

# Analysis and Comparison between Optical Fiber Communication System and Line of Sight Optical Communication System

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## ABSTRACT

Fiber optic communication system and Line of sight optical communication both are capable of high-speed large bandwidth data communication. This is extremely demanding in recent communication market. Optical communication system is ideal for long distance communication and Line of sight communication for short distance. Both of the system is unique in their own field. For optical communication system offers reliable data transmission through long distance with a very high bandwidth. But this system is quite expensive in terms of its equipment's, installation, and there are some factors which create losses while designing the system. The line-of-sight optical system is also having some drawbacks. During system design environment factors, beam alignment and some other factors are the challenges for line-of-sight system design. This system is fiber free, and it is relatively cheap. And there are lots of research going on to implement this system for long distance system so that it can take over conventional optical fiber system. Emphasis is placed on to analyze both the system, to give a basic idea on their characteristic, performance, operating system, modulation technique, merits, demerits, application and compare Fiber optics and line of sight optics from different aspects.

## 1 Optical Fibre Communication System

Like any other communication system, an Optical fibre Communication system consists of a transmitter or modulator at the source point, the optical fibre as transmission medium, and a receiver or demodulator at the destination end. The information source provides an electrical signal to the transmitter. In case of optical fibre communications, when the transmitter receives an electrical signal it modulate the signal through an optical source which provides the electro-optical conversion as a light-wave signal. The optical

source consists of either a semiconductor laser or light emitting diode (LED).

**Fibre optic Cable:** A fiber optic cable is a cylindrical pipe. It can be constructed by glass, or plastic, or combination of glass and plastic. Fiber optic is constructed in a way so that it can guide light from one end to other end. The types of fiber optic cables are:

Multimode Fiber

- Step-index Fiber
- Graded-index Fiber

Single Mode Fiber

### Advantages of Fiber Optics:

Here are some advantages which make the optical fiber communication unique:

- Fast transmission speed
- High Bandwidth
- Lower Attenuation and Greater Distance
- Smaller Diameter and Lighter Weight Cable
- Immunity to Inductive Interference
- Negligible Crosstalk
- High Security
- Low Installation and Operating Cost
- Safe
- Long life

### Disadvantages of Fiber Optics

- Although fibre optic systems offer data transmission rate up to Tb/s, currently few users have need for such a huge data transmission rate that still cannot be provided.
- The fibre optic system is costly. Because the components of fibre optics like transmitters, receivers, couplers, and connectors are expensive
- It is very time consuming and costly to re-install the optical fibre communication system.
- In nuclear radiation environment fibre glass faces the radiation darkness problem. So, optical fibre cannot be used in a nuclear environment

## 2 Link Power Budget:

'Link power budget is a process where it is determined whether there is enough power at the receiver after system losses and operating margins are considered for a specified work for the system. And the process which determine this , is called link power budget' [1]

$$P_e = P_t - (L_c + L_t + L_f + L_s) - M - MRP \quad (1)$$

Where,  $P_e$  = excess power in dB (should be 0 or dB or greater),  $P_t$  = source power coupled into the fiber in dBm(1mW),  $L_c$  = connector loss =  $l_c$  (dB/conn) x no of connectors,  $L_s$  = Total splice loss =  $l_s$  (dB/splice) x no of splices,  $L_f$  = Total fiber loss =  $l_f$  (dB/km) x distance (km),  $M$  = operating margin,  $MRP$  = receiver sensitivity expressed as the minimum required optical power in dB(1mW)' [1]

## 3 Optical Transmission Systems

There are some important components for fiber optic communication. The major components are transmitter, coupler, fiber, slice, repeater, detector and receiver. To understand the optical fiber communication it is necessary to understand the transmission process and its importance.

The role of transmitter is to convert the input electrical signal to an optical signal and to launch the optical power from a light source into a fiber for transmission. A transmitter consists of electronic bias and an optical source.

