Optical Communications: An Overview

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Abstract

Because of the inherent advantage of immunity to RFf, EMf, ground loop currents and to a large extent to nuclear radiations, optical transmission through dielectric wave guide or fiber optic transmission as it is popularly known is gaining considerable importance for both civil and military communication. The additional unique advantage of large bandwidth transmission capabilities, low weight, cost and use of inexhaustible raw material (silica) makes the use of this new technology as a forerunner, which would ultimately replace coaxial transmission completely. To use this new technology for transmission of signals both in analog and digital formats, for short haul low bit rate signals or long high bit rate signals special attention has to be given in the selection of the four basic components namely the fiber source, detector, and the amplifier. This paper discusses the progressive development of the above four components to meet the present day demand for high data rate long haul communication systems.

Keywords

Optical communications, Fiber-optics, LEDs, Laser Diodes, Photo detectors, Optical Amplifiers.

1 Introduction

Optical or Lightwave communication is not a new phenomenon. For many years sailors used to transmit messages by use of light signals. Greeks had used fire signals for transmission of messages as back as in eighth century B. C [19]. However with these signals only pre arranged messages could only be sent where a particular signal meant only one type of message. The invention of the telegraph by Samuel Morse in 1838 ushered in a new epoch in communications -the era of electrical communication [3]. In the ensuing years an increasingly larger portion of electromagnetic spectrum from 1 kHz to 100 GHz was utilized for conveying information from one place to another [4]. The trend in electrical communication systems development was to employ progressively higher frequencies, which offer corresponding increase in band width or information capacity . This activity led to the birth of radio, TV, Radar, and microwave links in the line of sight communication category and twisted pairs, coaxial cables and waveguides for guided communication or terrestrial communication: An atmospheric channel or guided wave channel. However as both could not meet the demands for present day traffic in data and information, optical transmission promised to be the hope for the present day communication needs. An important portion of electromagnetic spectrum encompasses the optical region, i.e. Infrared, visible, and ultra-violet regions, whose wavelengths are in the order of a few micrometers to few nanometers. The advantage of using light as carrier is due to its large frequency. When wavelength of light is converted into frequency, it will be in the region of 10^{14} to 10^{15} Hz. Even if 0.1 % of it is used for modulation purpose, we can show that up to 100 million audio channels or up to 100 thousand video channels can be transmitted on a single optical carrier. The present day optical communication technology aims at transmitting a large amount of data and information to meet the growing demand for band width in the existing channels of transmission. In the case of electric signal transmission we had both line and radio communication. Similarly in optical communication, we have two modes of transmission, namely guided wave transmission (Fiber optic communication) and Line Of Sight (LOS). Whereas the atmospheric channel can be used for transmitting a large amount of data and information to meet the growing demand for band width in the existing channels of transmission. In the case of electric signal transmission we had both communication between ground and satellite, satellite and ground, satellite and satellite, r even satellite to underwater, it is not suitable for terrestrial communications. The guided wave transmission or fiber optic communication is best suited for this purpose. To use light as a carrier, for transmission of large bandwidth signals, was not possible till the invention of laser in 1960 By T .H. Maiman. Whereas ordinary light is non-monochromatic and incoherent the laser light is monochromatic and coherent. With these two wonderful properties of light combined with the ability to modulate the light beam with the required information, it became possible to have the kind of light wave communication systems as we have today. The bit rate and distance product measures the transmission capacity of any communication channel. Since the inception of optical fiber communication in 1974, their capacity has increased ten folds every four years. Several

