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# Wireless Optical Communication System and its Vital Components

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**Abstract:** The primary aim of this paper is to highlight the importance of vital components used in the emerging field of wireless Optical Communication System. As the optical fibre is the choice of today's era for long distance transmission of signals as it gives a maximum transmission bit rate plus being a reliable source of transmission of signals without compromising much over long distance transmission losses to the surrounding medium. For the proper understanding of optical fibre communication systems it is indispensible to have a fair knowledge of these components and to know the basic principles on which this most emerging system of communication works.

**Keywords**: Wireless optical communication, transmission, bit rate, losses, components.

## I. INTRODUCTION

Innovations in optical fiber technology has revolutionised the world communication system. Optical fiber can be used as a medium for telecommunication over long distances and networking of respective signals as it is light weight and can be bundled in the form of cables. Fiber optics is the only technique known today to have the power to meet the strong demands for flexibility and high bandwidth posed by the rapidly growing communication networks. The optical systems were primarily used in point-to-point long distance links [1, 2]. As light propagates through the fiber with less attenuation as compared to conventional electrical cables hence it is used for long distance transmission of signals over long distance communication networks. Hence we place repeaters over long distance network so that the signal's attenuation can be minimised so that it can be effectively send over the channel so that the minimum loss of data should be there. Optical fibers find immense application in the field of data processing. So in forthcoming years the optical fibres are replacing conventional copper wires and cables for signal transmission over long distance communications paths and network.

The rapid progress and development in optical fiber communication and sensing systems have impulsively speed up the exploration of researchers and scientists to improve and develop the optical devices, which could overcome the existing limitations and perform the task of precursors for future advancements in photonics technology. The whole system of optical fiber communications consist of series of indispensible components which form a base for the basic and efficient working of optical transmission system.

## II. OPTICAL FIBER

Optical fibers are a kind of waveguides, which are usually made of some kind of glass, can potentially be very long (hundreds of kilometers). The most commonly used glass is silica (quartz glass, amorphous silicon dioxide = $SiO_2$), either in pure form or with some dopants. Silica is widely used because of its outstanding properties as it is most suitable for extremely low propagation losses.

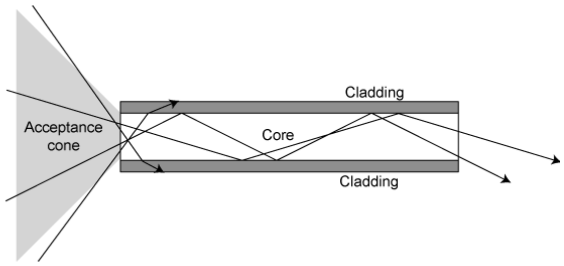


Fig 1: Schematic diagram of optical fiber [3]

Using a lens, the light pulses are funneled into the fiber-optic medium where they travel down the cable. The light (near infrared) is most often 850nm for shorter distances and 1,300nm for longer distances on Multi-mode fiber and 1300nm for single-mode fiber and 1,500nm is used for longer distances.

The travelling of light through the fiber is based on the principle of total internal reflection which states that "when the angle of incidence exceeds a critical value, light cannot get out of the glass; instead, the light bounces back in". When this principle is applied to the construction of the fiber-optic strand, it is possible to transmit information down fiber lines in the form of light pulses. The core must a very clear and pure material for the light or in most cases near infrared light (850nm, 1300nm and 1500nm).

The most widely accepted structure is the single solid dielectric cylinder of radius $a_{co}$ (1μm to 50μm) and refractive index $n_1$ known as the core of the fiber surrounded by a solid dielectric cladding of refractive index $n_2$ ($n_2<n_1$) and radius $a_{cl}$ (standardized to 62.5μm). Although, in principle, a cladding is not necessary for light guidance along the core of the fiber, it serves several purposes:

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(i) reduces scattering losses that result from dielectric discontinuities at the core surface
(ii) adds mechanical strength
(iii) protects the core from contaminants

