CO874 - Optic Fibre Data Transmission Report

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Abstract

This report covers the different aspects of fibre optic from its physical structure and the components used, to the way data is transmitted over the fibre via light signals and some interesting properties that apply. An observation is also made on the technology called Wavelength-division multiplexing.

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1. General structure

“An optical fibre is a thin, flexible medium capable of guiding an optical ray.” [2]

The objective is to transmit a light signal on the other end of the cable with a minimum loss of signal. Fibre optics components are arranged as more or less five concentric layers [1].

The **core** is a very thin strand with a diameter that varies from 8 to 62.5 µm. Often made from silica glass or plastic, this is the innermost section of the fibre optic cable. The light passes through it.
The **cladding** surrounds the core and is made of glass or plastic as well. It has different properties such as a lower refractive index than the core and thus acts as a reflector. This property allows the light to be confined within the core otherwise it would escape from it. It serves as a boundary that contains the light and causes the refraction.
A **buffer coating** is added around the cladding to protect the inner sections from external light and reinforce the core. An opaque hard plastic is used for this purpose.
Next comes the **strength member**. Used between the buffer coating and the cable jacket against crushing forces and excessive tension, it can be either aluminium foil, steel, kevlar or other strengthening fibres.
The outermost layer is the **jacket**. Made of polymer, it protects the fibre against environmental dangers such as water and dirt. This is the main and the first protection layer.

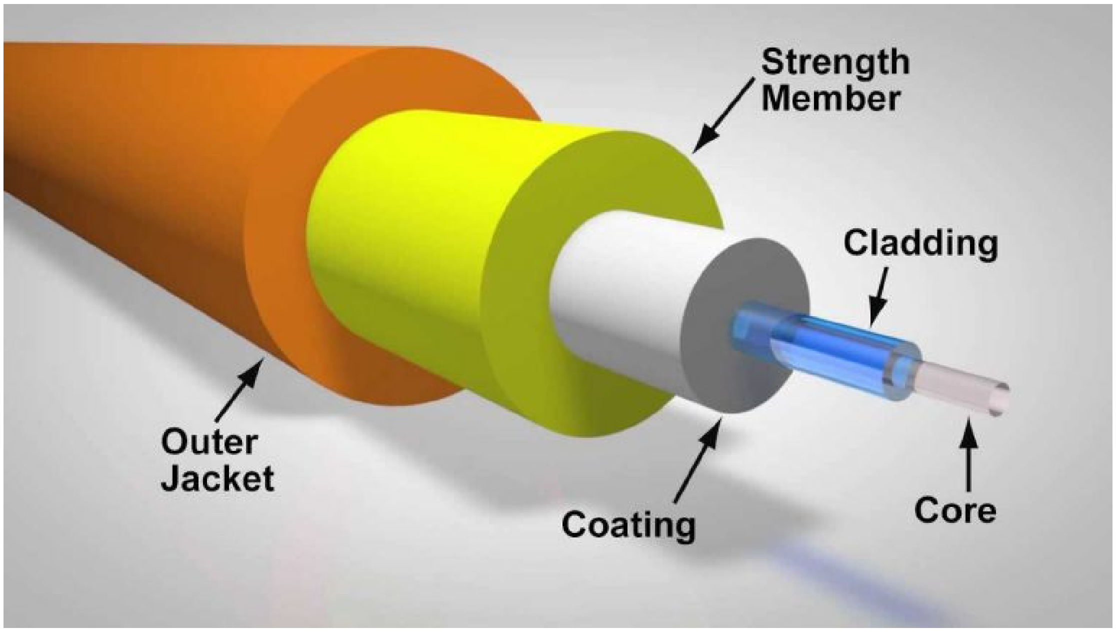

Illustration 1: Fibre Optic Cable Structure (from fiber-optical-networking.com)

Glass fibre optic cable has a glass core and a glass cladding which is why it provides the lowest attenuation among fibre optic cables. This cable type is well-known and is the most deployed. Ultra-pure glass is a must (often made of silicon dioxide or fused quartz). Plastic is also used as core and cladding main component, it makes it thicker than the glass version. The plastic used for the core is generally made of polymethylmethacrylate (PMMA) and the cladding of fluropolymer.
As we can expect, plastic fibre optic cable is more resistant to bending than glass fibre optic cable.
An alternative version with a core made of glass and a cladding made of plastic also exists. Called Plastic Clad Silica (PCS) fibre optic cable, it falls between the two first cable categories in term of attenuation rate.

A multi-fibre optic cable can contain from one to hundreds of fibres inside. In this configuration a light-absorbing glass is used to mitigate light leaks thus reducing “cross-talk” between the fibres.
For external environment usage, tubes can be inserted in the cable so the cable can stretch without causing any harm to the fibre around. Heavily protections exist to make the cable resistant in water environments, for example when the cable is on the ocean floor. Most of the harm to the cable generally appends during handling.

