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ABSTRACT

A crucial component of the global broadband networks' telecommunications backbone is fibre optic systems. In today's applications, a wide bandwidth signal transfer with less delay is essential. Optical fibres are presently the transmission medium of choice for long distance and high data rate transmission in telecommunication networks because they offer massive and unparalleled transmission bandwidth with little delay.A crucial component of the global broadband networks' telecommunications backbone is fibre optic systems. In today's applications, a wide bandwidth signal transfer with less delay is essential. Optical fibres are presently the transmission medium of choice for long distance and high data rate transmission in telecommunication networks because they offer massive and unparalleled transmission bandwidth with little delay.

Keywords: Optical Fiber, Communication Techniques, Optical Devices, Principle.

INTRODUCTION

An important piece of the global broadband network architecture is the optic fibre communication system [1]. Massive and distinctive transmission bandwidth is offered by optical fibres with barely perceptible latency. It is currently the transmission method of choice for long-distance transmission [2]. Some of the desirable qualities, such the high and quickly rising consumer and commercial interest in the restricted transmission of media, are the driving force behind the widespread acceptance and use of fibre optic communications [3,4].Fibre optics serve as the foundation of the telecommunications infrastructure and are perfect for gigabit transmission due to their characteristics [5]. Global demand for high data rates is rising, thus researchers are looking for different ways to supply gigabit capacity [6,7]. There are various sorts of optical communication networks [8]. For instance, the most current optical signal technique-based code division multiple access networks [9]. LI [10] provides a thorough review of the security aspects of the OICl physical layer.

Currently, optical communication has replaced other forms of communication due to the explosive rise of data services and the resultingly congested roads. Optical fibre communication, a novel communications technology, sparked a lot of attention right once due to its many benefits. It has a low loss, high communication capacity, immunity to electromagnetic interference, security, and other excellent benefits over conventional cable transmission.

According to optical fibre communication theory, there are two types of optical modulation: direct modulation and indirect modulation. To complete the process of a fibre optic communication, we must first transfer sound from the source, convert electrical signals, other images, and data into optical signals, and then transmit those signals through an optical fibre to the sink, where they must be received by light from the sink and converted back into electrical signals. Thus, when compared to fibre optic communication cable, there are two primary differences: the use of fibre optic cable as the transmission medium rather than employing an optical signal to transmit an electrical signal.

Because optical fibre communication technology has a wider frequency band and a larger load range than other materials, it can load more information capacity in a given amount of time. Additionally, optical fibre communication technology's transmission speed and quality are much higher than those of traditional cable and fibre optic cable, resulting in high specificity and effectiveness. The role that singles wavelength optical fibre communication technology can play in the applications of optical fibre technology is greater fibre wide range of load, bandwidth characteristics, greatly increase communications transmission capacity, enhance the effect of the underlying dense wavelength division multiplexing (DWDM), and improve the quality of information transmission.

Low-loss optical transmission fibres have without a doubt been essential to the huge success of optical communications technology, which has revolutionised our lives in many ways over the past forty years. Without a doubt, the phenomenal success of optical communications technology has been largely due to the use of low-loss optical transmission fibres. The so-called passive optical network was suggested for the already planned fiber-to-the-home

(FTTH) network in the telecommunications industry. The usage of passive optical splitters was critical to the operation of this network. These splitters were created using single-mode fibres (SMFs) that are commonly used.

Evolutionof Fiber Optics

Around 1975, the development of fiber-optic communication systems began. The first generation of light wave systems employed GaAs semiconductor lasers and operated in the 0.8 m range. Such devices were made commercially available in 1980 following a number of field tests conducted between 1977 and 1979 [11]. They could have up to 10 kilometres between repeaters and operated at a bit rate of 45 Mb/s. System designers were heavily influenced by the larger repeater spacing compared to coaxial systems' 1-km spacing since it reduced the installation and maintenance expenses related to each repeater.Early in the 1980s, the second generation of fiber-optic communication systems were available, however due to dispersion in multimode fibres, the early systems' bit rates were constrained to less than 100 Mb/s [12]. The adoption of single-mode fibres allowed for the elimination of this restriction.