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major technology growths had spurred their growth. The four key technology areas, which have undergone tremendous advances in the last few years, are: the fiber, the optical source, the detector and the optical amplifier. The first generation links operated at around 850 nm, which was a low loss transmission window of early silica fibers. These links used then existing Gallium Arsenide (Ga As) based optical sources, silicon photo detectors, and multimedia fibers. Intermodal dispersion and fiber loss, which will be discussed in the next section, limited the capacity of these systems. Some of the initial telephone system field trials in the USA were carried out in 1977 by GTE in Los Angeles [6] AND BY AT&T in Chicago [18]. Links similar to these were demonstrated in Europe and Japan. Intercity applications ranged from 45 to 140 Mb/s with repeater spacing of around 10 km. The development of optical sources and photo detectors capable of operating at 1300 nm, resulted in a substantial increase in the repeater less transmission distance for long haul telephone trunks, since optical fibers exhibit lower attenuation and less signal dispersion at 1300 nm. Earlier inter city application first used multimode fibers but in 1984 switched exclusively to single mode fibers, which have a significantly larger bandwidth. Both multimode and single mode 1300 nm fibers are used in local area networks where bit rates range from 10 to 100 Mb/s over distances ranging from 500 m to tens of kilometers [15, 21]. Systems operating at 1550 nm provide the lowest attenuation, but have much larger signal dispersion than at 1300 nm. Fiber manufacturers overcame this limitation by creating the so-called dispersion shifted fibers. Thus 1550 nm systems attracted much attention for high capacity long span terrestrial and undersea transmission links [12, 22]. These links routinely carry traffic at around 2.5 Gb/s over 90 km repeater less distances. By 1996, advances in high quality lasers and receivers allowed single wavelength transmission rates of around 10 Gb/s. The introduction of optical amplifiers in 1989 gave a major boost to fiber transmission capacity. Although Gallium Aluminum Arsenide (Ga Al As) based solid state optical amplifiers appeared first [25], the most successful and widely used devices are erbium doped fiber amplifiers (EDFAs) operating around 1550 nm [5]. During the same time period, long distance high capacity systems were made using optical soliton signals. As an example solitons at the rate f 10 Gb/s were sent over a 12, 200-km experimental link using optical amplifiers and special modulation techniques [8]. The use of wavelength division multiplexing (WDM) offers a further boost in fiber transmission capacity [14]. Starting in mid 1990s a combination of EDF As and WDM was used to boost fiber capacity to even higher bit rate levels and to increase the transmission distance. A detailed discussion of all the topics will be beyond the scope of the present paper due to limitation of space. Therefore only a brief review of the development of fibers, sources, detectors, and optical amplifiers to meet the increasing demand for high data rate Long haul optical communication systems will be discussed in the following sections. Wherever possible references are given. A list of textbooks where most of the material is available is also given at the end.

2 Optical Link

An optical fiber transmission link comprises of the elements shown in Figure 1. The key sections are a transmitter consisting of light source, which can be modulated either by an analog or digital signal, an optical fiber, a receiver consisting of photo detector with associated amplifier and signal processing circuits. Additional components include optical amplifiers, connectors, splices, couplers and regenerators.

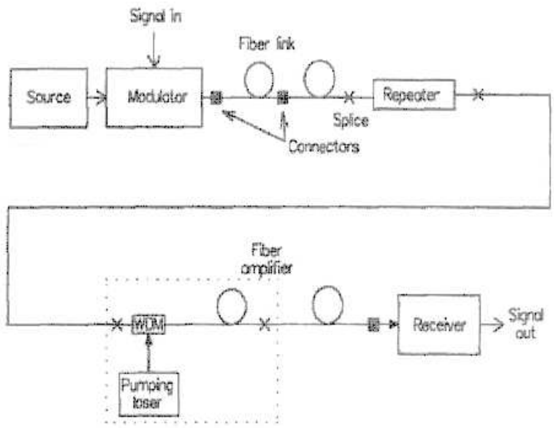

Figure 1: Elements of an optical fiber transmission link

3 Optical Fiber

One of the most important components in any optical fiber system is the optical fiber itself since the transmission characteristics play a major role in determining the performance of the entire system. In this topic we shall briefly discuss the structure of an optical fiber, the propagation of light along the fiber, the materials for fabrication, the signal loss or attenuation mechanism and distortion or dispersion mechanism in the optical fibers.

3.1 Fiber Type

An optical fiber is a dielectric wave-guide that operates at an optical frequency. It confines electromagnetic direction parallel to its axis. The structure basically determines the information carrying capacity of the fiber and also influences the response of the waveguide to environmental energy in the form of light to within its surfaces and guides the light in the fluctuations. The most widely used structure is the single solid dielectric cylinder of radius a, and refractive index n_1. This cylinder is known as core of the fiber. The core is surrounded by another solid dielectric called cladding with a refractive index n_2, that is less than n_1. Although in principle a cladding is not necessary for light to propagate along the core of the fiber it serves several purposes. The cladding reduces scattering losses, it adds mechanical strength, and it protects the core from contamination and most importantly the amount of dispersion is reduced. The physical principle on which the propagation of light in optical fiber depends is the well known principle of total internal reflection, due to which the light rays are confined to the core. To improve the performance of optical fiber with reference to the signal dispersion, which we discuss below, the optical fibers are fabricated in three different configurations. These are:

a) Step index multimode fibers,

b) Graded index multi mode fibers and

c) Single mode fibers. It is enough to say here that the dispersion decreases as we go from a to c.