### Optical Sources:

The optical source mainly works for conversion of electrical signal into corresponding light source. In fiber optic communication system the optical sources are Light Emitting Diode (LED) and Injection Laser Diode (ILD). Their basic advantages are reliability, small, cheap, require low voltage, and have desired wavelength for optical communication. Another important thing is optical source should be forward bias and LED and ILD has that benefit.

- **Light Emitting Diodes**

A Light-Emitting Diode (LED) is a semiconductor device that emits incoherent narrow-spectrum light when electrically biased in the forward direction. [2] Light emitting diode is a pn-junction semiconductor material that produce light when the diode is forward biased. LED is incoherent in terms of output form.

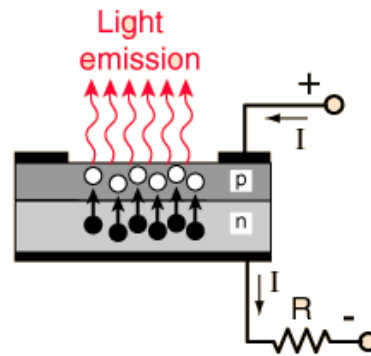


Figure 1: LED Device structure [3]

From the above figure, it has been shown that, there are two region p-type and n-type semiconductor layers. The LED junction is forward bias. P region contains hole and the n-type region contains electron. When electron cross the junction from n-type to p-type the electron and hole combination produce phonons in the IR. This process is called electroluminescence. Then a semiconductor surface emits light. [3]

Performance characteristics of LED depends on Junction temperature Modulation current

- **Laser Diode**

Laser stands for Light Amplification by Stimulated Emission of Radiation. It is an optical source that emits photon in a coherent beam. Laser diode consist a single wavelength or hue and emitted in a narrow band.

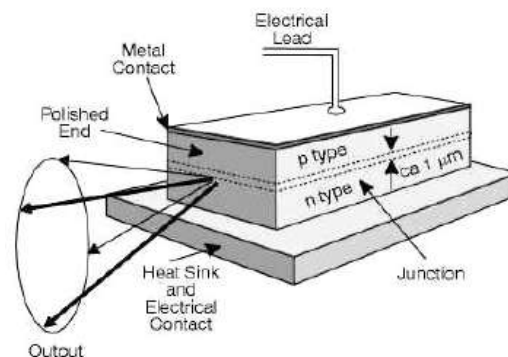


Figure 2: Laser diode structure [4]

Laser diode and light emitting diode have quite similar construction. Laser action can be achieved in a pn-junction forming by two doped of Gallium Arsenide layers. The two end of the layer need to be optically parallel and flat with one end mirrored and one parallelly reflected. The length of the junction must be preciously related to the

wavelength of the light to be emitted. [5] Laser diodes are edge limiter, under forward bias electron charges are injected into the active layer, where the recombination process happens. If the current flow is relatively high, then the large numbers of injected charges are available for stimulated recombination. When the threshold current is available then gain is large to offset the diode loss and the laser oscillation start. [6]

Laser diode performance depends on Peak wavelength, Spectral width, Emission pattern, Power and Speed.

#### 4 Losses Related to Fiber Optic Communication System:

Optical loss means the amount of optical power lost as light is transmitted through fiber, splices, couplers, etc.

Usually these junction losses happen for the combination of two loss mechanism. Those mechanisms are Intrinsic and extrinsic.

**Intrinsic Loss:** Intrinsic losses include core size mismatch, NA mismatch, core concentricity offset and graded index profile differences. [1]

**Extrinsic Loss:** Extrinsic losses are mostly related to fiber end preparation and connector or splice tolerance variations. Such as lateral offset, angular misalignment, fibre end separation, reflection, and surface roughness. [1].