History of Optical Fiber Development

After the first laser was demonstrated in May 1960, it was quickly labelled as a "solution in search of a problem." The ever-increasing demand for bandwidth in communications, brought on by greater telephone use, the relaying of television signals, and other forms of electronic data transmission, was to be addressed in this context by the laser. Coaxial cables, transmission lines, and radio frequency wireless were all used for direct signal transfer in data communications prior to the 1960s. These technologies were all severely constrained. Any system using metal wires experiences signal transmission losses, which sharply rise with data rate, necessitating the use of numerous repeaters for lengthy lines.

Basic Principles of Fiber Optic Communication

A fibre optic cable is used in fibre optic communication, which employs light pulses to transmit data from one location to another. Essentially digital information produced by computer systems, cable television providers, and telephone systems makes up the information conveyed. An optical fibre is a low-loss dielectric cylindrical waveguide typically constructed of silicon dioxide. Total internal reflection is used to steer light pulses along the fiber's axis since the waveguide's core has a refractive index that is somewhat higher than the cladding's [13].

The components of a fibre optic communication system include an optical transmitter to convert an electrical signal into an optical signal for transmission through an optical fibre, a cable made up of several bundles of optical fibres, optical amplifiers to boost the power of the optical signal, and an optical receiver to change the received optical signal back to the original transmitted electrical signal.

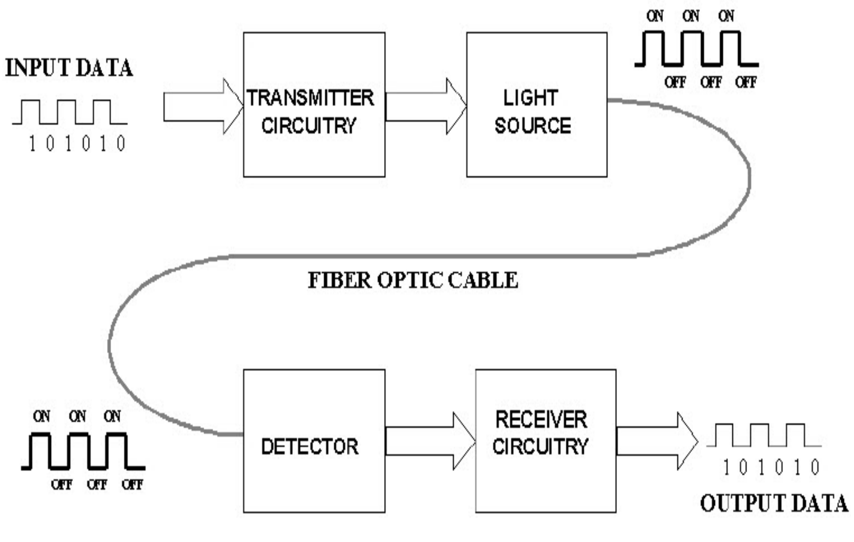

Fig.1. Basic fibre optic communication system [14]

Step index optical fibre, which includes single mode optical fibre and multimode optical fibre, and graded index optical fibre are the two main categories into which optical fibres can be divided. The core diameter of single mode step index optical fibre is less than 10 micrometres, and it only permits one light channel.

The core diameter of multimode step index optical fibre is more than or equal to 50 micrometres, allowing for many light channels that cause modal dispersion. Graded index optical fibres have a core refractive index that gradually decreases away from the core's centre. This increased refraction at the core's centre causes some light rays to travel more slowly, which allows all of the light rays to arrive at the receiver almost simultaneously and reduces dispersion.

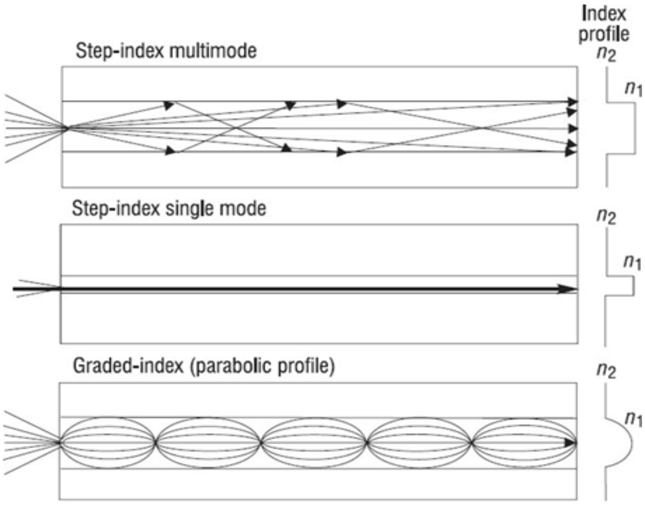

Fig. 2 Fiber Optic Modes [15]

Optical Devices

Planar Lightwave Circuits (PLCs) or Photonic Integrated Circuits (PICs), sometimes known as integrated optics, are advancing in the realm of optical communication devices. Integration has emerged as a key tool in the fight to lower optical device production costs, improve the functionality of telecommunications networks, and, ultimately, reduce the environmental impact of the amount of carbon emissions brought on by the use of electricity.