3.2 Signal Attenuation

Signal attenuation also known as fiber loss or signal loss is one of the basic attenuation mechanisms in a fiber are absorption, scattering, and radiative losses of the optical energy [13, 11]. Absorption is related to the fiber material, where as scattering is related to both the fiber material and with structural imperfections in the optical wave-guide. Attenuation due to radiative effects originates from perturbations (both microscopic and macroscopic) of the geometry. Another important parameter on which the attenuation depends is the wavelength of light being transmitted through the fiber. The core of the fiber should have a slightly more refractive index than the cladding, t o get this small variation in refractive index, small amounts of dopants are added to the silica to vary the refractive index. Germanium oxide (Ge O_2) and phosphorous pentoxide (P_2 O_5) will increase the refractive index and Beryllium oxide (B_2 O_3) and Fluorine (F) will decrease the refractive index. Therefore various combinations of pure silica with the doping material and wavelength three wavelength windows have been identified for fabrication of optical fibers. If a fiber has been identified to transmit in a particular window other system components have to match the properties of the fiber. These three wavelengths are 850 nm, 1330 nm, and 1550 nm. It may be noted that the attenuation coefficients are reduced from about 3 db/km in the first window region to about 0.2 db/km in most important properties of an optical fiber, because it largely determines the maximum unamplified or repeaterless separation between a transmitter and a receiver. Since amplifiers and repeaters are expensive to fabricate, install and maintain, the degree of attenuation in a giber has large influence on system cost. The third window region and the development of the fiber optic communication systems is the progressive development in that direction.

3.3 Dispersion

Since all optical fibers exhibit dispersion or pulse broadening phenomenon, it is necessary to know about it. Dispersion in fibers is of two types:

i) Inter modal and

ii) Intra-modal.

The first is due to the propagation of the same wave length rays in the core of the fiber along different path lengths. This evidently becomes predominant in wide core and step index fibers, in which the refractive index changes suddenly from core to cladding. It is considerably reduced in graded index fibers, where the refractive index in the core follows a certain profile gradually changing from the center of the core to its periphery where the refractive index equals that of the cladding. This becomes insignificant for single mode fibers, where the core is made so thin that only a single mode propagates, using narrow spectral width sources. The intramodal dispersion can again be divided into two types namely the material dispersion and wave-guide dispersion. The velocity of light being a function of wavelength causes material dispersion. The non zero spectral width implies that even with single mode propagation the longer wavelengths with their faster velocities will arrive at the receiver before the shorter wavelengths, thereby stretching the pulse. Thus the material dispersion depends upon the spectral width of the source and hence laser sources width of the narrow line width cause much less dispersion than LED sources as discussed under sources. Waveguide dispersion results from the propagation constant of a mode and hence its velocity being a function of the ratio of the diameter of the core of the fiber and the wavelength. For low material dispersion region near 1.3 μm, the waveguide dispersion becomes more important. This is negligible for multimode fibers and in single mode fibers operated below 1 μm. The combined effect of attenuation and dispersion is a point of interest to get maximum unrepeatered distances with maximum bit rate. It is found that the lowest attenuation occurs at a wavelength of 1500 nm and lowest dispersion occurs at 1300 nm. Since these two wavelengths occur near to each other, it has become the goal of researchers to combine the features so that optimum performance in terms of bandwidth and loss occurs at the same wavelength. Of the two parameters dispersion is the most adjustable and is the one that is manipulated. This manipulation has led to two adjustments; one is to move the dispersion wavelength called dispersion shifting to higher values in the vicinity of 1550 nm and the other is to minimize or flatten the dispersion over a range of wavelength values called dispersion flattening. Multi-layer profiles have been used successfully to flatten the dispersion characteristics of fibers. The dispersion shifted fibers could attain a low loss of 0.17 dB/km at 1550 nm [1].