Two main types of optical fiber used in optic communications include multi-mode optical fiber and single-mode optical fiber. A multi-mode optical fiber has a larger core (≥ 50 micrometers), allowing less precise, cheaper transmitters and receivers to connect to it as well as cheaper connectors. However, a multi-mode fiber introduces multimode distortion, which often limits the bandwidth and length of the link. Furthermore, because of its higher dopant content, multi-mode fibers are usually expensive and exhibit higher attenuation. The core of a single-mode fiber is smaller (<10 micrometers) and requires more expensive components and interconnection methods, but allows much longer, higher-performance links [4]

## III. OPTICAL ADD-DROP MULTIPLEXER

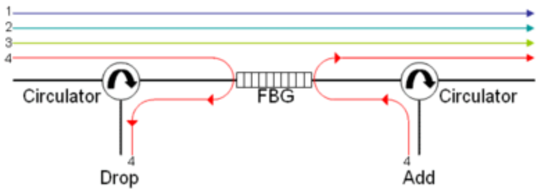


Fig 2: Optical add-drop multiplexer, using a fiber Bragg grating (FBG) and two circulators [5]

An Optical Add-Drop Multiplexer (OADM) is a device used in wavelength-division multiplexing (WDM) systems for multiplexing and routing different channels of light into or out of a single mode fiber (SMF). This is a type of optical node, which is generally used for the construction of optical telecommunications networks. "Add" and "Drop" in the Fig 1 refers to the capability of the device to add one or more new wavelength channels to an existing multi-wavelength WDM signal, and/or to drop (remove) one or more channels, passing those signals to another network path. An OADM may be considered to be a specific type of optical cross-connect. A traditional OADM consists of three stages: an optical demultiplexer, an optical multiplexer, and between them a method of reconfiguring the paths between the optical demultiplexer, the optical multiplexer and a set of ports for adding and dropping signals. The optical demultiplexer separates wavelengths in an input fiber onto ports. The reconfiguration can be achieved by a fiber patch panel or by optical switches which direct the wavelengths to the optical multiplexer or to drop ports. The optical multiplexer multiplexes the wavelength channels that are to continue on from demultiplexer ports with those from the add ports, onto a single output fiber. All the light paths that directly pass an OADM are termed cut-through light paths, while those that are added or dropped at the OADM node are termed added/dropped light paths. An OADM with remotely reconfigurable optical switches (for example 1×2) in the middle stage is called a reconfigurable OADM (ROADM). Those without this feature are known as fixed OADMs. While the term OADM applies to both types, it is often used interchangeably with ROADM.

## IV. ARRAYED WAVEGUIDE GRATING

Arrayed waveguide gratings (AWG) are commonly used as optical (de)multiplexers in wavelength division multiplexed (WDM) systems. These devices are capable of multiplexing a large number of wavelengths into a single optical fiber, thereby increasing the transmission capacity of optical networks considerably. The devices are based on a fundamental principle of optics that light waves of different wavelengths interfere linearly with each other. This means that, if each channel in an optical communication network makes use of light of a slightly different wavelength, then the light from a large number of these channels can be carried by a single optical fiber with negligible crosstalk between the channels. The AWGs are used to multiplex channels of several wavelengths onto a single optical fiber at the transmission end and are also used as demultiplexers to retrieve individual channels of different wavelengths at the receiving end of an optical communication network.

## V. OPERATION OF AWG DEVICES

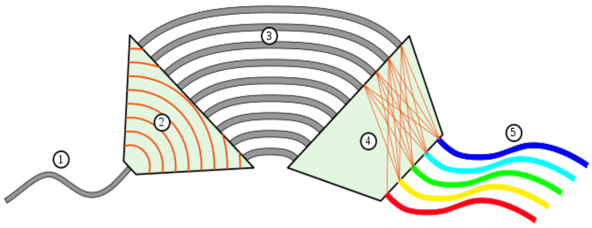


Fig 3: Arrayed waveguide grating [6]

