

Optical fibers for computer applications

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Abstract — the use of optical fiber in field of computers is a topic of recent research interest. The world of computing is likely to change rapidly in near future on replacing the metal wiring between components in conventional computers with faster and more efficient fiber-optic links. Optical fiber has immense capability to transport signals having much larger information, over much longer distances at much higher speed than the copper wire link can do. The principle of working of optical fiber along with the parameters affecting and benefits of optical fiber communication are presented. Limitations of Von Neumann architecture and metal wire interconnection in conventional computers system are presented along with how they are got rid of by employing fiber optics interconnection in optical computers. Applications of optical fibers in the field of computers including PC to PC communication, computer network, internet and optical computing are covered. The development of optical transmitters and receivers circuit for transmitting and receiving 0-10 V analog signal in optical fiber cable is presented, which shows a close match between input signal transmitted and output signal received.

Index Terms—Fiber optic communication, Optical compute, Optical transmitter and receiver, Von Neumann architecture.

I. INTRODUCTION

The fiber optic cables was first commercially utilized for carrying telephone signals in California in 1977 and then for fiber optic television network in England in 1978. The fiber optic technology was improved for faster transmission rates throughout the 1980s. In 1990s, the development of optical amplifiers with improved signal strength over distances as well as wavelength-division multiplexing in optical fiber without any interference led to an increase in demand for fiber optic networks. The optical fiber communication technology has improved further to allow transmission of sound, image, video, data and microwaves etc., all traveling along the same fiber optics cable without electromagnetic interference from other sources. It has got immense bandwidth, high signal security, total immunity to interference and crosstalk, complete electrical isolation, very low transmission loss, very low power consumption and unique capability to transport signals over long distances [1]. Because of its advantages over electrical transmission, optical fibers have largely replaced copper wire communications in the developed world to transmit telephone signals specifically for long distance phone calls, cable television signals and also in internet communication. Fiber-optic communication system has a wide range of applications in variety of fields. Computer, telecommunications as well as biomedical industry are

significant beneficiaries to this technology. The use of optical fiber for various computer applications like interconnection between PC to PC, in computer network, in internet as well as in optical computing are covered in this paper. Conventional computers system uses wires and cables for various interconnection purposes. Wires and cables have resistance and capacitance, which are proportional to their length. For longer wire, more power has to be expended in overcoming its resistance and its RC time constant also places a fundamental limit on the maximum data bit rate that can be transmitted. Fiber optics interconnection does not consume power as it carries light instead of electric current. As the computer networks are getting complex day by day, long distance interconnections using optical fibres is becoming popular as it has immense capability to transport signals having much larger information, over much longer distances at much higher speed than the copper wire link can do [2]. Internet communication started with the dial-up connection through telephone cables, then to broadband through the network of optical fibers and also to wireless for mobile applications. Fiber optic technology is the fastest and most reliable internet technology in existence today and is cheaper than the wireless technology. Fiber optic communication has played a major role in creating the internet revolution around the world. Today more than one third of the world's human population has used the internet services. Email is one of the most popular and effective communications service available on the internet. It is widely used for social networking through face book, twitter, and my space; as well as for fostering commercial and business connections through LinkedIn. However, the speed of average internet plan in India is less than 1 Megabit per second (Mbps). As the internet user market matures further, there will certainly be a demand for fiber optics based high speed internet plans across the country to effectively address congestion issues. Recently, Google fiber came to Kerala, India with its ultra-fast speed 1 Gigabit per second (Gbps) connection network, which is only second to one installed in Kansas, USA [3]. With a speed of 1Gbps, any high definition version movie can be downloaded within 30 seconds. It can provide both the internet service and the television service simultaneously. Fiber-optic broad band is most common in Japan, Korea and Sweden. Japan leads with 68.5 percent penetration of fiber - optic links, with South Korea closely behind it at 62.8 percent, Sweden is in third place at 35.9 percent. The fastest growth in new fiber connections has taken place in Mexico with a 290 percent increase, closely following it UK at 172 percent; Chile at 171 percent; New Zealand at 141 percent; Australia at 121 percent

during the year 2012 to 2013 [4]. European Commission and Japan have announced developing still higher speed 100 Gbps fibre optics line by combining new optical packet switching technology, optical transceivers and other hardware with updated controlling software, to cater to demand of ambitious research projects.