4 Optical Sources

Optical source is the device, which has to be modulated by an electrical signal. For optical communications the main sources are LEDs or laser diodes (LDs). LEDs are used with short haul, low bit rate communication systems, whereas laser diodes are used for long haul high bit data links. The source characteristics have to meet the desired transmission window and the core diameter of the fiber to be attached. Sources are currently classified according to wavelength. Earlier sources in the 850-nm region were fabricated using Gallium Arsenide (Ga As) as substrate and with different layers of Gallium Aluminum Arsenide (Ga Al As). The structure is same as that of a laser diode, which is discussed in the next section. The present day sources are for 1300 nm and 1550 nm regions are being fabricated using quaternary semiconductor blends such as Indium Gallium Arsenide Phosphide (In Ga As P). The devices are basically forward biased semiconductor junctions. The materials are a combination of direct and indirect band gap opto-electronic materials, which can produce photons (light) when they are forward biased. The typical device structures are homojunction structure and hetero junction structure. The main aim of these structures is what is known as carrier confinement and light confinement. The carrier confinement aims at reducing charge density required to produce light or other words to improve quantum efficiency of the device and the light confinement aims at reducing the divergence of the beam.

4.1 LEDs

In the case of LEDs two types of configurations have become popular [20]. They are surface emitters and edge emitters. The surface emitter is also called Burrus LED. The surface emitters are widely used in multimode fiber systems, since the wide-angle beams produced by them are more efficiently coupled into multimode fibers. Edge emitting LEDs remove light along an axis transverse to the current flow, as shown in Figure 2.

The insulating Si O_2 layer has a stripe hole in it that guides the current down into the active region, laterally confining the current. The typical width of the active region of an edge emitter is 50 to 70 μm, chosen to match the core size of multimode fibers. The combined structure of the five layers makes an effective optical waveguide. Thus optical confinement is achieved and with both optical and electrical confinement the efficiency of the device increases. The above structure is called Double Hetero (DH) Structure. Typically, LEDs used in fiber communications, produce power levels of several hundreds of microwatts of optical power that can be coupled into the fiber. For low drive currents the out power is a linear function of current. Linearity is important to allow faithful analog modulation of the out put power by direct current modulation. The spectral width of the source is important because it determines the contribution to the material dispersion. Typical LED spectral widths can be in the order of 100 nm for a surface emitting LED and of the order of 60-80 nm for edge emitter [26]. The modulation band -width depends upon the speed of response of an LED, which in turn depends on the LED rise time. The speed of response of an LED depends on several factors. At low drive current levels, the speed can be increased by increasing the doping levels. At high current levels the speed can be improved by decreasing the thickness of the active region. We can trade off between high output power and high speed in the case of LED. In summary we can conclude that LEDs are typically suitable for systems using multimode fibers requiring less than 50 Mb/sinformation rates. They are relatively cheaper and robust and do not require complicated circuitry for biasing and modulation.

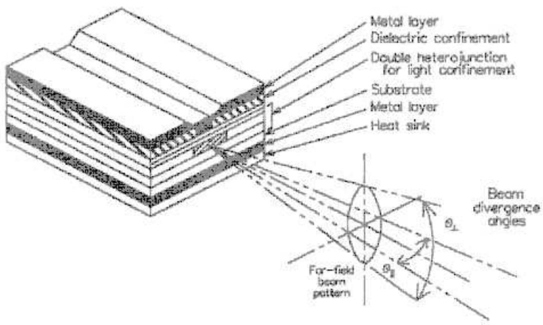

Figure 2: Edge emitting LEDs

4.2 Laser Diode Sources

Laser diode (LD) sources produce more power than an LED, have a narrower spectrum, and can couple more power into a fiber. The structure of a LD is much like that of an edge-emitting LED. The principle difference between an edge emitting LED and the edge emitting laser is that in the laser, the active region is thinner vertically and narrower horizontally. In addition multi layer reflectors are added to the ends of the structure to provide optical feed back. This feed back is required for laser action in which the stimulated emission is the main factor that differentiate the non coherent light produced by LED to coherent light produced by LD. DH structures are used to provide both charge confinement and optical confinement. Additional structures are incorporated to confine the current and the light laterally. The typical diode laser emitting region at the output face is 150 to 500 μm long by 5 to 20 μm across by 0.1 to 0.2 μm high. These dimensions give the beam pattern an asymmetric field pattern with a perpendicular beam divergence of 30 to 50^0 and parallel beam divergence of 5 to 10^0 . This latter value is about one fifth of the comparable value of an edge emitting LED and implies that the laser beam pattern is more directional than the LED. This directionality is beneficial in trying to couple the light into optical fibers.

