CHAPTER-1

OPTICAL FIBER RECIPE

CONTENTS

1.1 INTRODUCTION :

Many forms of communication systems[1] for sending messages from one distant place to another have appeared over the years. The use of horns, fire signal etc. in ancient times is of historic interest only. The discovery of the telegraph started the era of electrical communications. Since then attempts have been made to exploit increasingly larger portion of the electromagnetic spectrum on higher frequency side e.g. wire pairs, coaxial cables and waveguides were devised as communication means respectively for the longwave, shortwave and microwave regions of the radio-frequency spectrum. In these electrical systems, sinusoidally varying e.m.waves are used as carriers over which the information signals are superimposed. The amount of information that can be transmitted is directly related to the frequency range over which the carrier wave operates. Employing higher frequency means increasing the bandwidth and hence the information capacity.

The logical extension[2] to optical region on higher frequency side followed the discovery of the laser in 1960. The optical spectrum ranges from 50 nm (ultraviolet) to approximately 100 μm (far infrared) including the visible spectrum from 400 to 700 nm. Since the optical frequencies are extremely large ≃ 10^{15}Hz, the laser provides a theoretical information capacity about 10^5 times that of microwave systems. It is roughly equal to 10 million TV channels. As in the case of the radio frequency spectrum, two transmission media can be used at optical frequencies. Early in 1960's, atmospheric optical channels were exploited. Though there are a number of difficulties, numerous developments of free-space optical channels are in progress for earth-to-space communications.

Optical fibers however provide a much more reliable and versatile optical channel than the atmosphere. In the beginning, their use seemed to be impractical as extremely large losses ≈ 1000 dB/km were found in the best optical fibers available at that time. Soon the semiconductor and optical waveguide technologies were developed. In 1970, Kapron, Keck and Maurer fabricated a fiber having a 20 dB/km attenuation. In 1980, Fujikara Ltd., of Japan developed a super low optical fiber with losses below 1 dB/km over a wide wavelength range of 1.0 to 1.7 μm[3]. Proper understanding of the attenuation mechanism has resulted in the production of single, unspliced length of fibers with losses as low as 0.2 dB/km. The optical fiber technology is constantly undergoing changes and improvements.

Optical fibers have certain advantages like low loss, wider band width, no electromagnetic interference, light weight and small diameter as compared to conventional cables. Optical cables may be non-conductive and non-inductive. As a result optical communication systems having large capacity, greater stability and reliability can be operated over long transmission distances. Virtual elimination of cross talk and freedom from conventional tapping are other advantages. It has been possible to use optical fibers in telecommunications and other areas. The impact of optical fiber technology on telecommunications is really irreviersible.

In view of the importance of optical fibers in the communicaton systems,[4] we take in this chapter a brief survey of structure and design of fibers, optical sources used, power launching, working of optical communication systems and important applications of optical fibers.

1.2 STRUCTURE AND DESIGN OF OPTICAL FIBERS[3] :

An optical fiber is a long cylindrical structure usually with a circular cross-section. In this simplest design it consists of two co-axial regions. The inner region called 'core' is a single solid glass cylinder.

It is surrounded by a solid glass or plastic cylinder known as 'cladding' (Fig. 1.1). The refractive index (n_1) of cladding is less than the refractive index (n_0) of the core. The cladding is useful in several ways; it reduces the scattering loss due to the dielectric discontinuities at the core surface, it adds mechanical strength to the fiber and protects the core from absorbing surface contaminants for practical purpose, the cladding is encapsulated in an elastic, abrasion- resistant plastic material. This buffer coating adds further strength to the fiber and mechanically isolates it from small geometrical irregularities, distortions or roughnesses of adjacent surfaces.

TYPES OF FIBERS[5] :

Depending upon the composition of core material the refractive index (n_0) may be uniform throughout or may undergo a regular change with the radial distance in the core. Accordingly the fibers are classified into step-index and graded-index types. Both these types are further divided into single mode and multimode classes. Fig. (1.2.) illustrates index profiles, dimensions and the refractive index profiles of different types of optical fibers.

In a step-index fiber, the refractive index (n_0) of the core is uniform throughout except at the cladding where it undergoes an abrupt change (or step). In a graded index fiber, the core refractive index varies as a function of the radial distance from the center of the fiber.

A single-mode fiber sustains only one mode of propagation, whereas multimode fibers contain many hundreds of modes. A monomode (single mode) fiber is free from intermode dispersion. However, due to larger core radii of multimode fibers it is easier to launch optical power using a light-emitting-diode (LED) source. But multimode fibers suffer from intermodal dispersion.