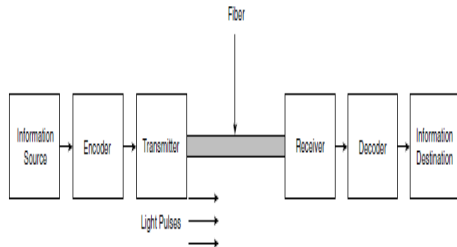


Fig.1. Typical fiber optics communication system

II. OPTICAL FIBRE COMMUNICATION

Fig.1 shows a typical fiber optics communication system. Information source can be in the form of voice, video and data. First of all, information from the source is encoded into electrical signals that can drive the transmitter. Transmitter converts electrical signals into light pulses. The fiber acts as an optical waveguide for the photons as they travel down the optical path toward the receiver. Receiver converts light pulses into electrical signals, which are decoded and are sent to their destination.

A. Principle of working of a optical fibre

When light traveling in an optically dense medium hits a boundary at an angle larger than the critical angle (θ_c), it gets totally reflected. This is called total internal reflection. This effect is used in optical fibers to confine light in the core, bouncing back and forth on the boundary between the core and cladding. To confine the optical signal in the core, the Refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt (in step-index fiber) or gradual (in graded-index fiber). Fig. 2 shows the total internal reflection of light when it is incident at an angle equal to or greater than θ_c . The light ray incident at an angle less than θ_c are partially transmitted and partially reflected.

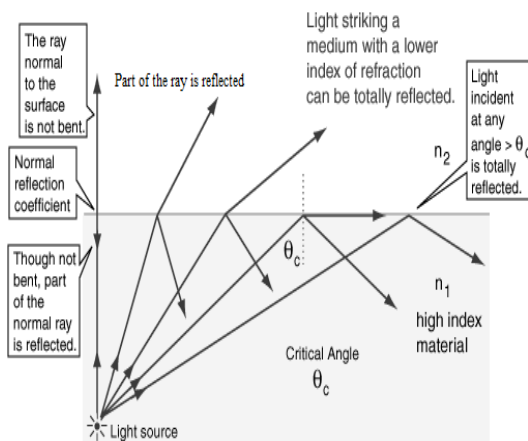


Fig. 2. Critical angle for total internal reflection

B. Parameters affecting optical fibre communication

Parameters affecting optical fiber communication are listed below:

1) Bandwidth–distance product:

Fiber optics transmission system is often characterized by its bandwidth–distance product, usually expressed in MHz.km. This value is the 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 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.

2) Attenuation and Regeneration:

When light travels a larger distance through optical fiber, signal gets attenuated, which needs to be amplified or regenerated at intermediate points by optical communications repeaters. Recent advancements in fiber optics technology have reduced signal degradation to such an extent that repeaters are only needed to transport signals over distances of hundreds of kilometers. This has greatly reduced the cost of optical networking over long distances, particularly under sea where the cost and reliability of repeaters are key factors determining the performance of the whole system.

3) Dispersion:

For modern glass optical fiber, the maximum transmission distance is limited not by direct material absorption but by several types of dispersion or spreading of optical pulses as they travel along the fiber. Dispersion limits the bandwidth of the fiber because the spreading optical pulse limits the rate that pulses can follow one another on the fiber and still be distinguishable at the receiver.

C. Benefits of optical fibers

Advantages of using optical fibers are listed below.

1) Immunity to electromagnetic interference:

Electromagnetic Interference (EMI) is a common type of noise in ordinary wires transmission and even in coaxial cables. But fiber optics is immune to this EMI, since signals are transmitted as light instead of current. Thus, they can carry signals even through EMI prone areas.

2) High bandwidth over long distances:

Fiber optics cable has high bandwidth to carry high speed signals over longer distances than other types of cables. The information carrying capacity increases with frequency.

3) Data security:

There are no radiated magnetic fields around optical fibers, so the electromagnetic fields are confined within the fiber, making it impossible to tap the signal being transmitted through a fiber without cutting into the fiber. Since fiber optics cable does not radiate electromagnetic energy, emissions cannot be intercepted. Thus, the fiber is the most secure medium available for carrying sensitive data.

4) High voltage isolation:

The optical fibre link provides high voltage isolation by converting electrical signals into optical signals. It can be used in high voltage floating applications, where the reference point is not at the earth potential, instead it is floating at certain high voltage. Because fiber optic cables do not contain any metallic members, it is the most reliable solution for communication between two points having high potential difference.

