Application Note 030 – Optical Fibre

This document describes optical fibre technology

Introduction

In 1880 Bell demonstrated a primitive optical communication system based on the photophone, enabling sunlight to transmit information over hundreds of metres by using a reflective diaphragm to modulate incident light, which was collimated and direct towards a detector. The photophone demonstrates the fundamental nature of any communication system, the transfer of information from one point to another. In most cases information is imparted on a carrier wave by simply modulating the amplitude of the carrier.

Advances in the manufacture of the laser in the 1960's offered bright, coherent sources that could be modulated. Such developments renewed interest in utilising optics for communication. In 1966 at ST Labs Kao and Hockham proposed that a dielectric waveguide, such as an optical fibre, could be used to transmit optical signals. From this pivotal the communications industry has been transformed and optical fibres now transport information to all corners of the planet virtually transparently at the speed of light.

Optical Fibre – A Simple Guide

In its basic form, an optical fibre is a composite material, typically consisting of a silica-based core and cladding surrounded by one or two layers of polymeric material, figure 1. For guiding to occur, the refractive index (i.e. light bending capability) of the core (n_1) must be greater than that of the surrounding cladding (n_2). By satisfying this condition any light ray travelling in the core and striking the core-cladding interface within a certain angle experiences total internal reflection and so remains confined to the core.

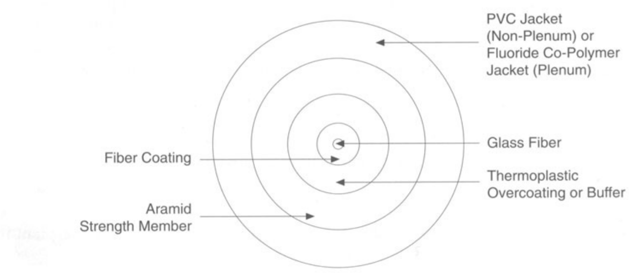
This so-called critical angle is defined by Snell's Law as

$$\sin \theta = n_2 / n_1$$

Although air would satisfy this condition, the interface in any real system would be subject to damage, cracking, contamination etc., and this is overcome by incorporating a cladding layer.

Historical Fact: As early as 1854, John Tyndall demonstrated that light could be guided inside a transparent medium by showing light being guided along a stream of water flowing from a container.

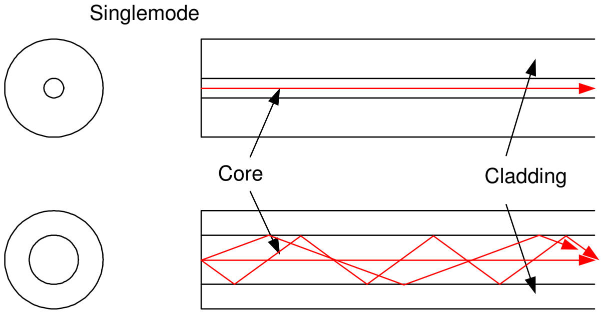
Figure 1



Tight-Buffered Cable

There are a number of core-cladding refractive index profiles used in optical fibre manufacture, ranging from a step-index to graded index and other more complex profiles that influence the nature of the light transmitted through the core.

Figure 2



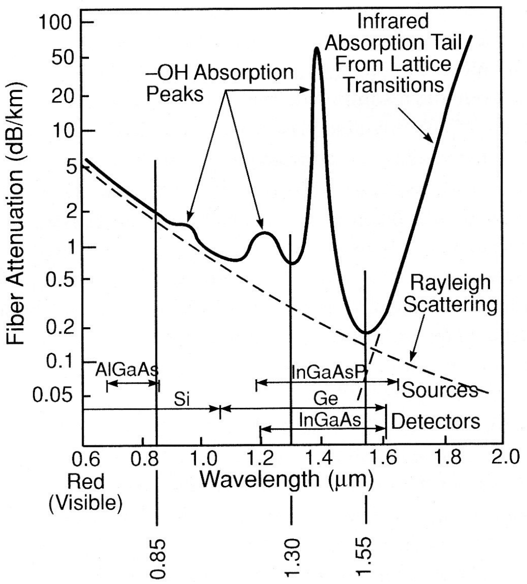
By tuning the size of the core diameter, the manufacturer of optical fibre is able to define two main products that are utilised in the communications industry. Multimode fibre, supports multi-path light ray transmission and has a core diameter of 50µm or 62.5µm. Single mode fibre propagates only one transmission mode and has a core diameter of 9µm. For practical convenience, the outer diameter of both fibre types is 125µm, see figure 2.