**Fiber Optics Splices:** "A fiber optic splice is a permanent fiber joint whose purpose is to establish an optical connection between two individual optical fibers. System design may require that fiber connections have specific optical properties (low loss) that are met only by fiber-splicing. Fiber optic splices also permit repair of optical fibers damaged during installation, accident, or stress. System designers generally require fiber splicing whenever repeated connection or disconnection is unnecessary or unwanted." [6] There are many types of splices used in optical fiber communication system, but the most commonly used ones are fusion splice, mechanical splice, and rotary splice.

**Fusion Splice:** Fusion splice aligns two optical fibers and fuses or melts them together with an electrical arc. This is portable and self-contained unit.

**Mechanical Splices:** Mechanical splice is any kind of splice which is not a fusion splice. It happens by using a fibre alignment mechanism, inserting the

two fibre ends into that mechanism and fixing or gluing them in place.

**Rotary Splice:** This is a unique type of mechanical splice also known as polished-ferrule splice. It has been developed by AT&T. For this splicing fiber ends have been inserted into a glass ferrule. Then the two polished ferrules are butted together in an alignment sleeve that contains the gel. The eccentric bores of the ferrules slightly mount the fibres off-centre. After the insertion of the ferrules into the alignment sleeve, they are rotated while there is a monitoring of the splice loss. Then, the ferrules are fixed at the point where there is minimum splice loss. [5]

#### Connector:

'Connectors are used whenever two fibers or a fiber and an electro-optical source or detector, are to be joined and disconnected repeatedly. This is generally at fiber terminal equipment, optical patch panels, or fiber couplers within a LAN'[1]

For each connector power loss happens. In transmission and receiving interface connectors are used but the number of connectors need to be used depends on the system.

Lots of different connectors are used in Fiber optic system for example, **SubMiniature Version A(SMA) connector, Biconic connector, ST connector, SC connector, FC connector, FDDI connector.**

Here are some basic requirements for good connectors:

- **Low loss:** This is the most important requirement. When designing connectors, it must ensure that misalignments are minimized automatically when connectors are mated.
- **Predictability:** To achieve the same efficiency, the loss should be insensitive to the skill of the assembler if the same combinations of connectors and fibres are used.
- **Repeatability:** There should not be a lot of changes in the coupling efficiency with repeated mating.
- **Long life:** The rate of loss of a mated connector should not change as time passes.
- **High strength:** The connector should not be degraded for any applied forces on the connector body or tensions on the fibre cables
- **Compatibility:** Need to be compatible for large temperature fluctuations, moisture, chemical attack, high pressure, vibrations and dirt.

- **Simple use:** Mating and un-mating the connections should be easy and simple.
- **Economy:** Need to be economic. Expensive connectors increase the system cost. [6]

**Couplers:** ‘Optical couplers used to attach more than one set of transmit and receive terminals to a single fiber rather than running a separate fiber cable for each transmit-receive pair.’ There are many couplers used in Fiber optic system some popular couplers are **Tree and Branch Coupler, Star Coupler, Directional Coupler** [1]

#### Characteristics of Coupler:

- Divide the input signal into two or more than output channels in pre-designed ratios. Can split the signal with orthogonal polarization in each output.
- Can combine two or more input signals to one output channel. If a splitter is reciprocal, passive device, it can then be used as a combiner
- Combines two or more than light signals of different wavelengths on the other side.
- Used at the receiving end in order to split the multiplexed signals according to the wavelengths.

#### 5 Wavelength Division Multiplexing:

Wavelength division multiplexing allows power to be transmitted from multiple sources at different wavelengths on a same fiber. It also allows multiple communication channels composed of power of multiple wavelengths to be separated by different wavelength. Power does not split here. So there is no power splitting loss. But the internal excess loss and any connector insertion loss is present. [1]

**6 Optical Amplifier:** ‘An optical amplifier is a device that amplifies the optical signal directly without photon-to-electron conversion; it amplifies the light itself.’ [7]

#### Basic Properties of Optical Amplifier:

- An ideal amplifier needs to have high bandwidth.
- Provide high and uniform gain over its spectral width.
- Must Allow bidirectional operation
- When inserting into a optical link it needs to have low insertion.
- Good conversion efficiency.