5) Eliminating spark hazards:

Fiber optic cables do not produce sparks since they do not carry electric current. But transmitting signals electrically may be dangerous. Even tiny spark can create a big explosion in sensitive areas causing serious hindrance to data communication.

6) Ease of installation:

Fiber cables are easier to install since they have smaller diameter, lightweight and more flexible. They can also run along the same routes as electric cables without picking up noise. Increasing transmission capacity of metallic wires generally makes them thicker and more rigid making it difficult to install.

III. CONVENTIONAL COMPUTERS TECHNOLOGY

Conventional computer technology is based on electric current (and electrons) flowing through metal wirings among various components and subsystems. The speed at which signal travel through a metal wire, is actually the speed of the electromagnetic wave. The speed of the electromagnetic field through a metal wire depends on the exact composition of the wire, its thickness and on whether it's in an electromagnetic field from the earth or from other current carrying wires around it or from a magnet somewhere nearby and so forth. Again, electromagnetic wave propagation in a material depends on its dielectric constant. All these limits the speed at which electric current travels in a metal wire and typically in a copper wire, it is about $1/10^{\text{th}}$ of the speed of light. Electric currents flowing through metal wires are likely to interfere with each other due to electromagnetic interferences. Data sent through parallel paths are also likely to interfere, leading to crossed data paths. So only one data set can be sent through a metallic wire in one data path at each time and crossed data paths lead to loss of data. Hence conventional computers have limited parallelism capability. Conventional computers system mostly uses wires and cables for various interconnection purposes. Wires and cables have resistance and capacitance, which are proportional to their length. For longer the wire, more power has to be expended in overcoming its resistance and its RC time constant also places a fundamental limit on the maximum data bit rate that can be transmitted. So data bandwidth of metallic wire interconnection is lower and the ultimate connection to the user will be slower, even after employing a fastest processor. In addition, copper wire can carry data only up to limited distance. Typically, data bandwidth of copper wire is only

about 1.5 Mbps in contrast to approximately 2.5 Gbps for fiber optics cable and copper wire can carry data up to distance of about 1.5 miles in contrast to approximately 124 miles for fiber optics cable [5]. Hence, on the motherboard of conventional computers, the CPU, RAM and graphics card etc., have to be as close as possible to increase the rate of data transfer and restricts how computers can be built. Conventional computers consume a lot of energy, specifically in performance mode and release heat requiring fans or air conditioners for its heat extraction. Thus, it causes a lot of noise due to rotating fans and drives leading to wear out of mechanical parts. Conventional computers are normally based on the Von Neumann architecture. Von Neumann architecture broadly describes general-purpose computers having four main organs, namely the arithmetic logic unit, the control unit, the memory and the input-output devices. In Von Neumann architecture, data and instructions are kept in the same memory and are executed sequentially. Since memory is common to both data and instructions, two memory accesses need to be made, either first to access data and then to access the instruction or vice versa. Again, these instructions and data have to pass through the same shared common multiplexed bus to get in or out of the processor, making the overall execution process is slower. This is called the Von Neumann bottleneck. It happens because CPU is the fastest device in modern computers but bus systems as well as the RAM are not fast enough to provide instructions or data for the CPU to function without intermission. Thus the processor is unable to maintain its designed performance and the effective processing speed is seriously limited.

IV. OPTICAL FIBERS FOR COMPUTER APPLICATION

The use of optical fiber in field of computers is a topic of recent research interest. The world of computing is likely to change rapidly in near future on replacing the metal wiring between components with faster, more efficient fiber-optic links. It has immense capability to transport signals having much larger information, over much longer distances and at much higher speed than the copper wire link can do. Some of the major applications of fiber optics for computer applications are listed below.

A. Fibre optics for PC to PC communication

PC to PC fiber optic communication deals with data transfer from one computer to another. An MAX 232 is employed to convert RS 232 logic from the serial port of computer to TTL logic, which is then sent to an optical transmitter circuit to transmit optical data via fiber optic cable. In fact, transmitter converts electronic information into pulses of light, a pulse represents one, while no pulse represents zero. At the receiver end, an optical receiver circuit receives data using a photo transistor and another MAX 232 again employed to convert TTL logic to RS 232 to receive data on the serial port at the receiving end of computer. Fig.3 shows block diagram of PC to PC fiber optics communication

for data transfer between two PC, which can also be extended for data transfer among a set of computers in a computer network.