For the manufacture of optical fibers silica is the most predominent material used. In the silica fiber both the core and cladding consist of silica. Only the dopant will be different for varying the refractive index. e.g. oxides of Ge, Al, Ti or P. However, silica fibers are costlier as compared to the newly introduced plastic fibers. Silica fibers give better performance at higher bit rates, while plastic fibers are useful for communication at low transmission rates over short distances. Plastic fiber cables are preferred because of their low cost, high source-fiber coupling efficiency and ease of handling. There are also hybrid fibers which consist of silica core and polymer cladding known as PCS. These fibers exhibit properties which lie midway between plastic and silica fibers.

1.3 OPTICAL SOURCES[6] :

In order to understand the optical fiber communication it is necessary to know how a source at the transmitting end generates optical power, how this power is transmitted through the fiber and how detectors are used to collect the power at the receiving end. The principal light sources used for the fiber optic communication applications are hetero-junction structured semiconductor laser diodes (injection laser diodes or ILD_s) and light-emitting diodes (LED_s). These devices are chosen because no other light source can be directly modulated at such high bit rates (≃ 50 mb/s) to give high output power with low drive current. These two devices satisfy the economic and technical criteria such as cost, ease of maintenance, lightness, size, life span efficiency, spectral properties like wavelength, spectral width and linearity modulation capability.

Both can be operated in either the short wave or long wave spectrum.

1.3.1 LIGHT EMITTING DIODES[6] (LED_s) :

These are usually the best light source choice because of less complex drive circuitry than laser diodes. No thermal or optical stabilization circuits are needed for LED_s. These are similar to visual display LED_s. However, they operate in the infrared range and the intensity of emission is many times greater. The principle on which these LEDs operate is outlined below.

In a semiconductor, photon emission takes place due to the recombination of hole electron pairs when the pn junction is forward biased. This is the spontaneous emission. The energy gap between the valence and conduction bands decides the wavelength of the photon emission. This emission being in the low attenuation region of the fiber can be transmitted with minimum loss through it.

The efficiency of LED can be increased by etching a well into the top layer. Such an etched LED is called burrus diode, which emitts high radiance from the top. However a well can also be etched at the edge so as to cause edge emission.

This gives rise to ELED which is more efficient than a burrus diode.

In general LEDs have simple structures and are easier to handle. These are low cost devices and have linear input/output characteristics and hence are suitable for the linear systems. At room temperature, the life time of a LED is more than a million hours. In general LED power outputs are lower in the range 50 to 100 μw, but their spectrum has a wider range $\simeq$ 50 to 100 nm.

1.3.2 LASER DIODES[6] :

A laser diode works on the principle of stimulated emission. A dense population of electrons is created in the conduction band by applying a large forward bias to a semiconductor junction. A spontaneously emitted photon can stimulate an electron to jump into the valence band thereby emitting an additional photon. The two photons then stimulate the emission of further photons.

Laser diode has a very high light intensity and a narrow spectral width of 1 to 4 nm. The power output may range from 2 to 20 mw. A laser diode is not a vary stable device.

Its threshold current increases nonlinearly with temperature. Therefore, it should be operated either at some fixed temperature within the operating range or by using a negative feedback circuit. In the latter case a portion of the emitted light is sampled, detected and fed back to control the drive current.

Laser diodes for long wavelength are particularly difficult to fabricate and require special precautions. Their life time is 100,000 hours. These are 10 to 40 times more expensive than LEDs.

1.4 POWER LAUNCHING AND COUPLING[5] :

In connection with optical fiber link two main questions arise :

i) How to launch optical power into a particular fiber from some type of luminescent source.

ii) How to couple optical power from one fiber into another.

The former problem is studied by considering the following factors related to the optical fibers :

i) numerical aperture,

ii) core size,

iii) refractive-index profile,

iv) core-cladding refractive index difference .

The size, radiance and angular power distribution of optical source are also important factors in connection with the power launching.

The amount of optical power which can be coupled from a source to a fiber is measured by the coupling efficiency η defined as :

$$\eta = \frac{P_F}{P_S}$$

where P_S = light emitted from the source. &

P_F = power coupled into the fiber.

The efficiency η depends upon the type of the fiber to be coupled and on the coupling process. In practice a small device called flylead or a pigtail is provided for the coupling purpose. The optical power to be launched into a fiber depends upon the radiance pattern of the optical source. e.g. more light can be coupled from a laser diode because of its narrower output pattern than the light emitting diodes.

However, the power is independent of the wavelength of source, For a given wavelength the radiated power per mode into the fiber is the product of radiance or brightness of the source and the square of the source wavelength. i.e.

$$\frac{P_S}{M} = B_o \lambda^2$$

where, M = number of modes propagating in a graded index fiber.

