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Optical Fiber: The New Era of High Speed Communication (Technology, Advantages and Future Aspects)

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Abstract:- This paper deals with the Basic communication model and the types of fibers for the optical fiber communication system. Then the different technologies in optical fiber communication along with their features are discussed briefly. Some comparisons of optical signals with the traditional electrical signals are explained concisely. Finally the general system of optical fiber communication is briefly mentioned along with its advantages and limitations. The future aspects of the Optical Fiber is also shows that how the new technology can be overcome the shortcomings of the old one.

Keywords:- Transmission windows, Wavelength Division Multiplexing, Chromatic Dispersion, Semiconductor Laser Transmitters, VCSEL (Vertical Cavity Surface Emitting Laser), DFB (Distributed Feed Back), Bandwidth–distance product, Wavelength-division multiplexing (WDM)

I. INRTODUCTION

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed fiber-optic communication systems have revolutionized the telecommunications industry and have played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, optical fibers have largely replaced copper wire communications in core networks in the developed world. The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

II. BASIC OPTICAL FIBER COMMUNICATION SYSTEM

The basic components in the optical fiber communication system are shown in fig. The input electrical signal modulates the intensity of light from the optical source. The optical carrier can be modulated internally or externally using an electro-optic modulator (or) acousto-optic modulator. Nowadays electro-optic modulators are widely used as external modulators which modulate the light by changing its refractive index through the given input electrical signal. In the digital optical fiber communication system, the input electrical signal is in the form of coded digital pulses from the encoder and these electric pulses modulate the intensity of the light from the laser diode or LED and convert them into optical pulses. In the receiver stage, the photo detector like avalanche photodiode (APD) or positive-intrinsic negative (PIN) diode converts the optical pulses into electrical pulses. A decoder converts the electrical pulses into the original electric signal.

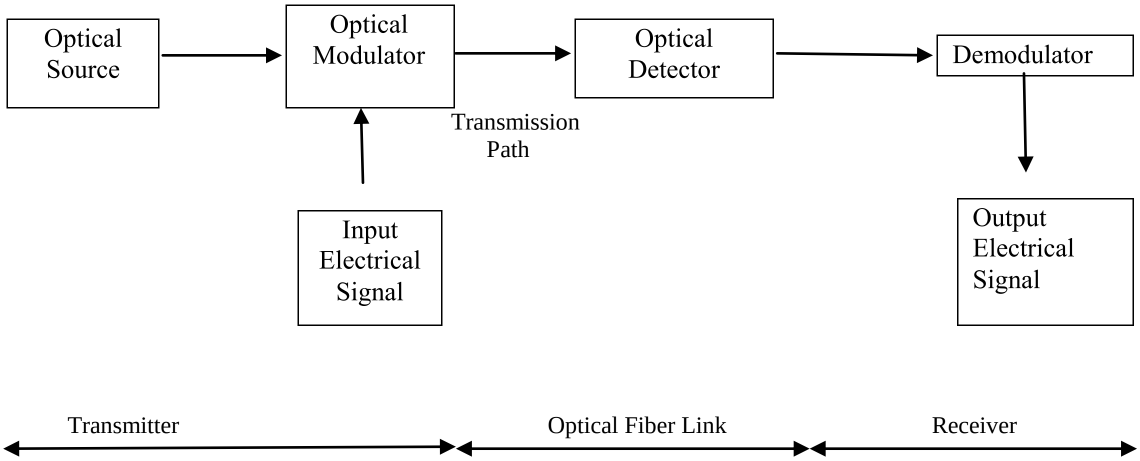

Figure: Basic analog optical fiber communication system.

III. FIBER TYPES

A typical glass fiber consists of a central core glass (50 mm) surrounded by a cladding made of a glass of slightly lower refractive index than the core's refractive index. The overall diameter of the fiber is about 125 to 200 mm. Cladding is necessary to provide proper light guidance i.e. to retain the light energy within the core as well as to provide high mechanical strength and safety to the core from scratches. Based on the refractive index profile two types of fibers are:

i. Step index fiber

In the step index fiber, the refractive index of the core is uniform throughout and undergoes an abrupt or step change at the core cladding boundary. The light rays propagating through the fiber are in the form of meridional rays which will cross the fiber axis during every reflection at the core cladding boundary and are propagating in a zigzag manner.