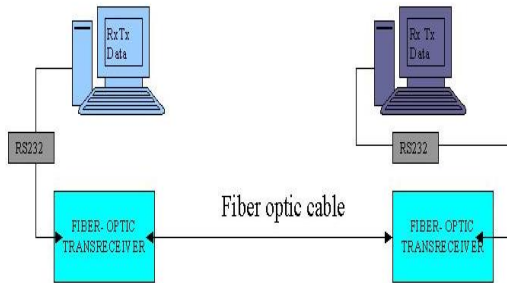


Fig.3. PC to PC fiber optics communication

B. Fiber optics in computer networking

Computer networking is defined as a network of many computers connected to each other for resource sharing, information interchange and communication purposes. By creating a computer network, devices like printers and scanners, various software, files and data that are stored in the network can be shared, as and when necessary. For example, a document can be printed on a printer from any computer connected in that network, so each computer need not require its own printer. It is established with integration of various computer hardware and software. The common hardware devices employed in computer network are routers, hubs, switches, network gateways, network firewalls and network interface card. There are broadly two types of computer networks: Local Area Network (LAN) and Wide Area Network (WAN). A LAN is a computer network that extends to a comparatively smaller area; say to one building or group of buildings in an organization within a restricted region. Most of the LANs connect personal computers and workstations. In a LAN, each computer has its own CPU in which it executes programs and is also capable of sharing the information with other computers in it. LAN is more significant and capable in transferring the data quickly at fast rates but the distances of transmission are limited. On the other hand, WAN enables the connectivity among many computers to transfer data in large geographical area, such as in a country or in a continent and even it can span across the world. So, offices in different countries can be interconnected through WAN. Speed of data transmission in WAN can be as low as a few Kbps or as fast as a few Gbps, depending on the technology adopted. Internet could also be called as largest WAN in the world, The majority of computer networks today use some type of cable to connect the computer systems and hardware that make up a network. Most cables used in computer networks can be categorized into three groups: coaxial, twisted pair and fiber optic. Coaxial cable consists of a central conductor surrounded by insulating material, which is then surrounded by a braided metal shield and an outer plastic jacket of the cable. In coaxial cable, the central conductor wire and the braided metal shield share the same central axis. Coaxial cable is effective at shielding data from Electro-Magnetic Interference (EMI) and is commonly

used to enable a cable modem to connect to an Internet Service Provider (ISP). Twisted pair cable, which consists of multiple pairs of wires twisted around each other at specific intervals, is commonly used in computer networks. Fiber-optic cable transmits data via waves of light through glass as opposed to electrical current through copper wire. The main advantages of fiber-optic over twisted pair cable are distance and speed. Fiber optic cable can transmit data for hundreds of kilometers with very low transmission loss as opposed to only a few hundred meters with twisted pair cable. Similarly, it can carry multiple wavelengths of light simultaneously, which greatly increases the speed at which data can be transmitted in more secure and reliable manner. Fibre optic cables are already being used in a variety of ways, from delivering television signals at homes to transferring data between computers that are thousands of miles apart. As the computer networks are getting complex day by day, specifically for applications demanding high bandwidth and long distance of transmission, interconnections using optical fibres are indispensable choice.

C. Fibre optics in Internet

The internet is a global system of interconnected computer networks that use the standard TCP/IP protocol to link several billion devices worldwide. It is a globally distributed network that consists of millions of private, public, academic, business and government switched networks, which operates without a central governing body. The Internet carries an extensive range of information resources and an extremely large number of services, such as applications of the World Wide Web (WWW), the infrastructure to support email, internet phone, audio, video and file transfer services and networks for file sharing. So WWW is one of the large numbers of services running on the Internet and Hyper Text Transfer Protocol (HTTP), is the main access protocol of the WWW and is the language used for information transfer. WWW browser software, such as Microsoft's Internet Explorer, Mozilla, Opera, Apple's Safari and Google chrome lets users navigate from one web page to another. The most prominent component of the internet is the Internet Protocol (IP), which provides addressing systems called IP addresses for all computers on the internet and enables internet working. The commercialization of internet started in 1990s, but has grown to such an extent that it has virtually impacted into every aspect of modern human life, creating the so called internet revolution. Today more than one third of the world's human population has used the services of the internet. Email is one of the most important communications service available on the internet. The internet allows computer users to remotely access other computers in the network with or without computer security. It is also widely used for social networking through face book, twitter and my space for fostering commercial and business connections through LinkedIn as well as for storing and transferring large amounts of data, whenever necessary. Common methods of internet access by users is either by dial-up with a computer modem via telephone circuits or by wireless or by broadband over coaxial cable and fiber optic cable.