There are a wide variety of cables available, the main decision criteria are the surrounding environment, the length of the link and the cost. They have various properties such as the operating temperature range, the equipment necessary to install and terminate them and the protections they come up with.

Fibre optic cables are terminated by a connector and there are plenty of them [2]:

- Polish and Epoxy connectors offer a good resistance against stress, they fit varying diameters of cable size and can handle multiple fibre in a single connector.
- No-Polish and No-Epoxy connectors are more simple in their design which implies a reduced cost.

The E2000 (on the right) is increasingly used in telecommunication networks nowadays.

Sometimes we just want to join to optical fibres without having connector nor receiver. This action is complex and involves to make a precise cleave in the fibre. To merge both ends, the end faces must be perfectly flat, thus a controlled break is necessary.

There are 2 processes to do the “termination”:

- Mechanical splicing
- Fusion splicing

Illustration 2: Fiber Optic Connector Types (from flukenetworks.com)

Mechanical splices are alignment devices. The two fibres ends are held in contact (by mechanical forces) and aligned. As we can guess, a signal loss is inevitable.
Fusion splicing on the other side “melt” the glass ends together using heat or electric arc. This method requires special skills and interconnection technology in order to align the fibres correctly. A lower loss in the light transmission is to be expected compared to the mechanical splicing.
The main reason for choosing one method over the other is the cost. The more precise the alignment, the less the loss, the more expensive it will be.

In the fibre optic world, there are two different types of light sources:

- LED (Light Emitting Diode)
- ILD (Injection Laser Diode)

LED are low cost, simply designed, reliable, and they have a wide output pattern. They are made from Indium gallium arsenide phosphide (InGaAsP) or gallium arsenide (GaAs) and the energy requirement is lower compared to laser diodes thus producing a less concentrated light.
Superseded by VCSEL (Vertical Cavity Surface Emitting Laser) that combines high bandwidth at lower cost. Laser diodes can be modulated at very high speeds and have higher coupling efficiency.

2. Transmission

The total internal reflection principle allows the light pulses to move down the fibre after being reflected on surfaces. When the angle of incidence of the light against the cladding exceeds a critical value, light bounces back in instead of getting out of the core. This is how the light is confined within the core. That implies that the refractive index of the core must be greater than the index of the cladding. The speed of light can be measured via this index. During the fabrication, impurities (called dopants) are purposely added to the pure glass to obtain the desired indices of refraction.

The light that propagates through the fibre is immune to electromagnetic interference because the components (glass, plastic…) are electrically non-conductive. The latter property allows the fibre to be used in high-risk environments where for example sparks must be avoided. Unlike copper cables, there is no "crosstalk" between optical fibres, the attenuation is very limited. This means a higher bandwidth over long distances.

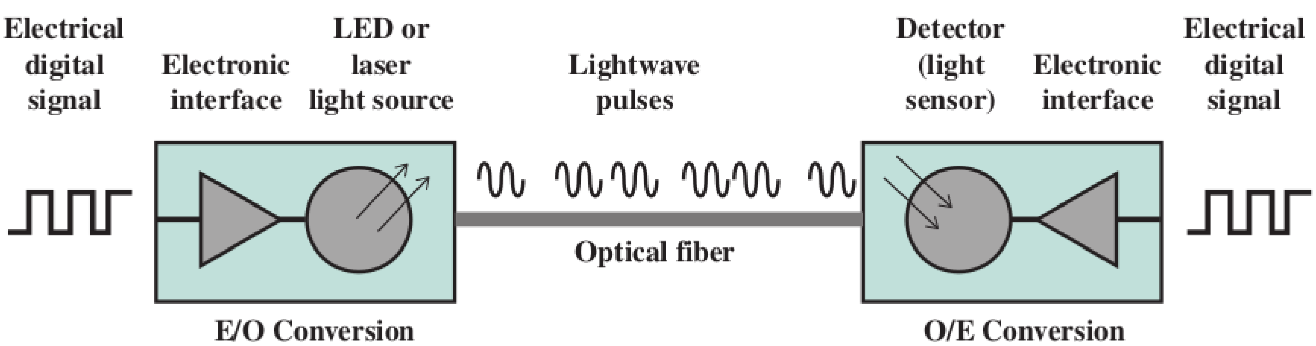

Illustration 3: Optical Communication (from William Stallings [1])

In order to be transmitted along the fibre, the electrical signal must be converted to light-wave pulses and then back to an electrical signal [3]. A LED or laser light source is coupled to an electronic interface and act as the transmitter. On the other end, we have a detector (light sensor) that is coupled to an electronic interface which converts the light signal back to an electrical digital signal.