#### Semiconductor Optical Amplifier:

Semiconductor optical amplifier must have a semiconductor laser with anti-reflection design. It

is small in size and electrically pumped, but the performance is not good enough like EDFA.

**Erbium-Doped Fiber Amplifier:** This amplifier is the most popular because of some desirable features:

- EDFA allow information to be transmitted over long distance without any conventional repeater.
- The fiber is doped with erbium, a rare earth element that atomic structure of the energy level is appropriate to amplify light signals. This device is designed to amplify light at 1550 nm, where the fiber loss is minimum.
- This device use 980 nm or 1480 nm pump laser to inject energy into the doped fiber.
- The device is simple
- It creates very low distortion when it amplifies WDM signal.
- There is no cross talk.
- It is an all-fiber device so virtually polarization insensitive.

**Raman Amplifier:** It is an amplifier which boosts the eaten optical signal by transferring energy through powerful pump beam. It can use any installed transmission optical fiber. Raman amplifier can amplify any signal wavelength by pumping at 13 THz but has range of bandwidth about 6 THz. [8] Raman scattering only occurs when two optical beams are available. One beam is called pump and the other is signal. The pump provides the amplification for the signal.

**7 Optical Isolator:** Optical systems are made of many components and all of them are obviously not perfect. Connectors and other components have some problems which affects the signal that is being transmitted. The installation of new devices creates some problems sometimes like reflection, scattering or absorption of the optical signal. These problems can attenuate the signal and causes interference. In order to reduce this effect, an optical isolator is used. [9]

**Detector:** Optical detector is a part of optical receiver. Another name of optical detector is Photodetector. Photodetector does the opposite function of optical source it converts the optical input signal to electrical output signal. Optical detectors are photodiodes and these are photoelectric device. It operates in .005 to 4000 $\mu$ m. The wave length range includes ultraviolet, visual and infrared. The most popular photo detectors are PIN photodiodes nad Avalanche photodiodes.[6]

**PIN Photodiode:** PIN photodiodes are most commonly used detector in fiber optic. PIN diode

has wide intrinsic layer between p and n region. Intrinsic layer has no free electron charges, it comes with high resistance and most of the diode voltage appears across it.[6]

**Avalanche Photodiode:** Avalanche Photodiode (APD) is a semiconductor junction that has internal gain. This APD are photodetector and also known as analog to photomultipliers. By applying high reverse bias voltage typically (100-300 V), APD show internal current gain effect and higher the reverse voltage the higher is the gain. [6]

**8 Optical Receiver:** Optical receiver is an optical to electrical converter. It detects the light incident which it gets and then converts it into a electrical signal. A receiver contains photodiodes, pre-amplifiers, equalizer and filter as signal processing equipment. The filter is used to get rid of the unwanted frequency components that might have been generated by the signal processing up to the filter. Optical receiver can work as a repeater as well, and extend the distance between the terminals.

### 9 Applications of Fiber Optic Communication System:

There are versatile use and applications of fiber optic communication system. Here some of them are discussed:

1. The most important use of fiber optic system is for transmission of data. For secure, reliable systems to transfer
2. It has an extensive use for delivery of digital video and data services
3. Fiber optic communication system is widely used is fiber-optic-based telemetry systems. Intelligent transportation systems.
4. Biomedical industry is using fiber optics
5. Optical fiber used as a carrier in Plain Old Telephone Service (POTS) for their nationwide network. Local exchange carriers (LECs) do this same service between central office switches at local levels, it also used for individual home (fiber to the home [FTTH]).
6. Optical fiber also vastly used by space, military, automotive and industrial sector.