B_o = Brightness of the source.

Thus, two optical sources with identical sizes and radiances but operating at different wavelengths can launch same amount of optical power into a given fiber. Special lensing schemes are employed to improve the coupling efficiency while launching optical power from source to the fiber.

In the installation of any fiber optics system there can be interconnections between two fibers at intermediate points. There can be power loss at the fiber joints on account of different types of mechanical misalignments. Further the power to be coupled from one fiber to the other is limited by the number of modes propagating in each fiber. The fiber to fiber coupling loss is given by the relation.

$$L_F = -10 \text{ Log } \eta_F$$

where, η_F = fiber to fiber coupling efficiency which is determined by the number of modes in the fiber that launches power into the next fiber and also by the common mode volume. When all the modes in a fiber are equally excited during the launching process, the emerging optical beam will fill the entire exit numerical aperture of the emitting fiber. However, in the steady state modal equilibrium in the emitting fiber, the optical power emerging from it will partially fill the fiber core i.e. the optical power is concentrated near the center of core. (Fig. 1.3).

1.5 APPLICATIONS OF OPTICAL FIBER[6] :

The optical fibers are quite useful in optical communication mainly because of their enormous potential bandwidth and low transmission loss. The public network applications of optical fibers include the trunk network, junction network and local and rural networks. Among the military applications, the prominent use of optical fiber communication system is within the military mobiles such as air crafts, ships and tanks. Optical fibers are also used for short and long distance communication links for the military purpose.

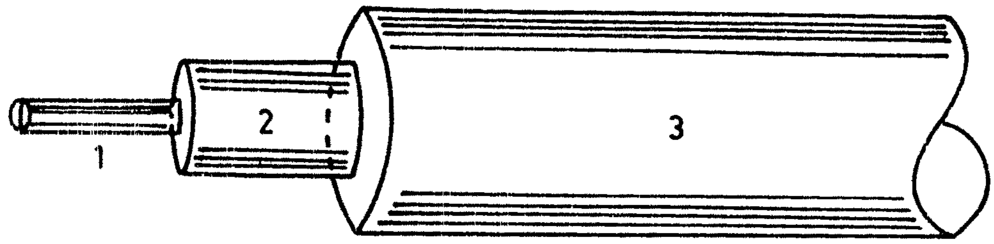
In the industrial applications are included the digital transmission, the analog transmission etc. Optical fibers find a promising use in modern high speed computers.

1.6 SUMMARY :

In the beginning of this chapter the role of optical fibers in communications has been brought out. The structure and design of optical fibers is discussed at length by giving various types of fibers employed for communication purpose. The charactristic features of optical sources viz. LEDs and laser diodes which are used alongwith optical fibers are discribed in somewhat detail. The problem of power launching and coupling into the optical fibers is qualitatively explained. Finally, the important fiber applications in various fields have been listed.

REFERENCES

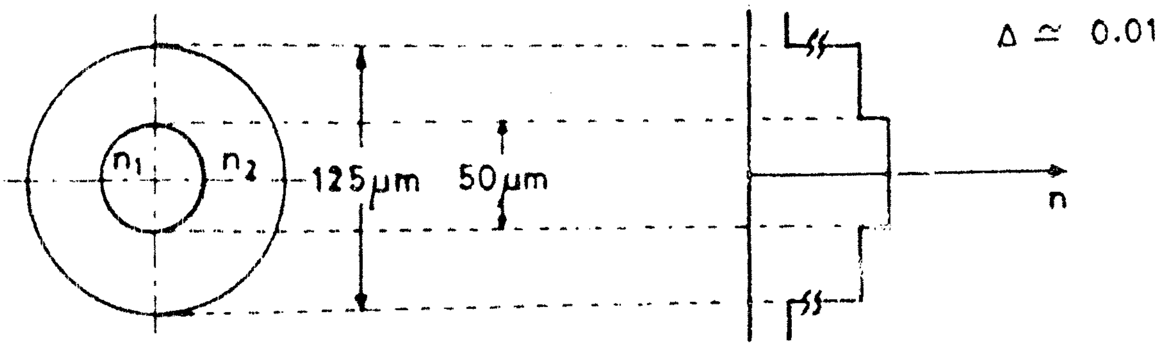
1. Okoshi T. 'Optical Fibers' (Academic Press 1982) Capter-1.
2. Senior J.M. ' Optical Fiber communications- Principles and practice' (Prentice-Hall International 1985) Chapter-1.
3. Sam M.P. in 'Electronics for you' (May 1988) Page 29
4. Sundararajan K. in 'Electronics for you' (May 1988) Page 35.
5. Ghatak A. 'Fibre Optics And Optical Communications' in School on Optoelectronic Materials and Devices, T.I.F.R. Bombay, August 28, Sept. 4, 1989.
6. Keiser G. 'Optical Fiber communications (McGraw-Hill Co.1986) Chapters 1,2, 4 and 5.



