Unit-1

Lecture -8

Mode Theory of Circular Waveguide

Mode theory for Circular waveguide

a. Overview of modes
b. Summary of key modal concepts
c. Maxwell's Equations
d. Waveguide Equations Wave Equations for Step Index Fibers
e. Modal Equation
f. Modes in Step-Index fiber
g. Linearly polarized modes

Overview of modes

The optical waveguide is the fundamental element that interconnects the various devices of an optical integrated circuit.

Optical waves travel in the waveguide in distinct optical modes.

A mode, in this sense, is a spatial distribution of optical energy in one or more dimensions that remains constant in time.

The mode theory uses electromagnetic wave behavior to describe the propagation of light along a fiber.

A set of guided electromagnetic waves is called the **modes** of the fiber.

For a given mode, a change in wavelength can prevent the mode from propagating along the fiber.

If the mode is no longer bound to the fiber, this mode is said to be cut off.

The wavelength at which a mode is cutoff is called the **cutoff wavelength** for that mode.

However, an optical fiber is always able to propagate at least one mode.

This mode is referred to as the fundamental mode of the fiber.

The fundamental mode can never be cut off.

The wavelength that prevents the next higher mode from propagating is called the **cutoff wavelength** of the fiber.

An optical fiber that operates above the cutoff wavelength (at a longer wavelength) is called a **single mode fiber**.

An optical fiber that operates below the cutoff wavelength is called a **multimode fiber** n a fiber, the propagation constant of a plane wave is a function of the wave's wavelength and mode.

Maxwell's equations describe electromagnetic waves or modes as having two components.

The two components are the electric field, E(x, y, z), and the magnetic field, H(x, y, z).

The electric field, E, and the magnetic field, H, are at right angles to each other.

Modes traveling in an optical fiber are said to be transverse.

The transverse modes, shown in Fig., propagate along the axis of the fiber.

In TE modes, the electric field is perpendicular to the direction of propagation.

The magnetic field is in the direction of propagation.

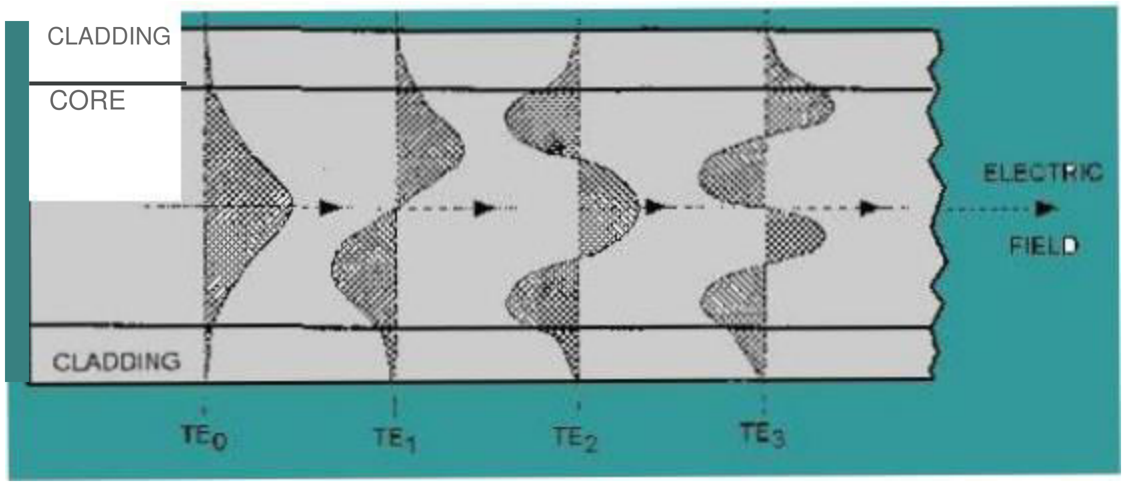
Another type of transverse mode is the transverse magnetic (TM) mode.

TM modes are opposite to TE modes.

In TM modes, the magnetic field is perpendicular to the direction of propagation.

The electric field is in the direction of propagation.

Fig. shows only TE modes.