There are two main Electrical to Optical Transducers light sources:

- LED (inexpensive, reliable, suitable for a use at speeds less than 1 Gbps)
- ILD (higher bandwidth, narrow spectrum)

And two main Optical to Electrical Transducers photo-detectors:

- Positive-Instrinsic-Negative (PIN) photo-diode (low cost and reliable)
- Avalanche photo-diode (APD) (higher sensitivity and accuracy)

Both of them are made from Silicon or inGaAs. A photo-detector that converts light into electricity coupled with an amplifier gives what’s called an optical receiver. Amplifiers have largely replaced repeaters mainly due to the cost of the latter.
The effective capacity of an existing fibre can be increased by **only upgrading the transducers** and not replacing the fibre.

Note that transmission is limited by the attenuation and dispersion.
Attenuation comes from 2 factors:

- Absorption (removes signal energy in the interaction between the propagating photons and molecules in the core)
- Scattering (redirects light out of the core to the cladding)

As of dispersion (which is the spreading of the light pulse over time), it comes from 2 main factors:

- Chromatic dispersion (light pulses arriving at a slightly different time because of the wavelengths)
- Modal dispersion (light pulses propagation is not the same for all modes)

The different paths that a light ray follows down the optical fibre are called **modes** [4].

There are two categories of optical fibre:

- MMF (multi-mode fibres)
- SMF (single-mode fibres)

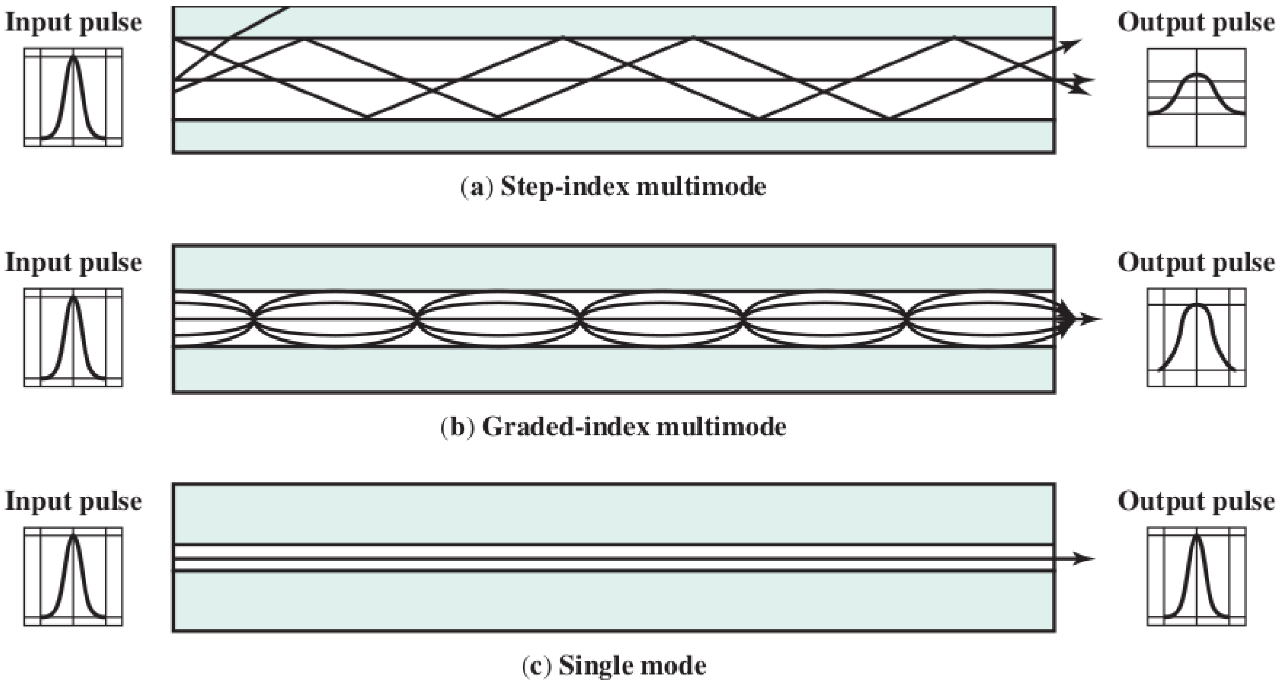

Illustration 4: Optical Fiber Transmission Modes (from William Stallings [1])

- **Step-index multi-mode** is a fibre with large core diameter (greater than 10mµ), usually 50-100 µm. Light rays bounce off the cladding and travel through the core via different paths. The larger core diameter means that a much larger wavelengths of light can be carried but also that light will be subject to chromatic dispersion. Different grouping of light rays (modes) arrive separately at the receiving point because they may not travel at the same speed. Data rates are varying from 100 Mbit/s (over 2km) to 10 Gbit/s (over 550 meters). The main usage is for short-distance communication links. An LED is usually used as a light source. The installation and operating equipments are cheaper than single mode fibre because a lower precision is required. That makes it easier to install and terminate in the field. An orange jacket colour is used for this type of cable.