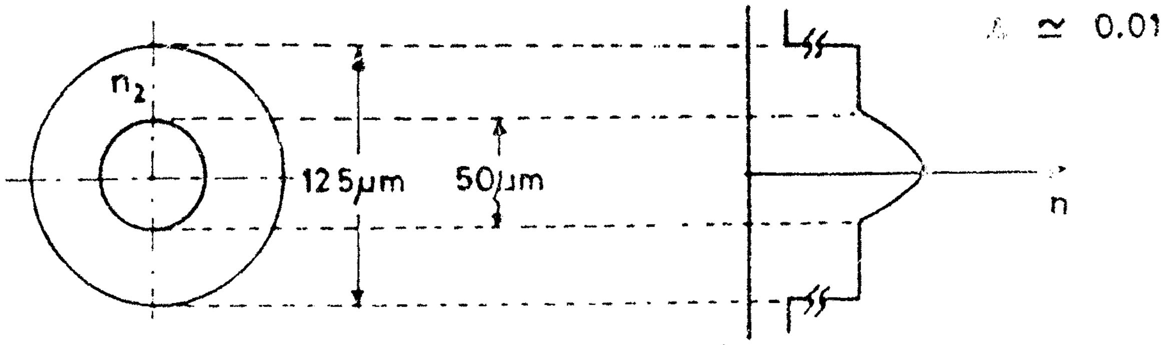
1. CORE
2. CLADDING
3. BUFFER COATING

FIG. 1·1 – SINGLE FIBER STRUCTURE $n_2 < n_1$.

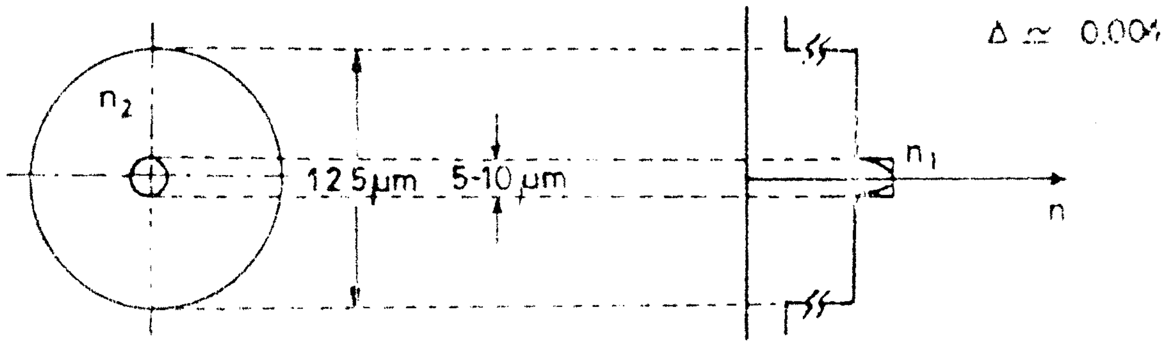
FIG 1.2. TYPES OF OPTICAL FIBERS



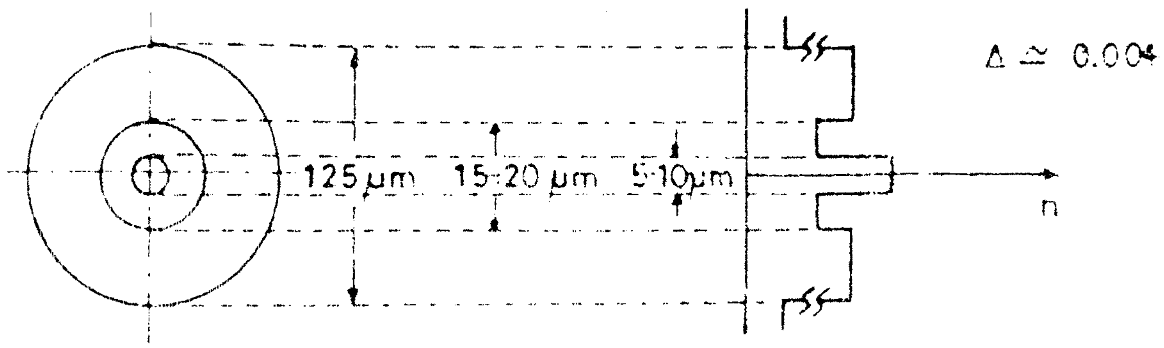
(i) MULTIMODE STEPINDEX



(ii) MULTIMODE (Near Parabolic)



