of the component layers.

4.3 Difference of Multi-Mode and Single-Mode

Both multi-mode and single-mode fibers are used in communications. Multimode fibers generally have a large-diameter core, and are used for short-distance communication links or for applications where high power must be transmitted. Singlemode fibers are used for most communication links longer than 200 meters. Because of the tighter tolerances required to couple light into and between single-mode fibers (core diameter about 10 micrometers), single-mode transmitters, receivers, amplifiers and other components are generally more expensive than multi-mode components.

5. Losses in the fiber and choice of operating wavelength

Losses in the fiber at a given wavelength can be described by an attenuation coefficient a . The intensity of the signal at a distance x along the fiber is then related to the starting intensity by the usual expression.

$$I(x) = I_0 \exp(-ax);$$

The attenuation is not the same for all wavelengths, however, and it is therefore important to choose a signal wavelength carefully. A plot of a VS λ for a typical silica glass fiber is shown in Figure 7. It is clear that dips in a near 1.3 and 1.55 μm provide “windows” in the attenuation, which can be exploited to reduce the degradation of signals. The overall decrease in attenuation with increasing wavelength is due to the reduced scattering from small random inhomogeneities which result in fluctuations of the refractive index on a scale comparable with the fourth power of wavelength.

Another consideration in choice of operating wavelength is the pulse dispersion, or spreading of data pulses as they propagate down the fiber.

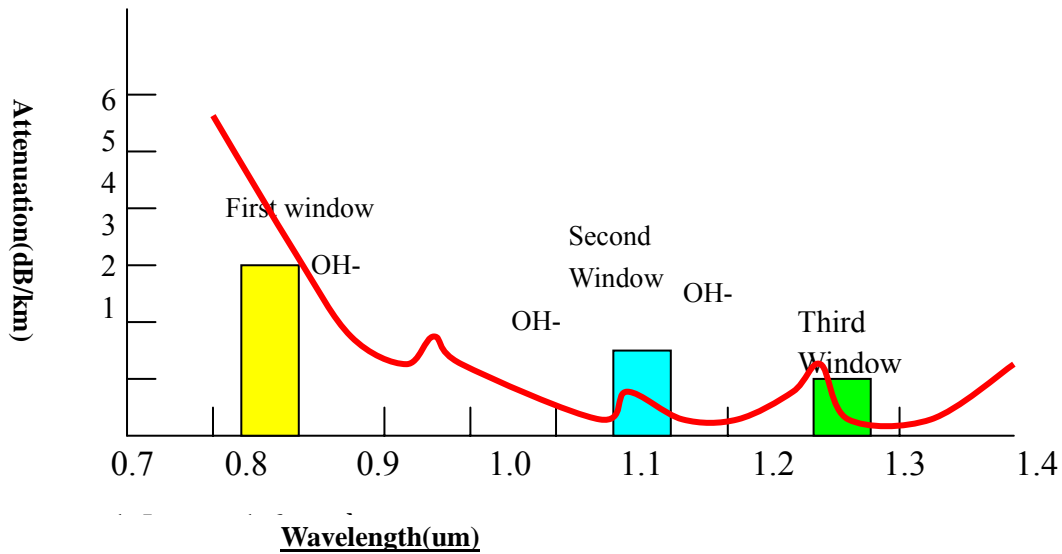


Figure 7 Wavelength VS Attenuation

The light source in a fiber-optic system today is laser, because the light is made up of essentially a single frequency and allows a very large information bandwidth. In early optoelectronic systems, it was to use the GaAs-Al-GaAs system for making lasers and LEDs. These light sources are highly efficient. However, these sources operate in the wavelength range near 0.9 um, where the attenuation is greater than that for longer wavelengths. Modern systems, therefore, operate near the 1.3-um 1.55-um minima.

6. Applications

- Optical fibers can be used as sensors to measure strain, temperature, pressure and other parameters. Optical fiber sensors for temperature and pressure have been developed for downhole measurement in oil wells. Another use of the optical fiber as a sensor is the optical gyroscope which is in use in the Boeing 767 and in some car models (for navigation purposes) and the use in Hydrogen microsensors
- Optical fibers are used as hydrophones for seismic or SONAR applications.
- Fibers are widely used in illumination applications.:
They are used as light guides in medical and other applications where bright light needs to be shone on a target without a clear line-of-sight path. Optical fiber illumination is also used for decorative applications, including signs, art, and artificial Christmas trees.
- In some buildings, optical fibers are used to route sunlight from the roof to other parts of the building.