ii. Graded index fiber

In the graded index fiber, the refractive index of the core is made to vary in the parabolic manner such that the maximum value of refractive index is at the centre of the core. The light rays propagating through it are in the form of skew rays or helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical (or) spiral manner. Based on the number of modes propagating through the fiber, there are multimode fibers and single mode fibers. Mode is the mathematical concept of describing the nature of propagation of electromagnetic waves in a waveguide. Mode means the nature of the electromagnetic field pattern (or) configuration along the light path inside the fiber. In metallic wave-guides there are transverse electric (TE) modes for which Ez = 0 but Hz 6= 0 and transverse magnetic (TM) modes for which *Hz* =0 but *Ez* 6=0 when the propagation of microwaves is along the *z*-axis. In optical fibers, along with TE and TM modes, there are also hybrid modes which have both axial electric and magnetic fields Ez and Hz.

IV. TECHNOLOGY

Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.

i. Transmitters

The most commonly used optical transmitters are semiconductor devices such as light-emitting diodes (LEDs) and laser diodes. The difference between LEDs and laser diodes is that LEDs produce incoherent light, while laser diodes produce coherent light. For use in optical communications, semiconductor optical transmitters must be designed to be compact, efficient, and reliable, while operating in an optimal wavelength range, and directly modulated at high frequencies. The output of a laser is relatively directional, allowing high coupling efficiency (~50 %) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. Furthermore, semiconductor lasers can be modulated directly at high frequencies because of short recombination time. Commonly used classes of semiconductor laser transmitters used in fiber optics include VCSEL (Vertical Cavity Surface Emitting Laser), and DFB (Distributed Feed Back). Laser diodes are often directly modulated, that is the light output is controlled by a current applied directly to the device. For very high data rates or very long distance *links*, a laser source may be operated continuous wave, and the light modulated by an external device such as an electro-absorption modulator eliminating laser chirp, which broadens the linewidth of directly modulated lasers, increasing the chromatic dispersion in the fiber.

ii. Receivers

The main component of an optical receiver is a photo detector, which converts light into electricity using the photoelectric effect. The photo detector is typically a semiconductor-based photodiode. Several types of photodiodes include p-n photodiodes, p-i-n photo diodes, and avalanche photodiodes. Metal-semiconductor-metal (MSM) photo detectors are also used due to their suitability for circuit integration in regenerators and wavelength-division multiplexers. Optical-electrical converters are typically coupled with a Tran's impedance amplifier and a limiting amplifier to produce a digital signal in the electrical domain from the incoming optical signal, which may be attenuated and distorted while passing through the channel. Further signal processing such as clock recovery from data (CDR) performed by a phase-locked loop may also be applied before the data is passed on.

iii. Amplifiers

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. An alternative approach is to use an optical amplifier, which amplifies the optical signal directly without having to convert the signal into the electrical domain. It is made by doping a length of fiber with the rare-earth mineral erbium, and pumping it with light from a laser with a shorter wavelength than the communications signal (typically 980 nm). Amplifiers have largely replaced repeaters in new installations.

iv. Wavelength-division multiplexing

Wavelength-division multiplexing (WDM) is the practice of multiplying the available capacity of optical fibers through use of parallel channels, each channel on a dedicated wavelength of light. This requires a wavelength division multiplexer in the transmitting equipment and a demultiplexer (essentially a spectrometer) in the receiving equipment. Arrayed waveguide gratings are commonly used for multiplexing and demultiplexing in WDM. Using WDM technology now commercially available, the bandwidth of a fiber can be divided into as many as 160 channels to support a combined bit rate in the range of 1.6 Tbit/s.

v. Bandwidth–distance product

The value of a product of bandwidth and distance, because there is a tradeoff between the bandwidth of the signal and the distance it can be carried. For example, a common multi-mode fiber with bandwidth–distance product of 500 MHz·km could carry a 500 MHz signal for 1 km or a 1000 MHz signal for 0.5 km. In intensive development NEC scientists have managed to reach speed of 101 Tbit/s by multiplexing 370 channels over single fiber, while similar Japanese effort reached 109 terabits per second, but through a difficult production of cable with seven fibers. But this is barely matching the 50%-per-year exponentially increasing backbone traffic.

vi. Transmission windows

Each effect that contributes to attenuation and dispersion depends on the optical wavelength. The wavelength bands (or windows) that exist where these effects are weakest are the most favorable for transmission. These windows have been standardized, and the currently defined bands are the following:

Band	Description	Wavelength Range
O band	original	1260 to 1360 nm
E band	extended	1360 to 1460 nm
S band	short wavelengths	1460 to 1530 nm
C band	conventional ("erbium window")	1530 to 1565 nm
L band	long wavelengths	1565 to 1625 nm
U band	ultralong wavelengths	1625 to 1675 nm

This table shows that current technology has managed to bridge the second and third windows that were originally disjoint.

