Fibre Optic Transmission for Technicians

Working for the Benefit of the Broadband Industry

Reference Manual

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Welcome to the SCTE™ Manual

This handbook is designed as a stand-alone reference manual for technicians working in the broadband telecommunications industry. It may be used either on its own or as an integral part of a classroom course including practical work to enable the student to progress to examination and certification.

We hope you and your career benefit greatly from this handbook and associated training course. Please consider joining the SCTE and taking advantage of the benefits that come from being part of the industry's foremost technical institution.

About the SCTE™

Founded in 1945, the SCTE is a non-profit making organisation, managed by an Executive Committee of elected volunteers, whose aim is to raise the standard of broadband engineering in the telecommunications industry. The Society particularly concerns itself with the training and career advancement of technical professionals in this field.

First introduced in 1994, the SCTE training courses have achieved wide acceptance as the standard for young technicians wishing to enter the field of cable telecommunications and for those wishing to advance their knowledge and career prospects. They are used in-house by a number of operating companies and SCTE engineers can be found working in a variety of international organisations.

As a Learned Society, SCTE is able to provide accreditation and certification for its members, giving them professional standing within the industry. Full Members and Fellows are allowed to use the designations MSCTE and FSCTE after their names whilst Technician Members may use TMSCTE. There are also categories for Student and Associate Members which carry the designations SMSCTE and AMSCTE respectively.

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1.1 Optical Theory

Optics is a branch of Physics that covers light, its properties and behavior. It covers many simple and complex subjects including interaction with materials (reflection and refraction) and devices to interact with it (lens) and instruments to measure it (Optical Time Domain Reflectometers).

1.2 Electromagnetic Spectrum

Light is a type of electromagnetic radiation (EMR) usually characterized by the length of the radiation of interest, specified in terms of wavelength, or lambda (λ). Wavelength is commonly measured in nm (10^{-9} meters) or μm (10^{-6} meters).