4.3 Laser Power Characteristics

The drive mechanism that operates the laser is the current through the forward biased device. When the drive current is small the diode is not lasing and operating as an LED, emitting a small amount of incoherent light. When the current exceeds a certain limit called the threshold current the stimulated emission starts and the diode is lasing and the output is a coherent radiation with a very narrow beam width and spectral width. The threshold current is a very important parameter of the LD and the designs of the laser diode is aimed at reducing this threshold current and there by increase the efficiency of the laser. Several structures are devised to achieve this. All these structures aim at confining electrical carriers to a narrow region and also confine the optical radiation in a narrow region. The first step in that direction has been the use of a metallic stripe to confine the carriers. This is called stripe geometry laser diode. The mechanism of providing lateral wave guiding with the change in the refractive index caused by the current carriers is called gain guiding. Other techniques used in gain guiding are proton bombardment or providing a v-shaped groove [2]. In another type of lasers dielectric waveguide structures are fabricated in the lateral direction. The variations in the refractive index of the various materials in these structures control the lateral modes in the laser. Thus, these devices are called index-guided lasers. If a particular index guided laser supports only one longitudinal mode and one transverse mode it is known as single mode laser. Such a single mode laser emits a single well collimated beam of light that has a Gaussian intensity distribution. High performance laser diodes have been made using different techniques of index guiding [24].

4.4 Quantum Well Lasers

Although the active layer in a standard DH laser is very thin (1-3 μm) to confine electrons and the optical field, the electronic and optical properties remain the same as in the bulk material. This limits the achievable threshold current density, modulation speed and line width of the device. Quantum well lasers overcome these limitations by having an active layer thickness of about 10 nm [23]. Both single quantum well (SQW) and multiple quantum well (MQW) lasers have been fabricated. The MQW lasers have better optical confinement, resulting in lower threshold current density . The operating wavelength of the MQW laser can be changed by adjusting the layer thickness.

4.5 Single Mode Lasers

As mentioned earlier the single mode laser emits a very good optical beam. These lasers are used for high speed long distance communications. One way of achieving the single mode operation is to reduce the length of the laser cavity . But the reduction of cavity length limits the optical power output. Therefore alternate devices are developed. These are Vertical Cavity Surface emitting lasers (VCSL), structures that have a built in frequency selective grating and tunable lasers. In the VCSL [16]. the light emission is perpendicular to the surface. The active region volume of these devices is very small, which leads to very low threshold currents of less than 100 μA. In addition modulation bandwidths are much greater. There are three types of configurations in the category of lasers using the frequency selective gratings. These are distributed feed back (DFB) laser, distributed back reflector (DBR) laser and distributed reflector (DR) laser [10]. The last one has a high efficiency and high output capability when compared to the other two.

5 Photodetectors

At the output end of an optical fiber, there must be a receiving device, which interprets the information content of the optical signal. The first element of this receiver is a photodetector. The photodetector senses the light power falling upon it and converts the variation of this optical power into a varying current. Since the optical signal is generally weakened and distorted when it emerges from the end of the fiber, the photo detector must meet very high performance requirements. Among the most important are: a high responsivity or sensitivity in the emission wavelength of optical source, a minimum addition of noise to the system and a fast response speed or sufficient bandwidth to handle the desired dimensions of the optical fiber, have a reasonable cost in relation to the other components of the system, and have a long operating life. Out of the several types of the photodetectors in existence the semiconductor based photodetector, the photodiode is used most commonly for fiber optic systems because of its small size, suitable material, high sensitivity, and fast response time. The two types of photodiodes used are the pin photodiode and the avalanche photodetecte

(APD). We shall examine the fundamental characteristics of these two devices and their developments in the following subsections.