V. COMPARISON WITH ELECTRICAL TRANSMISSION

The choice between optical fiber and electrical (or copper) transmission for a particular system is made based on a number of trades-offs. Optical fiber is generally chosen for systems requiring higher bandwidth or spanning longer distances than electrical cabling can accommodate. The main benefits of fiber are its exceptionally low loss (allowing long distances between amplifiers/repeaters), its absence of ground currents and other parasite signal and power issues common to long parallel electric conductor runs (due to its reliance on light rather than electricity for transmission, and the dielectric nature of fiber optic), and its inherently high data-carrying capacity. Thousands of electrical links would be required to replace a single high bandwidth fiber cable. Another benefit of fibers is that even when run alongside each other for long distances, fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines. Fiber can be installed in areas with high electromagnetic interference (EMI), such as alongside utility lines, power lines, and railroad tracks. Optical fibers are more difficult and expensive to splice than electrical conductors. And at higher powers, optical fibers are susceptible to fiber fuse, resulting in catastrophic destruction of the fiber core and damage to transmission components. Nonmetallic all-dielectric cables are also ideal for areas of high lightning-strike incidence. In short distance and relatively low bandwidth applications, electrical transmission is often preferred because of its:

- Lower material cost, where large quantities are not required.
- Lower cost of transmitters and receivers.
- Capability to carry electrical power as well as signals (in specially designed cables).
- Ease of operating transducers in linear mode.

Because of these benefits of electrical transmission, optical communication is not common in short box-to-box, backplane, or chip-to-chip applications; however, optical systems on those scales have been demonstrated in the laboratory. Optical fiber cables can be installed in buildings with the same equipment that is used to install copper and coaxial cables, with some modifications due to the small size and limited pull tension and bend radius of optical cables. Optical cables can typically be installed in duct systems in spans of 6000 meters or more depending on the duct's condition, layout of the duct system, and installation technique. Longer cables can be coiled at an intermediate point and pulled farther into the duct system as necessary. In certain situations fiber may be used even for short distance or low bandwidth applications, due to other important features:

- Immunity to electromagnetic interference, including nuclear electromagnetic pulses (although fiber can be damaged by alpha and beta radiation).
- High electrical resistance, making it safe to use near high-voltage equipment or between areas with different earth potentials.
- Lighter weight—important, for example, in aircraft.

- No sparks—important in flammable or explosive gas environments.
- Not electromagnetically radiating, and difficult to tap without disrupting the signal—important in high-security environments.
- Much smaller cable size—important where pathway is limited, such as networking an existing building, where smaller channels can be drilled and space can be saved in existing cable ducts and trays.
- Resistance to corrosion due to non-metallic transmission medium.

VI. ADVANTAGES OF OPTICAL FIBER COMMUNICATION

i. Wider bandwidth

The information carrying capacity of a transmission system is directly proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the range 1013 to 1015 Hz while the radio wave frequency is about 106 Hz and the microwave frequency is about 1010 Hz. Thus the optical fiber yields greater transmission bandwidth than the conventional communication systems and the data rate or number of bits per second is increased to a greater extent in the optical fiber communication system. Further the wavelength division multiplexing operation by the data rate or information carrying capacity of optical fibers is enhanced to many orders of magnitude.

ii. Low transmission loss

Due to the usage of the ultra low loss fibers and the erbium doped silica fibers as optical amplifiers, one can achieve almost lossless transmission. In the modern optical fiber telecommunication systems, the fibers having a transmission loss of 0.002 dB/km are used. Further, using erbium doped silica fibers over a short length in the transmission path at selective points; appropriate optical amplification can be achieved. Thus the repeater spacing is more than 100 km. Since the amplification is done in the optical domain itself, the distortion produced during the strengthening of the signal is almost negligible.

iii. Dielectric waveguide

Optical fibers are made from silica which is an electrical insulator. Therefore they do not pickup any electromagnetic wave or any high current lightning. It is also suitable in explosive environments. Further the optical fibers are not affected by any interference originating from power cables, railway power lines and radio waves. There is no cross talk between the fibers even though there are so many fibers in a cable because of the absence of optical interference between the fibers.

iv. Signal security

The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a fiber in an easy manner. Therefore optical fiber communication provides hundred per cent signal security.

v. Small size and weight

Fiber optic cables are developed with small radii, and they are flexible, compact and lightweight. The fiber cables can be bent or twisted without damage. Further, the optical fiber cables are superior to the copper cables in terms of storage, handling, installation and transportation, maintaining comparable strength and durability.