The advancement of optical circuits predicts that the current hybrid systems will be replaced by less expensive monolithic ones. The present hybrid integrated circuit technology mixes multiple discrete or integrated circuits that, when coupled together, carry out certain optical and electrical activities.

The passive and active circuit elements of future monolithic integrated circuits will be combined into a single optical chip. Integrating laser light sources, transmitters, modulators, and signal processing components (and vice versa, detectors, demodulators, and receivers) on a single semiconductor substrate is the goal of contemporary research. Optical receivers will continue to receive extra attention since they require cautious handling because their signals are the weakest across the entire telecommunications link.

Communication Techniques

Thus, increasing the transmission capacity of optical networks while also extending their range is the goal of continuing to develop optical communications. Coherent optical systems are used today, which is both fascinating and significant. This concept first surfaced in the early 1980s, however it later "disappeared" as a result of the development of optical amplifiers.

1. **Amplitude Shift Keying (ASK):** ASK modulates the amplitude of the optical signal to represent digital data. It is a simple and straightforward technique but is sensitive to noise and signal distortions.
2. **Frequency Shift Keying (FSK):** FSK modulates the frequency of the optical signal to encode data. It uses different frequencies to represent different binary states. FSK is less susceptible to noise than ASK.
3. **Phase Shift Keying (PSK):** PSK modulates the phase of the optical signal to convey information. It provides higher spectral efficiency compared to ASK and FSK but is more susceptible to phase distortions.
4. **Quadrature Amplitude Modulation (QAM):** QAM combines amplitude and phase modulation to transmit multiple bits per symbol. It provides high data rates and spectral efficiency by mapping multiple bits to a single symbol.
5. **Orthogonal Frequency Division Multiplexing (OFDM):** OFDM divides the available bandwidth into multiple narrow subcarriers and modulates each subcarrier independently using techniques like PSK or QAM. It enables efficient utilization of the spectrum and can mitigate the effects of dispersion and other impairments.
6. **Wavelength Division Multiplexing (WDM)**: WDM enables the transmission of multiple optical signals simultaneously by assigning each signal to a different wavelength. It allows for increased data capacity in optical fibers.
7. **Time Division Multiplexing (TDM):** TDM divides the time into discrete slots, and each slot is assigned to a different signal. It allows multiple signals to share the same fiber by transmitting them in different time slots.
8. **Code Division Multiple Access (CDMA):** CDMA uses unique codes to distinguish between different users sharing the same frequency band. It provides multiple access capabilities in optical communication networks.

CHARACTERISTICS OF OPTICAL FIBRE COMMUNICATION TECHNOLOGY

Anti-em interference capability

Quartz is frequently utilised as the primary component of the insulating material for optical fibres because it has strong insulation properties and can effectively shield the fibre. As a result, optical fibre network connection has better anti-electromagnetic interference capabilities than standard cable communication when it comes to information transmission. The quality and speed of information transfer are fully assured, especially in severe weather conditions and hostile environments. The optical fibre communication technology is also given improved accuracy as a result of the strong sensitivity of this insulating material to the unique acoustic signal[16].

Wide frequency band and large communication capacity

Invisible light with wavelengths of 850 nm and 1310 nm and a very high frequency is used in optical fibre transmission. As a result, compared to typical copper wire, the communication capacity is quite huge, and the information transmission rate is also greatly increased.

Low loss and cost savings

Currently, silicon dioxide is a common raw material for fibre in communication systems, and increasing the quality of glass fibre can significantly minimise fibre loss. The distance between relay stations can be increased due to the decline in optical fibre loss, which can significantly lower production costs and raise the calibre of information and communication services.