CLADDING
CORE
ELECTRIC
FIELD
CLADDING
TE0
TE1
TE2
TE3

The TE mode field patterns shown in Fig. indicate the **order** of each mode.

The order of each mode is indicated by the number of field maxima within the core of the fiber.

For example, TE0 has one field maxima.

The electric field is maximum at the center of the waveguide and decays toward the core-cladding boundary.

TE 0 is considered the fundamental mode or the lowest order standing wave.

As the number of field maxima increases, the order of the mode is higher.

Generally, modes with more than a few (5-10) field maxima are referred to as high-order modes.

The order of the mode is also determined by the angle the wave-front makes with the axis of the fiber.

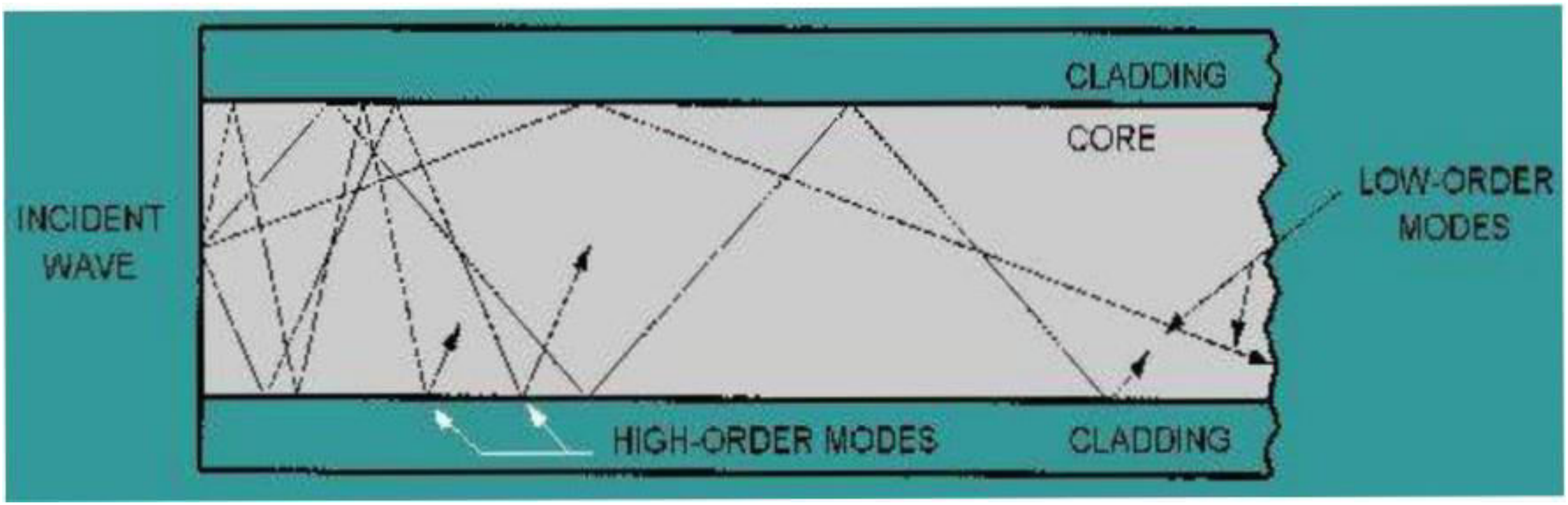

CLADDING
CORE
LOW-ORDER MODES
INCIDENT WAVE
HIGH-ORDER MODES
CLADDING

Fig. illustrates light rays as they travel down the fiber.

These light rays indicate the direction of the wave-fronts.

High-order modes cross the axis of the fiber at steeper angles.

Low-order and high-order modes are shown in Fig.

Low-order modes penetrate the cladding only slightly.

In low-order modes, the electric and magnetic fields are concentrated near the center of the fiber.

In high-order modes, the electrical and magnetic fields are distributed more toward the outer edges of the fiber.

The penetration of low-order and high-order modes into the cladding region indicates that some portion is refracted out of the core.

As the core and the cladding modes travel along the fiber, mode coupling occurs.

Mode coupling is the exchange of power between two modes.

Mode coupling to the cladding results in the loss of power from the core modes.