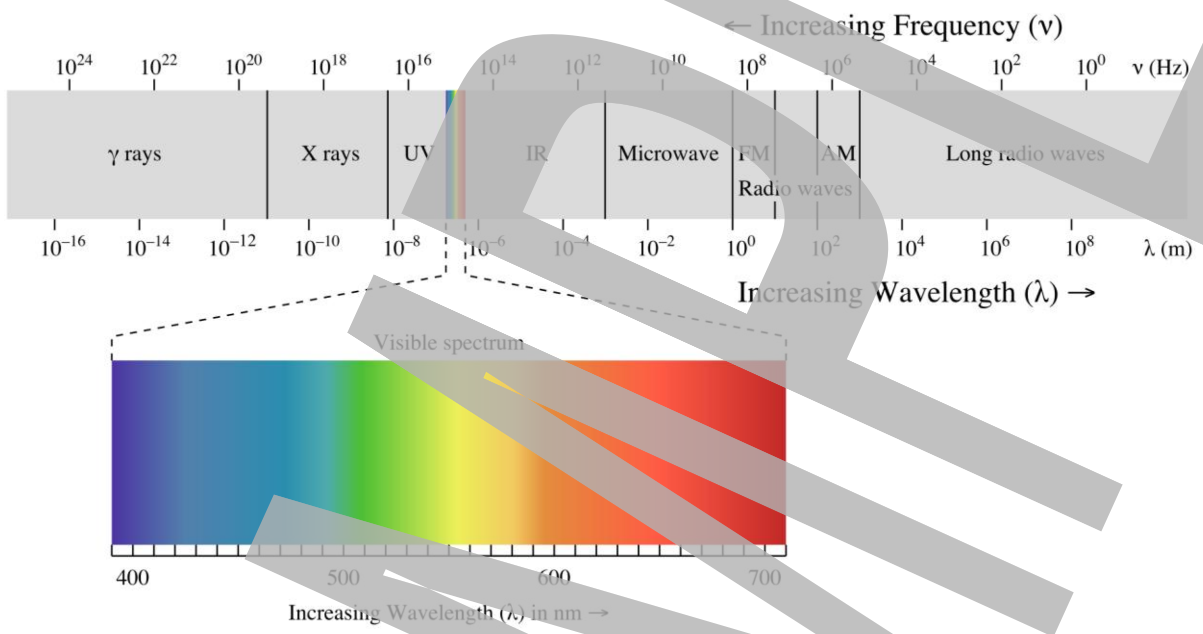


Figure 1.1: Electromagnetic Spectrum

The electromagnetic spectrum encompasses all wavelengths of radiation ranging from long wavelengths (radio waves) to very short wavelengths (gamma rays); Figure 1.1 illustrates this vast spectrum. The most relevant wavelengths to optics are the ultraviolet (UV) rays, defined as 1– 400nm, visible defined as 400 - 750nm comprise the part of the spectrum that can be perceived by the human eye and make up the colors people see and infrared (IR) rays, defined as 750nm – 1000μm and can be broken up further into near-infrared (750nm - 3,000nm), mid-wave infrared (3,000nm - 30,000nm) and far-infrared (30,000nm – 1,000,000nm).

The word light usually refers to visible light, which is visible to the human eye and is responsible for the sense of sight. The visible range is responsible for rainbows and the familiar ROYGBIV - the mnemonic many learn in school to help memorize the wavelengths of visible light starting with the longest wavelength to the shortest.

At the lower end of the visible light spectrum, infrared light becomes invisible to humans because its photons no longer have enough individual energy to cause a lasting molecular change in the visual molecule retinal in the human retina, which change triggers the sensation of vision.
Above the range of visible light, ultraviolet light also becomes invisible to humans, mostly because it is absorbed by the cornea below 360 nanometers and the internal lens below 400 nanometers. Furthermore, the rods and cones located in the retina of the human eye cannot detect the very short (below 360 nm) ultraviolet wavelengths and are in fact damaged by ultraviolet.

1.3 Speed of Light

The speed of light in vacuum, commonly denoted ***c***, is a universal physical constant important in many areas of physics. Its precise value is 299,792,458 metres per second (approximately 3.00×10^8 m/s), since the length of the metre is defined from this constant and the international standard for time the second.

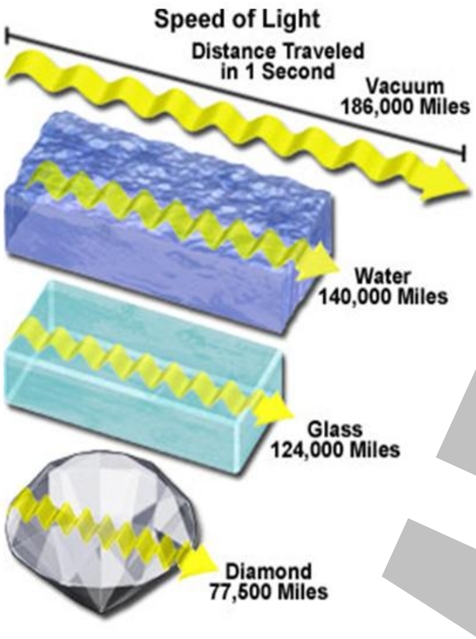


Figure 1.2: Speed of light in various materials

Speed Facts				
	Metres per Second	Kilometres per Hour	Feet per Second	Miles per Hour
Sound At Sea Level	340	1,225	1,116	761
Light	299,792,458	1,079,252,848	983,571,056	670,616,629

Table 1.1: Speed of light and sound comparison

1.4 Refractive Index

The speed at which light propagates through transparent materials, such as glass or air, is less than ***c***; similarly, the speed of radio waves in wire cables is slower than ***c***.

The ratio between ***c*** and the speed ***v*** at which light travels in a material is called the refractive index ***n*** of the material ($n = c / v$).

For example, for visible light the refractive index of glass is typically around 1.5, meaning that light in glass travels at $c / 1.5 = 199{,}861{,}638$ m/s;
The refractive index of air for visible light is about 1.0003, so the speed of light in air is about 299,700,000 m/s (about 90 Km/s slower than ***c***).