Figure 8. A frisbee illuminated by fiber optics

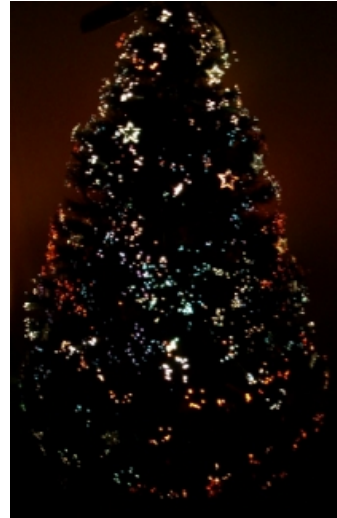


Figure 9. A fiber-optic Christmas Tree

- Optical fiber is also used in imaging optics.: A coherent bundle of fibers is used, sometimes along with lenses, for a long, thin imaging device called an endoscope, which is used to view objects through a small hole.
- Fiber-Optic Communication System

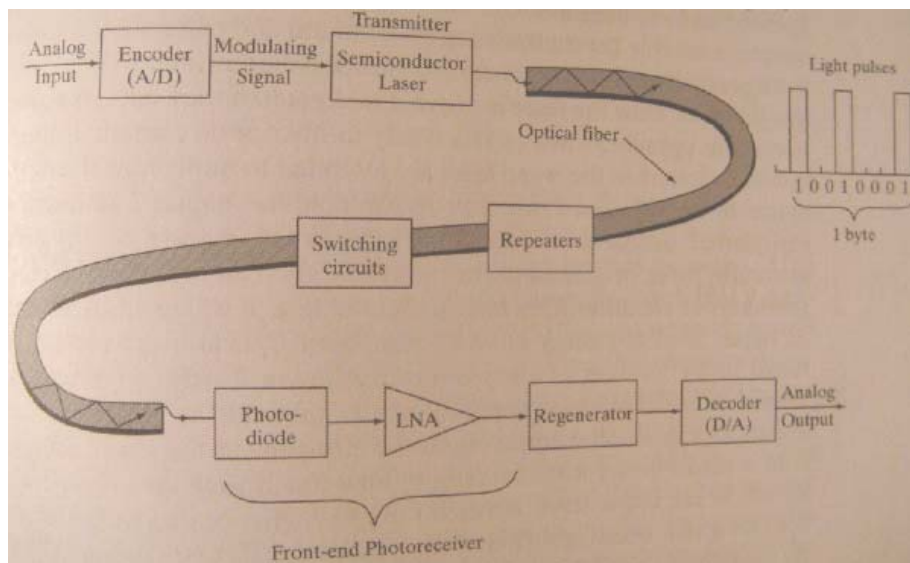
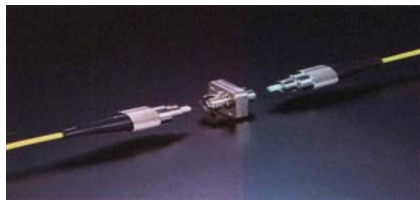
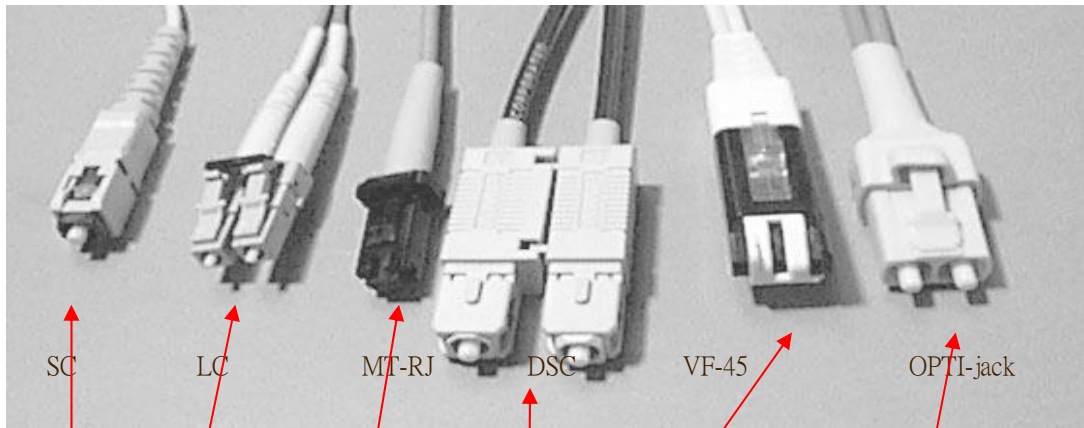


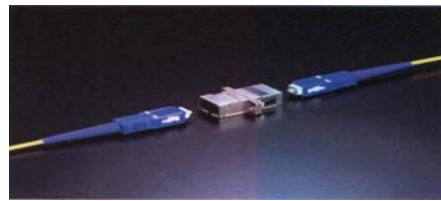
Figure 10. Fiber-Optic Communication System

7. Joining lengths of optical fiber

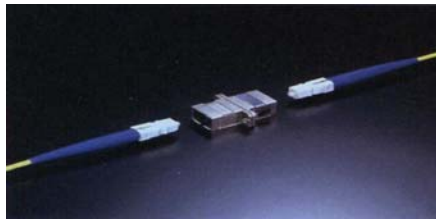
Joining lengths of optical fiber is more complex than joining electrical wire or cable. The ends of the fibers must be carefully cleaved, and then spliced together either mechanically or by fusing them together with an electric arc. Special connectors are used to make removable connections. There are several kinds of connectors as shown in Figure 11.



FC type



SC type



SC2 type



FDD type



BICONIC type



D4 type



SMA 905 type



SMA 906 type



MINI BNC Type



ST fiber connector on multimode fiber

Figure 11. Connectors