- **Graded-index multi-mode** is a fibre with a refractive index that diminishes from the centre to the cladding. The light rays just bend smoothly and appear to have a curved path. The core diameter is smaller than the core in the step-index multi-mode fibre. Also, it suffers less dispersion than step-index multi-mode.

- **Single mode** is a fibre with a core diameter around 8.5-10 µm. Light travels parallel to the axis “without” (almost) bouncing off the edges. Only one mode of light at the time is allowed through the core. As a consequence, it can reach a data rate close to 100Tbp/s (over 50km) since it is less subject to dispersion. This higher transmission rate is possible thanks to the little pulse dispersion. A laser is used to produce the light that is injected in the cable. A yellow jacket colour is used for this type of cable. The equipment is more expensive in the single mode because of the precise calibration required to injected light into the cable.

The cost between cables of different modes are negligible.

3. WDM (Wavelength-division multiplexing)

The way WDM technology [5] works is by sending signals from several sources into a single fibre. A greater overall capacity of a fibre can be reached with the DWDM (Dense Wavelength Division Multiplexing) technology. It “simply” brings the wavelengths closer to each other.

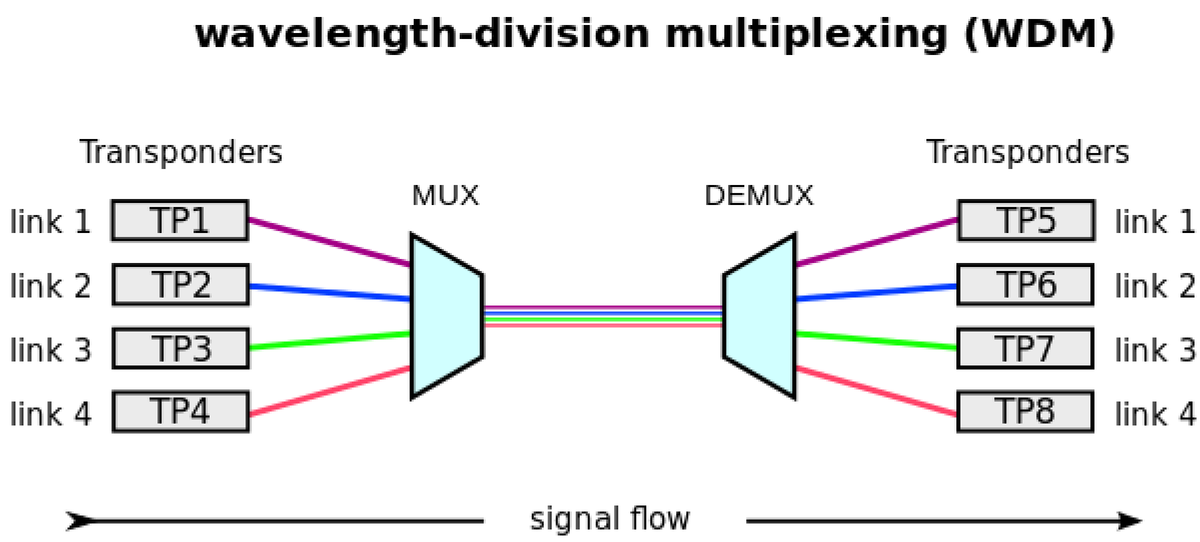

Illustration 5: WDM operating principle (from Wikipedia [2])

The transponders generate the signals which are then passed to the multiplexer in order to combine them in one beam. Once transmitted to the other end via the fibre, the component of the light are separated as they enter the de-multiplexer which does the “reversed” operation. The signal can then be processed by the receiver transponders according to their wavelengths. This system can be bidirectional if there is a multiplexer and a de-multiplexer on each end.

As multiple signals can be passed down to a single fibre at the same time, **the available capacity is taken to the next level.**

4. References:

- [1] William Stallings, Data and Computer Communications, 10th Edition, Pearson Education, 2007

- [2] Wikipedia Wavelength-division multiplexing
- [3] Wikipedia Optical fiber
- [4] Dr. Kenneth S. Schneider, Fibre Optic Data Communications for the Premises Environment
- [5] Vivek Alwayn, Fiber-Optic Technologies, Cisco Press, 2004