Good confidentiality

Since optical waves are primarily used in optical fibre communication to transmit signals, optical signal structures that are limited to optical wave guidance are completely confined to propagating in the fibre core, while other leaked light is absorbed by the cladding outside the fibre line, which will not produce electromagnetic radiation, in order to achieve the goal of preventing crosstalk and leakage[17].The spectrum of general electromagnetic radiation is very different from the spectrum of visible light, and it is challenging to reach the fibre core and interfere with the transmission of light data. As a result, common cable communication cannot compete with the confidentiality offered by optical fibre communication technology.

Rich Raw Material Resources

All kinds of electronic communication, whether wired or wireless, require a significant number of nonferrous metals, yet the glass silica used to make optical fibres is abundant on the planet and challenging to obtain materials for.

Light Weight and Small Size

The fibre only has a diameter of 50 micron, which is hardly larger than a human hair [18]. As a result, it is particularly practical for both packaging and transportation and can be finished when set alone. Lightweight, compact, free of bending, durable cable may be used on the plastic sheath surface, communication lines can be put on different types of terrain, and installation is very simple.

Advantages of Optical Fiber Communication

1. Huge potential bandwidth: Compared to the optical carrier frequency, metallic cables offer a smaller potential BW for transmission.
2. One of the features of optical fibre is its tiny diameter and light weight.
3. Electrical isolation: Glass or a plastic polymer are used to make optical fibres. Contrary to their metallic equivalent, these are electrical insulators and do not have earth loop or interface issues.
4. The security of signal: The high degree of protection of the signals is achieved because the optical fiber's light does not radiate significantly.

Disadvantages of Optical Fiber Communication

1. The exorbitant expense of installation.
2. Despite the low cost of fibre optics, the interfaces and connectors are rather expensive.
3. High-tech and specialised tools are used in the fibre optic repair and maintenance process. [19].

Applications of Optical Fiber Communication Technology

Application of Optical Fiber Communication Technology in Military Field

The military and economic development of modern China cannot be supported by traditional military communication network technologies. Military communication can be improved substantially by using optical fibre communication engineering technology, which can adapt to the complicated environmental conditions of various societal problems[20].

Application of Optical Fiber Communication Technology in Railway Communication

In addition to ensuring the consistency of information transfer, optical fibre communication technology can also increase its speed. Although optical fibre communication technology has just recently been used in railway transmission in China, it has many practical applications. Technology like wavelength division multiplexing, for instance, is frequently employed. To assure signal continuity, the railway department mostly uses it in low-level loss areas. Passengers can more fully enjoy online life since wavelength division multiplexing can expand communication channels [21].

Application of Optical Fiber Communication Technology in Power Communication

With the continued use of this technology in power communication, power communication can continue to advance in the direction of networks as the competition in the power enterprise industry has grown more aware of the crucial role that optical fibre communication information technology can play in power system communication [22].A lot of departments besides substations and the national grid employs optical fibre. Make sure the power supply arrives on time. Additionally, the use of optical fibre technology lessens the impact of outside factors on power communication and helps to lower the frequency of power accidents.

Application of Optical Fiber Communication Technology in Radio and Television

The television industry has heavily marketed optical fibre communication technologies, particularly in network television.On the one hand, radio and television use optical fibre communication technology as a carrier, which serves as a dependable platform for network transmission to assure the timely delivery of broadcast content. By effectively processing radio and television audio, video, and other information during the broadcast information processing, it is possible to deliver high-quality picture and sound for the public while also raising the bar for radio and television services.

Future Trends in Optical Fiber Communication

1. "Advancing Optical Fiber Communication: Exploring the Potential of Next-Generation Fiber Technologies".
2. "From Terabits to Petabits: Scaling Up Data Rates in Future Optical Fiber Communication Systems".
3. "Optical Fiber Communication in the Era of 6G: Enabling Ultra-Fast and Ultra-Reliable Wireless Networks".
4. "Harnessing the Power of Artificial Intelligence in Optical Fiber Communication Networks".
5. "Breaking the Transmission Barrier: Overcoming Nonlinear Effects in High-Speed Optical Fiber Communication".
6. "Green Optical Fiber Communication: Towards Energy-Efficient and Environmentally Sustainable Networks".
7. "Quantum Communications over Optical Fiber: Unlocking Unprecedented Security and Capacity".
8. "Flexible and Reconfigurable Optical Fiber Communication: Adapting to Dynamic Network Demands".
9. "Beyond Traditional Data Transmission: Exploring Optical Fiber Communication for Sensing and Imaging Applications".
10. "Integrating Photonics and Electronics: Bridging the Gap for Future Optical Fiber Communication Systems".