5.1 The Pin Photodiode

The most common semiconductor photodiode used in fiber optic communication is the p i n photodiode. It is called so because of its structure, in which a very lightly doped n layer called intrinsic layer is sandwiched between the p and n layers. When an incident photon has an energy greater than or equal to the band gap energy of the semiconductor material, the photon can give up its energy and excite an electron from the valance and to the conduction band. This process generates free electron hole pairs which are known as photo carriers. The photo detector is normally designed so that these carriers are generated mainly in the depleted intrinsic region where most of the incident light is absorbed. The high electric field present in the depletion region causes the carriers to separate and be collected across the reverse biased junction. This gives rise to a current flow in an external circuit, with one electron flowing for every carrier pair generated. This current flow is known as the photo current. The optical radiation absorbed will depend upon the absorption coefficient of the material, which in turn depends upon the wavelength. Therefore different materials are required for detecting photons at different wavelengths. Silicon has a cut off wavelength of 1.13 μm and is a suitable detector material for short wavelength sources (850 nm). In the long wave length regions the preferred semiconductor material for photodetectors is In Ga As. The next property for a good detector is the sensitivity . This can be represented as quantum efficiency or responsivity . Both these quantities basically tell us as to how much photocurrent is generated by application of a given amount of optical power. This will depend upon the material band gap, the operating wavelength and the doping levels in the p and n regions and thickness of these layers. Typical pin photodiode responsivities are 0.65 A/W for silicon at 900 nm, 0.45 A/W for germanium at 1300 nm and 0.9 A/W at 1300 nm, and 1.0 A/W at 1550 nm for In Ga As.

5.2 The Avalanche Photodiode (APD)

The avalanche photodiodes internally multiply the primary signal photo current before it enters the input circuitry of the following amplifier. This increases receiver sensitivity, since the photocurrent is multiplied before encountering the thermal noise associated with the receiver circuit. In order to achieve carrier multiplication the photo generated carriers must traverse a region where a very high electric field is present. A commonly used structure for achieving carrier multiplication with very little excess nose is the reach-through construction [9]. The photodiode so constructed is called a reach-through avalanche photodiode (RAPD). Compared to pin photodiode the responsivity of an APD is M times more where M is the photocarrier multiplication factor.

5.3 Photodetector Noise

In fiber optic systems the photodiode is generally required to detect very weak optical signals. Detection of the weakest signals is generally requires that the Photodetector and its following amplification circuitry be optimized so that a given signal to noise ratio is maintained. The power signal to noise ratio at the output of an optical receiver is defined by

$$S/N = \frac{Signal\, power\, from\, photo\, current}{Photodetector\, noise\, power + amplifier\, noise\, power} \quad (1)$$

To achieve a high signal to noise ratio the

a) Photodetector should have a high quantum efficiency to generate a large signal power

b) the photodetector and amplifier noises should be kept as low as possible.

The principle noises associated with photo detectors that have no internal gain are quantum noise, dark current noise generated in the bulk material of the photodiode and surface leakage current noise. The excess noise factor depends on the material used for the construction of the APD, and it is minimum for silicon where as it is maximum for Ge. In Ga As avalanche photodiodes have an excess noise factor which is higher than Si but as it is the best material for 1300 nm and 1550 nm regions special fabrication structures are used for In Ga As APDs to improve their performance. Two of structures are separate absorption and multiplication (SAM) APD configuration [7] and superlattice structure [17]. These structures are used to increase the response time and bandwidth of the devices. The superlattice structure has improved the device allowing its use for application in 10 Gb /s long distance systems such as SONET OC-192/SDH STM-64 links.

5.4 Detector Response Time

The frequency response of the photo diode depends on the response time. The response time of a photodetector together with its output circuit depends mainly on the following factors:

a) The transit time of the photocarriers in the depletion region

b) The diffusion time of the photo carriers generated outside the depletion region

c) The RC time constant of the photodiode and its associated circuit.

The photodiode parameters responsible for these three factors are the absorption coefficient of the material, the depletion region width, the photodiode junction capacitance, the package capacitance, and the photodiode series resistance. It will be seen that decreasing the depletion layer width of the photodiode can reduce the response time. But this will reduce the quantum efficiency, and hence in the design of the detector a compromise is made between the two. The comparison of the two types of detectors at different wavelengths are given in the following Table 1.