### 10 Line-of-sight Optical Communication System

Line-of sight (LOS) optical communication is a relatively new technology in the world of telecommunications. LOS optical communication is continuously evolving. LOS optical communication has the potential to replace the traditional fiber optic links for short distance communications as it has a lot of advantages over traditional optical fiber. Generally, this sort of

communication is done between close distance, usually less than 2 miles. It provides optical communications at the speed of light. Line-of-sight (LOS) is often referred to as “fibreless optics” or “optical wireless” or ‘free space optics’ (FSO) transmission.

The design of how Line-of-sight system works is very simple. Wireless optical system uses directed line-of-sight paths between transmitter and receiver. A narrow beam of light is launched at a transmission station, transmitted through the atmosphere, and subsequently received at the receive station. [10]

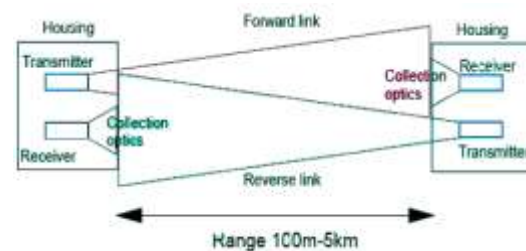


figure 3: basic Line-of-sight optical communication system [11]

The system design of a line-of-sight system depends on data rate, required range, and availability for its intended application. The overall transceiver design is influenced by several fundamental technical choices, like transmission characteristics, non-tracking versus automatic pointing and tracking, single transmitter/receiver versus multiple transmitter/receivers, and direct coupling versus fiber coupling.

**Advantage:** There are many advantages of wireless optical communications. Following are the list of those advantages’ system has license free frequency band from Federal Communication Commission (FCC) regulation. Compared to many other systems the cost of LOS is low. It can be easily upgraded. As LOS is a point-to-point communication, it is free from frequency interference or saturation, which may occur, in traditional radio-frequency wireless system. cables are not necessary in this kind of system so there is no associate cable cost. Installation time of LOS is less than other optical system like fiber optic.

**Disadvantage:** With so many advantages there are some disadvantages also exists in wireless optical communications. An infrared link nonresistant to shadowing or blocking caused by object or people positioned between the transmitter and receiver is a major disadvantage of wireless optical

communications. Infrared link operates in limited range, which is the result of power limit.

### 11 Components of Free Space Optical Communication System

**Transmitter:** Typically in line-of sight system light emitting diode (LED) or laser used as light source. They determine the transmitter capability of the system as well as provide optical signal.

**Infrared Link Modulation Technique:** There are various modulation techniques used in wireless optical communication system. They are On-Off Keying Modulation, Intensity Modulation (IM), Direct Detection (DD), and Multibarrier Modulation.

**On-off shift keying:** A modulator is required to react to the 1s and 0s in the data stream to allow the light source to be modulated. Usually in line-of-sight communication Amplitude Shift Keying (ASK) is used as the modulation method [12]

**Multibarrier Modulation:** In this modulation the large-water pouring bandwidth which is subdivided in to number of sub band and separate reduce-rate communication links are established in each sub bands.[12]

**Direct Detection (DD) Modulation:** Direct Detection Modulation is the most constructive down-conversion technique. Here photodetector produces a current proportional to the received spontaneous power that is proportional to the square of the received electric field. [13]

**Intensity Modulation (IM):** In Intensity Modulation the desired waveform is modulated onto the instantaneous power of the carrier [13]

**Receiver and Detectors:** Receiver is one of the most important components of free space system. Receivers receive light from transmission end. It is necessary for a receiver to be very sensitive. So that it can detect very weak transmission signals. At the receiver end, a detector is essential to detect the variation in light intensity that has taken place at the transmitter.

An amplifier is necessary to strengthen the detected signal and a demodulator to turn the detected signals back into base band data again.