The incoming light **(1)** traverses a free space **(2)** and enters a bundle of optical fibers or channel waveguides **(3)**. The fibers have different length and thus apply a different phase shift at the exit of the fibers **(3)** the light traverses another free space **(4)** and interferes at the entries of the output waveguides **(5)** in such a way that each output channel receives only light of a certain wavelength. The orange lines only illustrate the light path. The light path from **(1)** to **(5)** is a demultiplexer, from **(5)** to **(1)** is a multiplexer. Conventional silica-based AWGs schematically shown in the fig 2, are planar light wave circuits fabricated by depositing doped and un-doped layers of silica on a silicon substrate. The AWGs consist of a number of input **(1)** / output **(5)** couplers, a free space propagation region **(2)** and **(4)** and the grating waveguides **(3)**. The grating consists of a large number of waveguides with a constant length increment (ΔL). Light is coupled into the device via an optical fiber **(1)** connected to the input port. Light diffracting out of the input waveguide at the coupler/slab interface propagates through the free-space region **(2)** and illuminates the grating with a Gaussian distribution. Each wavelength of light coupled to the grating waveguides **(3)**, undergoes a constant change of

 

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phase attributed to the constant length increment in grating waveguides. Light diffracted from each waveguide of the grating interferes constructively and gets refocused at the output waveguides ***(5)***, with the spatial position, the output channels, being wavelength dependent on the array phase shift.

## VI. OPTICAL AMPLIFIER

The transmission distance of a fiber-optic communication system has traditionally been limited by fiber attenuation and by fiber distortion. By using opto-electronic repeaters, these problems have been eliminated. These repeaters convert the signal into an electrical signal, and then use a transmitter to send the signal again at a higher intensity than it was before. Because of the high complexity with modern wavelength-division multiplexed signals (including the fact that they had to be installed about once every 20 km), the cost of these repeaters is very high [4]. Thus an optical amplifier is used which a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Stimulated emission in the amplifier's gain medium causes amplification of incoming light.

## VII. DOPED FIBER AMPLIFIERS

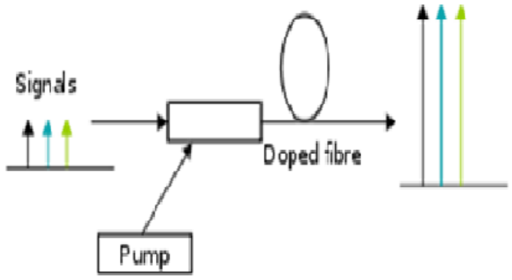


Fig 3: Schematic diagram of a simple Doped Fiber Amplifier [7]

Doped Fiber Amplifiers (DFAs) are optical amplifiers that use a doped optical fiber as a gain medium to amplify an optical signal. They are related to fiber lasers. The signal to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where the core of a silica fiber is doped with trivalent Erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1,480 nm, and exhibits gain in the 1,550 nm region. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fiber. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through non-radiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fiber, and the wavelength and power of the pump laser.

## VIII. ERBIUM-DOPED FIBER AMPLIFIERS (EDFA)

The Erbium-Doped Fiber Amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber. Two bands have developed in the third transmission window – the *Conventional*, or C-band, from approximately 1525 nm – 1565 nm, and the *Long*, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands. The principal difference between C- and L-band amplifiers is that a longer length of doped fiber is used in L-band amplifiers. The longer length of fiber allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain. EDFAs have two commonly-used pumping bands – 980 nm and 1480 nm. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stabilized laser sources are typically needed. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980 nm and 1480 nm pumping is generally utilized in amplifiers.

## IX. OPTICAL CIRCULATOR

The optical circulator has similar function and design as the optical isolator. An optical circulator is a non reciprocal passive device that directs light sequentially from port 1 to port 2, from port 2 to port 3, and so on in only one direction. The operation of a circulator is similar to that of an isolator except its construction is more complex. Like the isolator, its uses polarization to do its job. The typical construction of an circulator consists of a number of walk-off polarizers, half-wave plates and Faraday rotators. Typically an optical circulator has three or four ports. A variety of circulators are available commercially. They have low insertion loss, high isolation over a wide wavelength range, minimal polarization dependent loss, and low polarization mode dispersion. The typical insertion loss of an isolator is about 0.6dB, channel isolation is over 40dB, optical return loss is over 50dB and polarization dependent loss is lower than 0.1dB.