CONCLUSION

A significant component of the telecommunications infrastructure is fibre optics. It is best for gigabit and beyond transmission due to its high bandwidth capacity and low attenuation features.The way we transmit and communicate data has been revolutionised by optical fibre connection. The evolution of optical fibre technologies throughout the years has been tremendous, allowing for high-speed, dependable, and long-distance data transmission. Overall, optical fiber communication holds immense promise for addressing the growing demand for faster, more reliable data transmission in various applications, including telecommunications, data centers, internet of things (IoT), and smart cities. Further research and innovation in optical fiber communication will contribute to the development of efficient and sustainable communication networks, enabling seamless connectivity in our increasingly digital world.

REFERENCES

[1]. Hasan DA, Hussan BK, Zeebaree SR, Ahmed DM, Kareem OS, Sadeeq MA. "The impact of test case generation methods on the software performance: A review." International Journal of Science and Business. 2021; 5:33-44.
[2]. Idachaba F, Ike DU, H Orovwode. "Future trends in fiber optics communication"; 2014.
[3]. Joshi NK, Bhatt P. "A Technical assessment on fiber optics communication: Latest trends and its application"; 2016.
[4]. Sadeeq MA, Zeebaree SR, Qashi R, Ahmed SH, Jacksi K. "Internet of things security: A survey." in 2018 International Conference on Advanced Science and Engineering (ICOASE). 2018;162-166.

[5]. Sharma P, Pardeshi S, Arora RK, Singh M. "A review of the development in the field of fiber optic communication systems." International Journal of Emerging Technology and Advanced Engineering. 2013; 3:113-119.
[6]. Chen M, Mao S, Liu Y. "Big data: A survey." Mobile networks and Applications. 2014; 19:171-209, [7]. Taleb T. "Toward carrier cloud: Potential, challenges and solutions." IEEE Wireless Communications. 2014; 21:80-91.
[7]. Wang X, Kitayama K-I. "Analysis of beat noise in coherent and incoherent time spreading OCDMA". Journal of Lightwave Technology. 2004; 22:2226.
[8]. Shake TH. "Confidentiality performance of spectral-phase-encoded optical CDMA." Journal of Lightwave Technology. 2005; 23:1652.
[9]. Li X, Yu J, Dong Z, Chi N. "Photonics millimeter-wave generation in the E-band and bidirectional transmission." IEEE Photonics Journal. 2013; 5:7900107- 7900107.
[10]. R. J. Sanferrare, AT&T Tech. J. 66, 95 (1987).
[11]. D. Gloge, A. Albanese, C. A. Burrus, E. L. Chinnock, J. A. Copeland, A. G. Dentai, T. P. Lee, T. Li, and K. Ogawa, Bell Syst. Tech. J. 59, 1365 (1980).
[12]. Prachi Sharma et al, “A Review of the Development in the Field of Fiber Optic Communication Systems”, International Journal of Emerging Technology and Advanced Engineering, Vol. 3, no. 5, pp. 113-119, 2013.
[13]. G. Keiser, op cit, p 51.
[14]. Franz Fidler, Markus Knapek, Joachim Horwath, and Walter R. Leeb, “Optical Communications for High-Altitude Platforms”, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 16, no. 5, September/October 2010.
[15]. Ye Zuhang.Modern optical fiber communication transmission technology and its application [J]. Computer products and circulation, 2019 (10): 37.
[16]. Zhang Haoxiang. Application and development of optical fiber communication technology [J]. Information communication, 2020 (04): 216 – 21.
[17]. He Zhaoshun.On the characteristics and development trend of optical fiber communication technology [J]. Management and technology of small and medium-sized enterprises (early ten days), 2010 (03): 248.
[18]. Kwan S. "Principles of optical fibers." Partial Fulfilment of Course Requirement for MatE. 2002;115.
[19]. Dai Xiaoyuan.The application of optical fiber communication in the military field [J]. Electronic world, 2017 (15) : 172.
[20]. Zheng Jifeng. Application of optical fiber communication technology in railway communication system [J]. China New Communications, 2019, 21 (18): 115.
[21]. Wei Fang. Research on the application and development trend of optical fiber communication technology [J]. Digital communication world, 2019 (05) : 69.