The refractive index determines how much light is bent, or refracted, when entering a material.

1.5 Relationship of Frequency and Wavelength

Any electromagnetic wave's frequency multiplied by its wavelength equals the speed of light.

$$\text{Frequency X Wavelength} = \text{Speed of Light}$$

This relationship can be used to calculate the wavelength or frequency of any electromagnetic wave if we have the other measurement. Just divide the speed of light by whichever measurement you have and then you've got the other.

$$\text{Wavelength} = \frac{\text{Speed of Light}}{\text{Frequency}}$$

$$\text{Frequency} = \frac{\text{Speed of Light}}{\text{Wavelength}}$$

1.6 Geometrical Optics

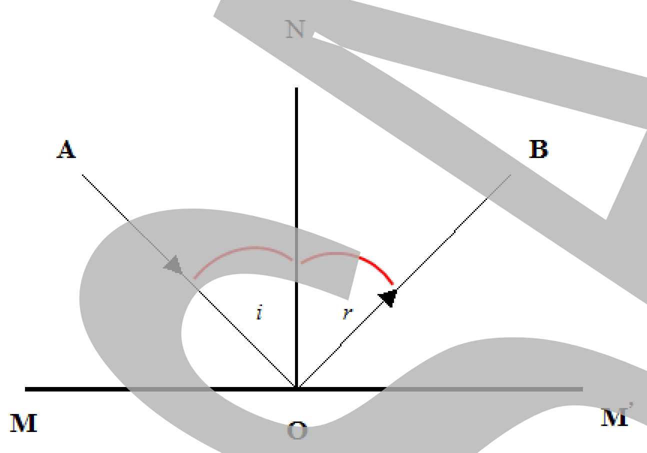
Geometrical optics, or ray optics, describes the propagation of light in terms of "rays" which travel in straight lines, and whose paths are governed by the laws of reflection and refraction at interfaces between different media. These laws were discovered empirically as far back as 984 AD and have been used in the design of optical components and instruments from then until the present day.

1.6.1 Reflection

Glossy such as mirrors reflect light in a simple, predictable way. This allows for production of reflected images that can be associated with an actual (real) or extrapolated (virtual) location in space.

With such surfaces, the direction of the reflected ray is determined by the angle the incident ray makes with the surface normal, a line perpendicular to the surface at the point where the ray hits.
The incident and reflected rays lie in a single plane, and the angle between the reflected ray and the surface normal is the same as that between the incident ray and the normal.

The angle of incidence is equal to the angle of reflection - This is known as the Law of Reflection.



- MM' represents the surface of a plane mirror.
- AO incident ray.
- OB reflected ray.
- ON, the *normal* to the reflecting surface.
- Angle (i) is the angle of incidence.
- Angle (r) is the angle of reflection.

Figure 1.3: Reflection

1.6.2 Refraction

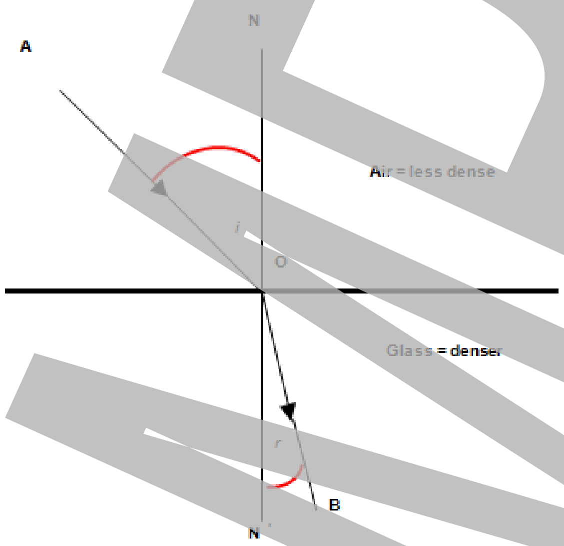
Refraction occurs when light travels through an area of space that has a changing index of refraction. The simplest case of refraction occurs when there is an interface between a uniform medium with index of refraction $\mathbf{n_1}$ and another medium with index of refraction $\mathbf{n_2}$.