6 Optical Amplifiers

Optical amplifiers, as their name implies, operate solely in the optical domain with no inter conversion of photons to electrons. Therefore, instead of using regenerative repeaters which, as currently implemented, require optoelectronic devices for source and detector, together with substantial electronic circuitry for pulse slicing, retiming and shaping, optical amplifiers can be placed at intervals along a fiber link to provide linear amplification of the transmitted optical signal. The optical amplifier, in principle, provides a much simpler solution in that it is a single in-line component, which can be used for any kinds of modulation at virtually any transmission rate. Moreover, such a device can be bi-directional and if it is sufficiently linear it may allow multiplex operation of several signals at different optical wavelengths (i.e. wavelength division multiplexing). In particular with single-mode fiber systems, the effects of signal dispersion can be small and hence the major limitation on repeater spacing becomes attenuation due to fiber losses. Such systems do not require full regeneration of the transmitted digital signal at each repeater, and optical amplification of the signal proves sufficient. Hence over recent years optical amplifiers have emerged as promising network elements not just for use as linear repeaters but as optical gain blocks, optical receiver preamplifiers and, when used in a nonlinear mode, as optical gates, pulse shapers and routing switches. The two main approaches to optical amplification to-date have concentrated on semiconductor laser amplifiers which utilize stimulated emission from injected carriers and fiber amplifiers in which gain is provided by either stimulated Raman or Brillouin scattering or by rare earth dopants. Both amplifier types (i.e. semiconductor and fiber; specifically rare earth and Raman) have the ability to provide high gain over wide spectral bandwidths, making them eminently suitable for future optical fiber system applications. Comparing the typical gain profiles for various optical amplifier types based around the 1.5 μm wavelength region, it may be observed that the in GaAsP travelling wave semiconductor laser amplifier (TWSLA), the erbium doped fiber amplifier and the Raman fiber amplifier all provide wide Spectral bandwidths. Hence these optical amplifier types lend themselves to applications involving wavelength division multiplexing. By contrast, the Brillouin fiber amplifier has a very narrow spectral bandwidth, possibly around 50 MHz and therefore cannot be employed for wideband amplification. It could, however, be used for channel selection within a WDM system by allowing amplification of a particular channel without boosting other nearby channels. Whereas semiconductor laser amplifiers exhibit low power consumption and their single-mode waveguide structures make them particularly appropriate for use with single-mode fiber, it is fiber amplifiers which present fewer problems of compatibility for in-line interconnection within optical fiber links. At present, semiconductor laser amplifiers are the most developed optical amplifier generic type but research into fiber amplifiers has also made rapid progress towards commercial products over the last few years.

6.1 Semiconductor Laser Amplifiers

The semiconductor laser amplifier (SLA) is based on the conventional semiconductor laser structure where the output facet reflectivities are between 30 and 35. SLAs can be used in both nonlinear and linear modes of operation. Various types of SLA may be distinguished including the resonant or Fabry-Perot amplifier which is an oscillator biased below oscillation threshold, the travelling wave (TW) and the near travelling wave (NTW) amplifiers, which are effectively single pass devices. The injection locked laser amplifier, which is a laser amplifier, designed to oscillate at the incident signal frequency. Such devices are capable of providing high internal gain.

6.2 Fiber Amplifiers

In a fiber amplifier the gain medium normally comprises a length of single-mode fiber connected to a dichroic coupler (i.e. a wavelength division multiplexing coupler) which provides low insertion loss at both signal and pump wavelengths. Excitation occurs through optical pumping from a high power solid state semiconductor laser which is combined with the optical input signal within the coupler. The amplified optical signal is therefore emitted from the other end of the gain medium. The types of fiber amplifiers are rare earth doped fiber amplifiers, Raman fiber amplifiers and Brillouin fiber amplifiers. But of these types erbium doped fiber amplifiers (EDFAs) are becoming more common for use in 1.55 μm systems.

7 Conclusion

The inherent advantages of fiber optic technology are immunity to RFI, EMI, ground loop currents and to a large extent

Characteristic	Pin diodes			APDs	
	Silicon	Germanium	In Ga As	Silicon	Germanium
$\lambda(\mu m)$	0.4-1.1	0.5-1.8	1.0-1.5	0.4-1.1	0.5-1.65
Quantum efficiency	80%	50%	70%	80%	75%
Rise time (ns)	0.01	0.3	0.1	0.5	0.25
Bias voltage	15	6	10	170	40
Responsivity (A/W)	0.5	0.7	0.4	0.7	0.6
Gain	1	1	1	80-150	80-150

Table 1: Comparison of the two types of detectors at different wavelengths

to nuclear radiations, coupled with the additional unique advantage of large bandwidth transmission capabilities, low weight, cost and use of inexhaustible raw material (silica). This makes fiber optic technology as a forerunner in the field of communications. It would ultimately replace coaxial transmission completely. To use this new technology for transmission of signals both in analog and digital formats, for short haul low bit rate signals or long high bit rate signals special attention has to be given in the selection of the four basic components namely the fiber, source, detector, and the amplifier. In the foregoing sections an attempt has been made to briefly discuss the progressive development of the above four components to meet the present day demand for high data rate long haul communication systems.

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