## X. FARADAY ROTATOR

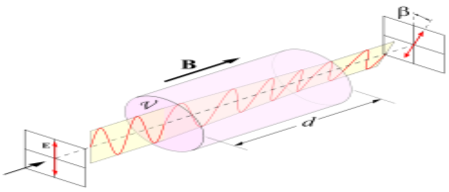


Fig 4: Polarization mechanism due to the Faraday effect. The field lines are usually closed through a permanent magnet around the rotator [8]


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A Faraday Rotator is an optical device that rotates the polarization of light due to the Faraday Effect, which in turn is based on a magneto-optic effect. The Faraday rotator works because one polarization of the input light is in ferromagnetic resonance with the material which causes its phase velocity to be higher than the other. The plane of linearly polarized light is rotated when a magnetic field is applied parallel to the propagation direction. The empirical angle of rotation is given by:

$$\beta = VBd$$

Where,
β is the angle of rotation (in radians).
*B* is the magnetic flux density in the direction of propagation (in tesla).
*d* is the length of the path (in meters) where the light and magnetic field interact.
Then *V* is the Verdet constant for the material. This empirical proportionality constant (in units of radians per tesla per meter, rad/(T·m)) varies with wavelength and temperature.

## XI. THREE PORT CIRCULATOR

This device is based on the principle of birefringent crystal and Faraday Effect.

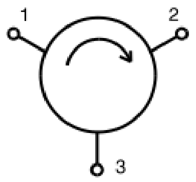
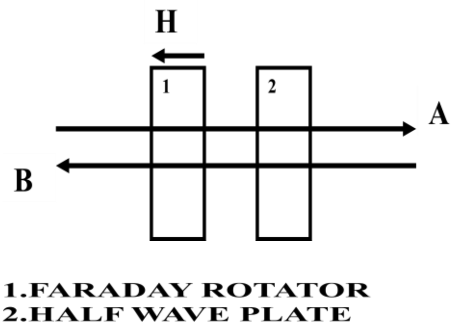



Fig 5: A Three Port Circulator [9]



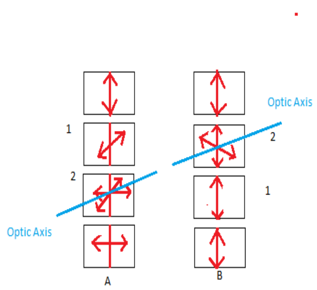




Fig 6: Principle of Operation of 3-port circulator

In Fig 6, if we observe the path along A, a vertically polarized beam enters the faraday rotator and is rotated by an angle (depending upon its properties). Then on entering the half wave plate it rotates by 2q where q is the angle the incident wave makes with the optic axis of the half wave plate. Therefore as shown in the figure the output wave from the faraday rotator is now horizontally polarized.
Similarly if we observe the path taken by wave along the opposite path (B), the vertically polarized wave enters the half wave plate first and is rotated in a similar manner as explained earlier. The output wave from the half wave plate then enters the faraday rotator which provides rotation in same direction as before (despite of the change in propagation direction). Therefore the output wave is vertically polarized i.e. input and output polarizations are the same in this case. After having understood the effects of the faraday rotator and the half wave plate we can now understand the working of a three port circulator completely. Referring to figure 2, let us consider that we input an unpolarized wave at port 1. This wave has two polarization components - “p polarized beam”, i.e. polarizations in the plane of incidence and “s polarized beam” i.e. polarization perpendicular to the plane of incidence. The polarization beam splitter (3) passes the p polarized wave and reflects the s polarized toward the prism reflector (5). Both these components after passing through the faraday rotator (1) and half wave plate (2) are reversed in their polarizations and received at port 2 but if we input an unpolarized wave at port 2, it is not received at port 1, but at port 3. This can be easily observed from figure 6.

## XII. CONCLUSION

Thus we have discussed the various components used in the optical communication systems which are indispensible for its efficient working. The basic principle underlying their working have been studied and it has been concluded that through study of these components is a must for better understanding so that they can be used for Human welfare in any field.

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