VII. OPTICAL FIBER LIMITATIONS

- Optical Fiber cables have limited bend radius (about 30 mm). So, if they are bent more, it might lead to some signal loss. But recently, bend resistant fibers have been introduced which have higher tolerance to bending.
- Unlike Copper UTP cables which have standard Rj-45 Jacks and connectors (mostly), optical fiber cables have many types of connectors and this lack of standardization adds confusion.
- By bending the normal optical fiber cables, some leakage of signal could be induced and that can be used for hacking the information in them. So, even though doing that might be difficult, they are not totally tamper proof.
- Single mode cables and their associated optics (active components) are very expensive. Even though multi-mode cables/ optics are less expensive, they are not even close to the costs of copper UTP cables/ ports. Moreover, multi-mode cables have restrictions in distance for supporting higher bandwidth (like 1 Gbps and 10 Gbps).
- There are outdoor fiber cables but they need to be shielded well. This shielding makes them less agile/ flexible to run in all the places and it increases the cost of cables as well.
- Fiber cables cannot be directly terminated on to the network/ optical switches. They need a whole array of active/ passive components like SFP Modules, Fiber Patch Cords, and appropriate connectors and Couplers. All these components add the cost of fiber network implementation at each location.

VIII. FUTURE OF COMMUNICATION

i. Wireless through optical fiber.

Getting the most out of limited bandwidth will be more and more essential as wireless demands increase in the near future. One optical networking group at the Institute of Technology in Atlanta is showing how to get the most of wireless capacity and bandwidth by splitting wireless signals into separate components and then using optical fiber to carry wireless signals to their destination where they are re-integrated. The long-range linkages are provided by optical fiber, but the last few tens of meters are provided by wireless. The result: users can communicate wirelessly at a much higher bandwidth over a longer distance than is possible without using a fiber.

ii. Ratchting up data rates.

IBM has developed a transceiver capable of boosting chip-to-chip bandwidth on printed circuit boards to 300 Gigabits per second (Gb/s) – the fastest rate to date and a development that ultimately will enable even faster speeds for data transmission in homes and businesses. The device, assembled from relatively low-cost components that might someday be easily mass-manufactured, allows for a bi-directional data rate nearly twice that of an earlier generation IBM transceiver. This increased bandwidth is the result of two specific advances. First, the new transceiver includes 24 channels for sending and receiving data compared to 16 such channels in the previous device. Second, the modulation rate of each of the transceiver's vertical cavity surface emitting lasers (VCSELs) has been increased by 25 percent to 12.5 billion bits per second. In an effort to speed commercialization efforts, IBM has incorporated lasers and detectors that operate at the industry-standard wavelength of 850 nanometers (nm) instead of the proprietary 985-nn technology used in the earlier transceiver.

iii. Alternative routes on the information superhighway

Data transmission capacity has grown enormously in recent years, but so has the demand for this capacity. Although the band currently used for optical communication (1.5 micron wavelength) is sufficient for the moment, the enormous increase of traffic expected in the future demands that scientists and engineers begin exploring new bands now.

iv. A new view of the Electromagnetic Spectrum

The terahertz band is relatively unexplored and unexploited because its range of frequencies is too high for conventional electronics and too small for semiconductor lasers and detectors, but new research to be presented at OFC/NFOEC reflects what scientists have always known - the terahertz band has great potential. One of a faculty of Institute in Berlin will explore the use of the terahertz band for applications in security, medicine, and materials science and the role telecommunications technologies play in its developments. Terahertz radiation, unlike other scanning technologies, can penetrate materials like paper, clothing and plastics and remain harmless to humans. So, terahertz spectra can indicate explosives or analyze complex pharmaceutical substances where today’s technologies, such as X-rays, cannot.

IX. CONCLUSIONS

This paper discusses thoroughly about optical fiber communication system with its basic model and types. After that it tells about technology used and its differences with electrical transmission system which is traditional system. It discusses the advantages and various limitations of optical fiber communication system. Finally it shows all the future aspects which will be in the market, out of which some became obsolete and some are still in use for research and for developing general application.

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