Snell's Law describes the resulting deflection of the light ray:

$$n_1 \sin(i) = n_2 \sin(r)$$

Where ***i*** and ***r*** are the angles between the normal (to the interface) and the incident and refracted waves, respectively.

Various consequences of Snell's Law include the fact that for light rays traveling from a material with a high index of refraction to a material with a low index of refraction, it is possible for the interaction with the interface to result in zero transmission. This phenomenon is called total internal reflection and allows for fibre optics technology. As light signals travel down a fibre optic cable, it undergoes total internal reflection allowing for essentially no light lost over the length of the cable.



- AO incident ray.
- OB refracted ray.
- ONN', the *normal* to the reflecting surface.
- Angle (i) is the angle of incidence.
- Angle (r) is the angle of refraction.
- The light is bent towards the normal.
- Hence fish appear deeper than actual.

Figure 1.4: Refraction

Figure 1.5: Fish Displacement

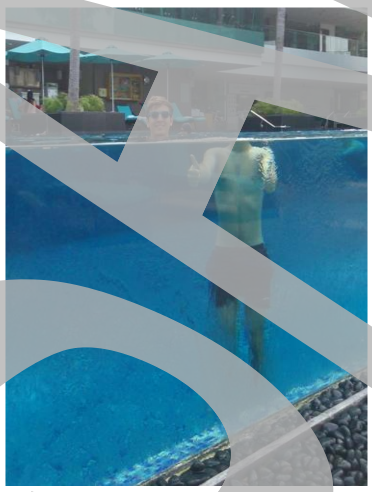


Figure 1.6: Refraction through water

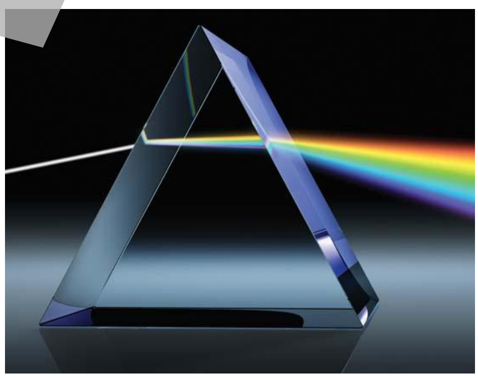


Figure 1.7: Refraction through a prism

1.6.3 Total internal reflection

A phenomenon which occurs when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. If the refractive index is lower on the other side of the boundary and the incident angle is greater than the critical angle, the wave cannot pass through and is entirely reflected.

The **critical angle** is the angle of incidence above which the total internal reflection occurs. This is particularly common as an optical phenomenon, where light waves are involved, but it occurs with many types of waves, such as electromagnetic waves in general or sound waves.

When a wave reaches a boundary between different materials with different refractive indices, the wave will in general be partially refracted at the boundary surface, and partially reflected. However, if the angle of incidence is greater (i.e. the direction of propagation is closer to being parallel to the boundary) than the critical angle – the angle of incidence at which light is refracted such that it travels along the boundary – then the wave will not cross the boundary, but will instead be totally reflected back internally. This can only occur when the wave in a medium with a higher refractive index (n_1) reaches a boundary with a medium of lower refractive index (n_2). For example, it will occur with light reaching air from glass, but not when reaching glass from air.