It is commonly found that the intensity (or brightness) of light is reduced as it travels along an optical fibre. This attenuation is measured in decibel (dB) and can be attributed to a number of causes including absorption and scattering due to irregularities at the core-cladding interface and through Rayleigh scattering due to inhomogeneities in the core refractive index.

Loss can also arise through joining (i.e. fusion splicing) and the process of terminating with connectors. The main cause of adsorption is the presence of transition metals such as Fe and Cu, water in the form of OH^- radicals and the intrinsic absorption of glass itself.

Losses in the best fibres are close to the intrinsic minimum value (i.e. Rayleigh background scattering) except around 1.4µm, where the contribution due to the hydroxyl radicals is clearly evident in the loss spectrum of a single mode fibre shown in figure 3.

Figure 3



Low Loss Transmission Wavelengths

A closer inspection of the spectra for single mode fibre clearly demonstrates that it is no coincidence that the transmission wavelengths extensively used in the communication industries are 1.3µm (S-band) and 1.5µm (C-band and L-band). The absorption spectrum clearly indicates significant dips at 1.3µm (where it is less than 0.4dB/km) and at 1.55µm (where it is less than 0.15dB/km).

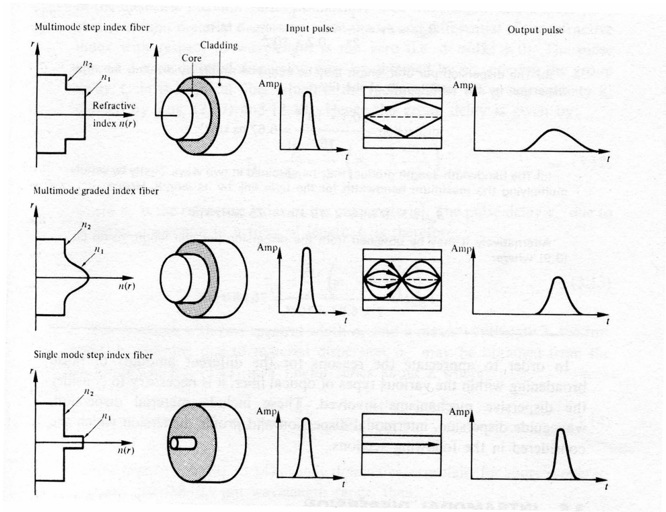
Useful Design Fact: Loss Measurement

Loss is usually quoted in terms of decibels per kilometre. This is defined for a launch power of P_{IN} giving rise to a transmitted power of P_{OUT} over L km length of fibre, the loss, ω, is governed by the equation:-

$$\omega = (10/L) \log_{10} (P_{IN}/P_{OUT}) \quad \text{db/km}$$

Optical Fibre Dispersion

For both digital and analogue transmission in optical fibres, chromatic (wavelength spreading) and modal dispersion of an optical signal causes distortion and bandwidth reduction. The bandwidth of an optical fibre system can be increased through the elimination of inter-modal dispersion by operating with a single mode fibre, as shown below.



Chromatic or inter-modal dispersion is ever present in all fibre. As a result of the finite spectral linewidth of any source, a propagation delay arises between the spectral components of the signal. This so called intra-modal dispersion causes broadening. The actual temporal delay may arise through the dispersive properties of the waveguide material (material dispersion) or through guidance effects within the fibre as a result of it structure (waveguide dispersion). Both affect the performance of a fibre optic link, and are usually measured in terms of pico-seconds pulse width increase per nanometre of source spectral width per kilometre path length of fibre (psec/nm.km).

Fibre Bandwidth

The fibre bandwidth quantifies the information carrying capacity of a fibre. Bandwidth is measured in units of MHz.km. Single mode fibre is inherently ultra-wide band.

Conclusions

Optical fibre is a glass or plastic fiber designed to guide light along its length. Optical fibres are widely used in fiber-optic communication, which permits transmission over longer distances and at higher data rates than other forms of communications. Fibres are used instead of metal wires because signals travel along them with less loss and they are immune to electromagnetic interference. Single mode optical fibres are often used In communications applications as they suffer less from dispersion and therefore maintain the highest bandwidth.

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