Broadband internet through fiber optic cable allows large amount of data transmitted at high speed for demanding applications like streaming and uploading online video, online gaming and multimedia applications. As the networks of internet is expanding rapidly and getting complex day by day, demand for high quality optical fibres with high bandwidth and long distance of transmission is increasing to meet the user expectations.

D. Optical Computing

An optical computer is a device that uses visible light or infrared beams to perform digital computations rather than electric current used in conventional computers. In the optical computer, micro sized optical fibres are fixed at chip level for transmission of data in the form of light. In the optical computing, information is sent from keyboard, mouse or other external sources to the processor. Processor sends these information through logic gates and switches to be programmed to different fibre optic cables depending on its final location and save them in the holographic memory. After information is saved, the program sends a command to the processor to receive them whenever required. The program receives the information and sends a signal back to the processor when the task is complete. A lot of research is going on worldwide to develop lower cost lasers, lower cost-receivers and associated optical components like optical switches, waveguides, optical routers and detectors as well as to make optical interconnections cheaper for widespread use inside computers. The silicon photonic chips could replace the electronic connections between a computer’s key components, such as its processors and memory.

1) Advantages of Optical Computer:

Advantages of optical computers compared to conventional computers are as under:

a) Higher performance:

The most significant advantage of optical computers is the potential of higher performance as photons are the perfect information carrier that moves at the speed of light. Again, optical communication devices are much faster than their electric counter parts and light is used in bus systems of optical computers. Another key to fasten up optical computers is to compute with higher parallelism. For achieving higher parallelism, the amount of data which is sent through bus systems and computed in the CPU at each time is increased. Within one optical data path, several data sets can be transmitted in parallel at the same time using different wavelengths or polarizations. The higher parallelism and the superior velocity of light allow extreme processing speed to transfer a full length HD movie even within few seconds. Furthermore optical data paths are able to cross each other without interference.

b) Less consumption and less noise:

Optical processor does not heat up and optical computers consume lesser heat compared to conventional computers as light is used as information carrier instead of electric current.

Currently, half of the consumption of energy in laptops is due to lighting of its screen. The use of fibre optics in computer screens brings just as much luminosity and contrast conserving the significant amount of energy. Optical computers could be almost noiseless since no fan will be needed and could be smaller in size.

c) Less communication loss and flexible layout:

The communication with optical fibers is almost loss less due to the total internal reflection. Using optical components the distance of communication does not matter. Once the signal is in an optical fiber it does not matter whether the signal runs 1 meter or 1000 meters. The components of one computer can have a flexible layout which can spread across a building or even a city with almost no loss in performance. Because of the low damping of optical signals, long-range communication is possible, data rate is very high and there is no crosstalk.

V. DEVELOPMENT OF OPTICAL TRANSMITTER AND RECEIVER SYSTEM

The transmitter and receiver circuits used for transmission of 0-10 V analog signal in the experimental set up are presented as in Fig 4 and Fig 5 respectively. An analog voltage 0-10 V is given as input to the transmitter, which employs an AD650 and HFBR 1521 to convert the input analog signal to digital form and then feed into the optical channel. Receiver circuit employs HFBR 2521 and AD650 for reception from optical fiber. An IC AD650 is used for voltage- to-frequency conversion at transmitter end and another AD650 is used in reverse mode for frequency-to-voltage converter at receiver end. The transmitter is connected to the receiver through optical fiber. The transmitter-receiver link is tested by observing the output voltage on the receiver side with intermediate frequency link, when the input analog voltage varies between 0 to 10 V. Table 1 presents input and output voltage transmitter and receiver circuits which shows that the output voltage closely matches with input voltage. It should be noted digital signal transmission through optical fiber is easier, which can be done directly with transmitter and receiver without requiring V to F and F to V conversion.