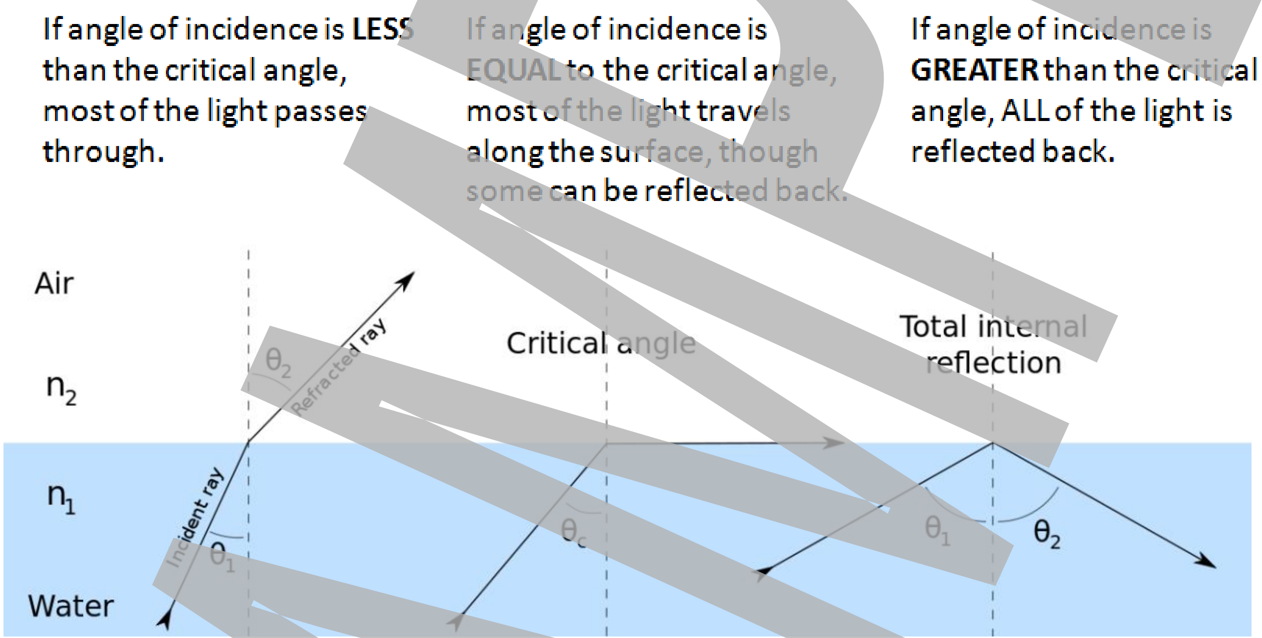


Figure 1.8: Internal Reflection

Figure 1.9: Internal Reflection Down a Light Pipe

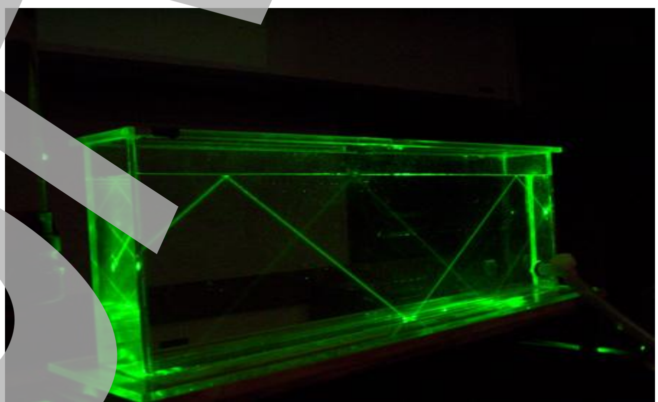


Figure 1.10: Internal Reflection in a Tank of Liquid

1.7 LASER

Light Amplification by Stimulated Emission of Radiation (LASER) is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

The first laser was built in 1960 by Theodore H. Maiman at Hughes Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow. A laser differs from other sources of light in that it emits light *coherently*. Spatial coherence is typically expressed through the output being a narrow beam. Lasers can have very low divergence in order to concentrate their power at a great distance.

Figure 1.11: LASER of Different Colour

Lasers are characterized according to their wavelength in a vacuum. Most "single wavelength" lasers actually produce radiation in several *modes* having slightly differing frequencies (wavelengths), often not in a single polarization. Although temporal coherence implies monochromaticity, there are lasers that emit a broad spectrum of light or emit different wavelengths of light simultaneously.