**Laser Safety:** Like sunlight, laser light arrives in parallel rays, which, depending upon wavelength, the eye focuses to a point on the retina, the layer of cells that responds to light. Just as staring at the Sun can damage vision, exposure to a laser beam of sufficient power can cause eye injury. [2]

Table 1: The laser safety classification [14]

	650 nm (visible)	880 nm (infrared)	1310 nm (infrared)	1550 nm (infrared)
Class 1	Up to 0.2 mW	Up to 0.5 mW	Up to 8.8 mW	Up to 10 mW
Class 2	0.2-1 mW	N/A	N/A	N/A
Class 3A	1-5 mW	0.5-2.5 mW	8.8-45 mW	10-50 mW
Class 3B	5-500 mW	2.5-500 mW	45-500 mW	50-500 mW

A laser safety standard has been established for Optical wireless sources where they are classified in accordance with their total emitted power.

**12 Challenges for FSO:** The performance of a Line-of-Sight Communication link is primarily dependent upon the climatology and the physical characteristics of its installation location. Weather and installation characteristics that damage or reduce visibility effect of Line-of-Sight Communication link performance.

- **Atmospheric Attenuation:** Atmospheric attenuation of Line-of-Sight Communication systems is typically dominated by fog but can also be dependent upon low clouds, rain, snow, dust, and various combinations of each.[10]
- **Scintillation:** Atmospheric scintillation can be defined as the changing of light intensities in time and space at the plane of a receiver that is detecting a signal from a transmitter located at a distance.[10]
- **Atmospheric Turbulence:** Mainly this is caused by wind. Wind produces temporary pocket on the air with slightly different temperature, with different densities. This occur changes in the index of refraction so the light path through which the transmission will happen chances. The index of refraction changes happens in a random motion since these wind cells are not stable in time or in space. And it causes turbulence.
- **Window Attenuation:** Even though windows allow optical signals to pass through them, they all add some amount of attenuation to the signal. Uncoated glass windows usually attenuate 4% per surface, because of reflection. This means that a perfectly clear double-pane window attenuates all optical signals at least 15% (four surfaces, each with 4% reflection). Windows that are tinted or coated can have much greater attenuation, and the actual magnitude is typically quite wavelength dependent. [10]
- **Alignment:** One of the key challenges with Line-of-Sight Communication systems is maintaining transceiver alignment. Line of Sight Communication transceivers transmit

highly directional and narrow beams of light that must impinge upon the receive aperture of the transceiver at the opposite end of the link.[10]

- **Solar Interference:** A FSO system uses the combination of a highly sensitive receiver with a large-aperture lens, and, as a result, natural background light can potentially interfere with FSO signal reception. This is especially the case with the high levels of background radiation associated with intense sunlight. In some circumstances, direct sunlight may cause link outages for periods of several minutes when the Sun is within the receiver's FOV. [10]

### 13 Line-of-Sight Optical System Power Budget

The link budget of a line-of-sight communication system can be done with a very simple equation. If the optical efficiencies, detector noises and any other factors has not been considered the equation can be expressed as,

$$P_{\text{Received}} = P_{\text{Transmitted}} * [d_2^2 / (d_1 + (D * R))^2] * 10^{(-a * R / 10)} \quad (12.1)$$

Where, P = power, d1 = transmit aperture diameter (m), d2 = receive aperture diameter (m), D = beam divergence (mrad)(1/e for Gaussian beams; FWHM for flat top beams), R = range (km), a = atmospheric attenuation factor (dB/km). [10]

To determine the performance of FSO, the best way is to calculate the link margin.

$$\text{Link Margin} = 10 \log_{10}(P_{\text{Received}} / P_{\text{Required}}) \quad (12.2)$$

[1]

To calculate the link budget, it is necessary to know transmit power receiver sensitivity, optical system loss, alignment loss geometric loss etc.

Transmit power: Transmission power means total optical energy transmitted by the FSO system.

Receiver sensitivity: It means the lowest amount of optical energy need to be received by the FSO.