(iii) SINGLE MODE (Step/Graded Index)



(iv) SINGLE MODE (Multiple Clad)

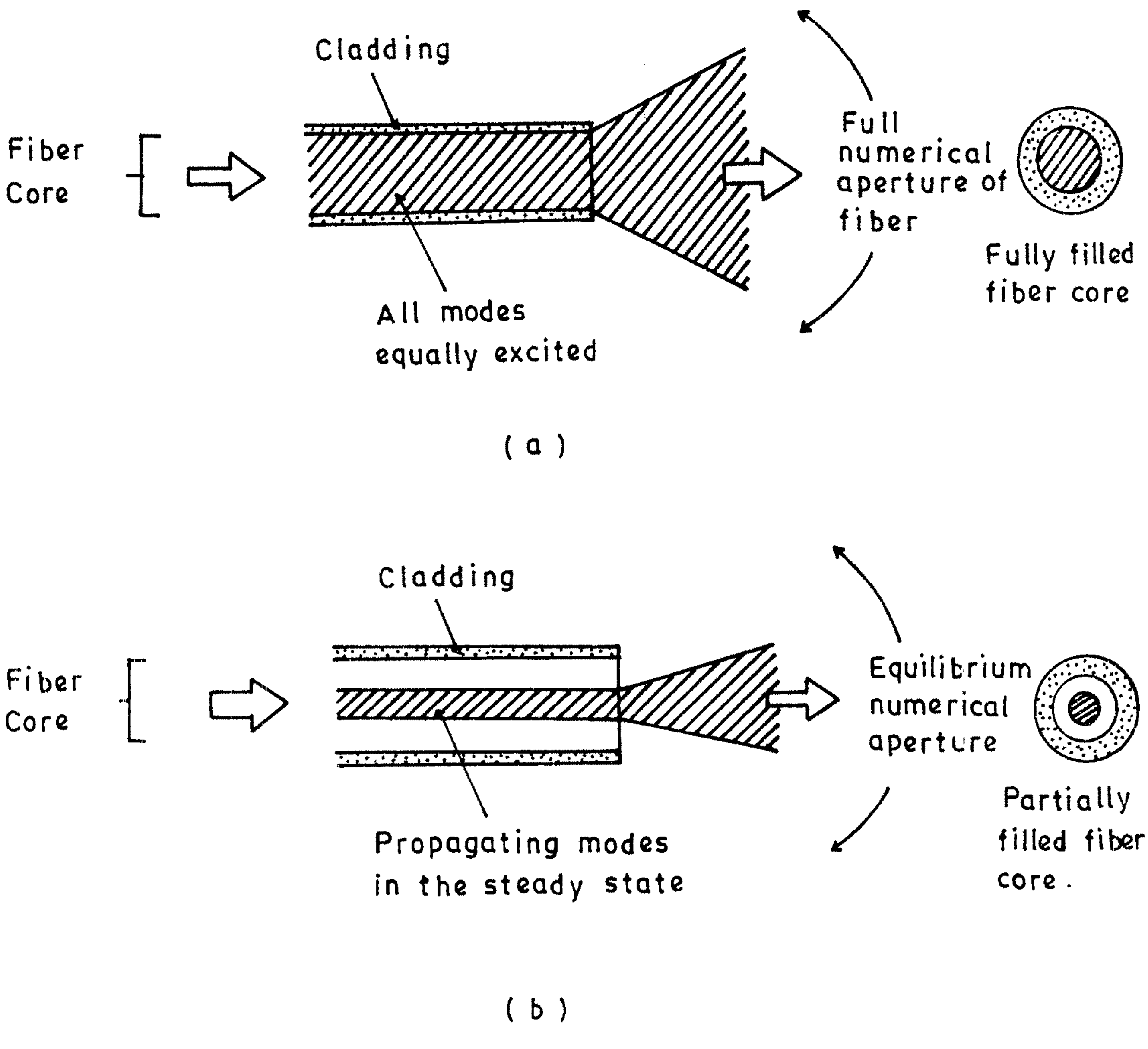


FIG. 1·3 – DIFFERENT MODAL DISTRIBUTIONS OF OPTICAL BEAM.

(a) WHEN ALL MODES ARE EQUALLY EXCITED.

(b) FOR A STEADY STATE MODAL DISTRIBUTION.