The most common type of laser uses feedback from an optical cavity—a pair of mirrors on either end of the gain medium. Light bounces back and forth between the mirrors, passing through the gain medium and being amplified each time. Typically one of the two mirrors, the output coupler, is partially transparent. Some of the light escapes through this mirror. Depending on the design of the cavity the light coming out forms a narrow beam.

Figure 1.12: Helium Neon LASER Cavity.

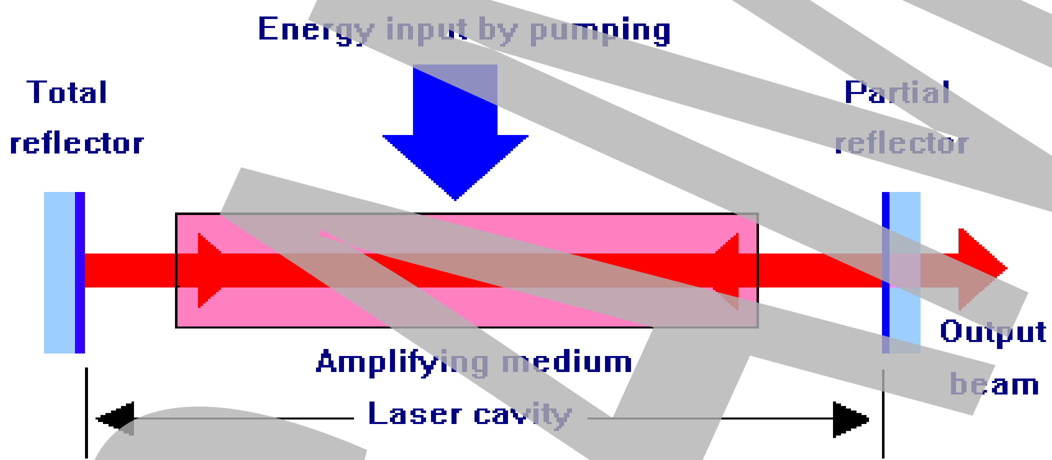


Figure 1.13: LASER Operation

Figure 1.14: LASER Warning signs

1.7.1 LASER Light Bulb Comparison

Light Bulb produces Incoherent light
Light from a light bulb contains waves with different wavelengths, producing different colours all mixed together radiating out in all directions.

LASERS produce Coherent light
Light from a laser contains waves with the same wavelengths, producing one colour with a collimated beam output.

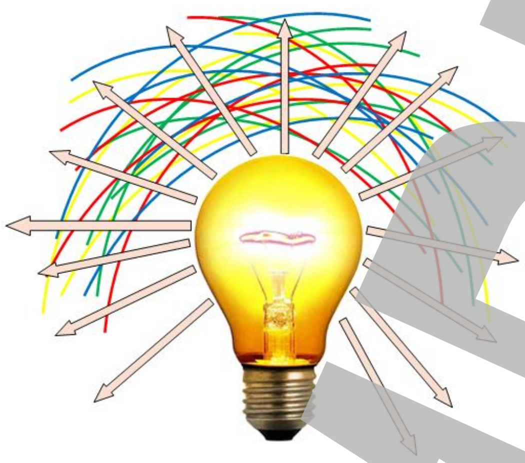


Figure 1.15: Light from a Light Bulb

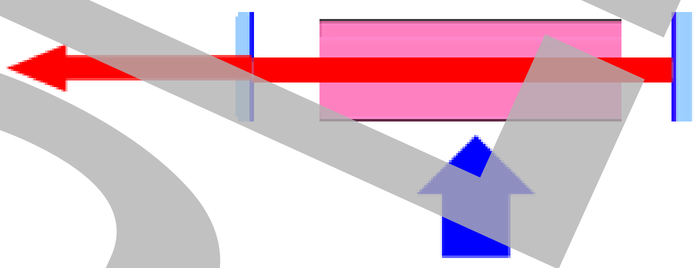


Figure 1.16: Light Beam from a LASER