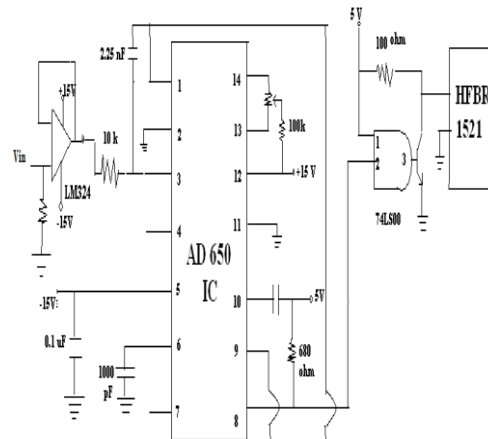


Fig.4. Analog Transmitter Circuit

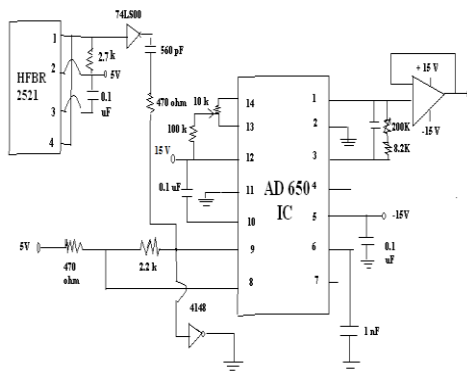


Fig.5. Analog Receiver Circuit

Table 1. Input and output voltage of transmitter-receiver circuits

Input Voltage (in Volts)	Frequency (in kHz)	Output Voltage (in Volts)
1.00	7.14	1.03
2.00	14.92	2.02
3.00	23.80	3.02
4.00	30.30	4.01
5.00	37.03	5.00
6.00	45.45	6.01
7.00	51.30	6.99
8.00	60.60	8.01
9.00	67.66	9.01
10.00	74.77	9.99

VI. CONCLUSION

Optical fiber has immense capability to transport signals having much larger information, over much longer distances and at much higher speed than the copper wire link can do. Metallic wire offer resistances and capacitances, which are proportional to their length and its RC time constant places a fundamental limit on the maximum data bit rate as well as the distance signal can be transmitted. This is in fact a major impediment in conventional computer system. Fiber-optic cables have the ability to transmit both electrical and computer data simultaneously, adding to the cables versatility. Recent advancements in fiber optics technology have reduced signal degradation to such an extent that regenerations of the optical signal are only needed to transport over distances of hundreds of kilometers. Data can also be transmitted through fiber-optic cable without any electromagnetic interference in more secure and reliable manner. Fiber optic internet is extraordinarily reliable and less likely to go down during a power outage or other situation. The biggest limitation hindering widespread fiber optic adoption is the cost of implementing new fiber optic network, specifically where existing cable network are still serving customers, as installing a new fiber optic network involves a large capital expenditure for service providers. But, fiber-optic can save money for network users in the long run, because it needs less maintenance and takes lesser fiber-optic cabling than coaxial cables or Ethernet cables as well as lesser number of switches and routers to create the

same size network. It should be noted that, traditional copper wires or coaxial cables needs separate lines for transmitting data for phones, computers and other electronics, but all these can be effectively transmitted with a single fiber optics cable. Optical fibre has potential to act as an excellent interconnector for computer applications. As the computer networks are getting complex day by day, long distance interconnections using optical fibres is becoming popular as it has immense capability to transport signals having much larger information, over much longer distances at much higher speed than the copper wire link can do. In the internet communication, fiber optic network has taken a major role, allowing broadband communications with sound, visuals, data and microwaves all traveling along the same fiber optic cable, creating the so called internet revolution. There is significant increase in the number of devices like laptops, mobile phones and tablets at home as well as growing desire to stay online on social networking sites, adding to internet traffic even for home users. The internet also allows computer users to remotely access other computers in the network with or without computer security. The world of computing is likely to change rapidly in near future on replacing the metal wiring between components with faster, more efficient fiber-optic links. Another key to fasten up optical computers is to compute with higher parallelism allowing several data sets in parallel at the same time using different wavelengths or polarizations within one data path. Optical computers promise speeds, which will be thousands of times faster than those of today's most efficient supercomputers as optical communication devices are much faster than electric ones. The use of optical fiber in field of computers is a topic of recent research interest. A lot of research is going on worldwide to use silicon photonics at the motherboard level and the development of low cost lasers, low cost-receivers and associated optical components like optical switches, waveguides, optical routers and detectors are topic of focused area of current interest. It is expected that while fully optical computer may take some more time for commercial utilization, hybrid computer employing some optical components with existing electronic hardware will come to market soon.

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