Geometric losses: Geometric losses include the losses related to the spreading of the transmitted

beam between the transmitter and the receiver. Large receive apertures or smaller transmit divergences can reduce geometric loss within a range

Miss point loss: Miss point loss means the imperfect alignment of the transmitter and receiver. [10]

### 14 Application of Line Of Sight:

- Line of sight communication system can be used for LAN-to-LAN connection at very fast speed (fast Ethernet or gigabyte).
- For Temporary Network installation.
- It can be used to recover from network disaster. Because, it can reestablish connection quickly.
- It is used in satellite communication to communicate between space craft.[14]

### 15 Comparison Between Optical Fiber Communication system and Line of sight optical communication system:

#### • Fiber cable:

One of the major components of fiber optic communication (FOC) system is optical fiber which is made of either glass or plastic. Line of sight optical system does not need any kind of fiber. In this technology laser transmitted in free space for communication.

#### • Distance:

Optical fiber communication is very much suitable for long distance communication. In fiber optic link, without using repeater more than 40 Km of data transmission is possible. Repeater of fiber optic link boost up the weaken signal and message can sent over thousands of kilometers. But LOS systems can only handle the short distance communication which is less than two kilometers.

#### • Modulation technique:

LOS system for free space communication system uses mainly on-off shift keying technique as a modulation technique. Here, Binary 1 represents Light on and Binary 0 for Light off. For fiber optic different types of modulation technique used Direct modulation, indirect modulation like electro optic and electro absorption modulation etc.

#### Signal:

Both systems are very much suitable for digital data. As the systems use light signal, they do not carry electricity so they do not make any interference with other electrical equipment's.

- **Wavelength:**

FOS and LOS system use same type of infrared wavelength.

- **Link budget:**

For both systems the link budget is different. Link loss occur for the effects of temperature on the electronics and the electro-optics (e.g., LED or laser), due to variation in optical coupling, the light propagates through fiber so transmission loss, losses due to splices and connectors. But for a LOS system it is totally different the major points related to links budget calculation are inputs of transmit and receive power receiver sensitivity, optical system loss, alignment loss geometric loss etc.

- **Environmental factor:**

Environment plays a very important role in Line-of-sight systems. The climate physical characteristics of the installation location have a big impact on performance of the system. Whereas in fiber optic communication the data transmission happens through fiber so, environment cannot make any difference in transmission.

- **Atmospheric Attenuation:**

Atmospheric attenuation can occur in line-of-sight system for fog, rain, dust, snow etc. atmospheric attenuation is absent in fiber optics. But in this system attenuation can happen by absorption like intrinsic absorption by silicon dioxide, absorption by core dopant, absorption by structural defect in glass etc and scattering.

- **Security:**

It is very difficult to encrypt data from FO cables as they do not radiate signals for eavesdropping purposes. It can be accomplished by bending of the cable. Los system usually use very narrow beam, it is not easy to encrypt so, it gives system secure transmission.

- **Safety:**

For optical fiber the light pass-through fiber not in free space. So the human safety is not a major concern for this system. High power beam can be injurious to skin and eye. IR light can damage the surface of the eye, the damage threshold is higher than that for UV light.

- **Installation cost:**

Fiber optic is relatively costly system than free space system. Fiber optic system needs fiber cable, security software and up-gradation. But LOS

system is cable free, no security software needed and only up-gradation of tera server is necessary.

- **Installation time:**

Most of the Fiber optic system takes far longer time to install than a LOS system.

### CONCLUSION:

After Analyzing and comparing fiber optic communication system and Line of sight communication system we can conclude some major points such as

- The fiber optic communication system and Line of sight communication has some similarities and some differences.
- Both systems are suitable for high speed and large bandwidth data communication. So, these systems are very much popular in current commercial telecommunication industry.
- Though the optical power used for both systems, each system has different applications.
- Basic characteristics of the both system made the unique in their own field of application
- Both the systems are improving day by day
- So, the demand is increasing in telecommunication sectors.

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