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Free Space Light Communication

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Abstract: **Today's communication field is highly focused on inventing new technologies both wired and wireless which will contribute in setting up of communication links with maximum performance and low errors as far as possible. In wireless technology, free space light communication technique has gained much attention and popularity of all researchers worldwide. This paper aims at providing the exact area which limits free space light communication, ways to overcome such limitations, designing of transmitter and receiver units and its advantages over existing technologies.**

Keywords: **Open Medium Optical Communication (OMOC), Field Effect Transistor (FET), VCSEL (Vertical Cavity Surface Emitting Laser), Infrared Region (IR), Pseudo Random Code Generator (PRBS), Bit error rate (BER), Free Space Light Communication (FSLC), Avalanche photodiode (APD).**

I. INTRODUCTION

Even though radio and microwave communication are still popular, free space light communication has now become the centre of interest. Although communication using light injected into tiny glass fibre has replaced copper cables to high extend, there are still many applications where the space between the transmitter unit and receiver unit is utilized.

II. IMPORTANCE OF LIGHT

A. Strength of light:

Speed of light in vacuum is 29979346 meters per second, commonly denoted as *c*. Light beam propagate through air with a lesser speed than *c* with 29970354.8 kilo meters per second. This is because the refractive index of air towards light range (ultraviolet, visible and infrared) is 1.0003. A single semiconductor laser emitting light within the range 800 nanometre to 10000nm has the capacity to transmit: data of 900 floppy disc, 10000 pictures, 300 minutes of voice recording, 1000 novels and approximately 600000 pages of a book all at a time.

III. WORKING

A. Choice of wavelength:

Wavelength range selected for free space light communication (FSLC) is in IR region where wavelength range starts from 850nm to 1660nm. This range is used for both FSLC as well as communication using optical fiber (enclosed medium).But especially for FSLC; highly preferred range is 850nm to 1550nm. This is due to the following reasons:

- Longer wavelengths tend to experience less scattering than shorter wavelengths.
- According to Food and Drug Administration (FDA), exposure to light having power density maximum up to 100mW/cm2 is safe for human body. Power density corresponding to 850nm is and for 1550nm is 50mW/cm2.
- Highly efficient lasers such as Distributer feedback (DFB) or Fabre Parrott lasers is well suited to generate light within the above mentioned range.
- 50-65 times as much power can be transmitted at this wavelength (850nm to 1550nm) that can be transmitted at 780-850nm with the same eye safety level.

B. Working and designing of transmitter unit:

As in radio communication, optical communication via open medium must rely on some type of modulation technique to transmit the data. The method chosen is on/off light pulse stream. The position or frequency of light pulses carries the information. To transmit human voice light flashing rate of the light source (laser) should be at least 7000 flashes per second. For television flashing rate needed is 10 million flashes per second .Here I am limiting my explanation only voice data transmission. The optical transmitter unit has six subsystems: amplifier, filter, voltage to frequency converter (VFC), pulse generator, light emitter and light collimator.

- Amplifier: used to amplify weak vocal signal.
- VFC: Provides an output frequency accurately proportional to the input voltage. Extensive testing by telephone authorities has concluded that frequencies beyond 3.5 KHz are not needed for voice audio communication. Voice audio, whose upper frequency is 3.5 KHz, is connected to VFC which is an oscillator whose frequency is shifted up and down according to the amplitude and frequency of the vocal signal.
- Pulse generator: the generator is known as Pseudo Random Binary Sequence (PRBS) generator. Its output is in the form of binary pulses, a sequence of “1” (ON) and “0” (OFF). Then it has a subsystem which makes the pulses of the transmitted signal using line-coding (Return-to-zero (RZ), Chirped Return-to-zero (CRZ), Non Return-to-zero (NRZ)). Pulse generator that can generate 10000 pulses per second is sufficient enough as long as pulses with 1micro meter width are pulsed by laser (light emitter).
- Collimator: light bent by a lens as it leaves its transmitter unit towards the free space is said to be “collimated”. Mirrors or/and lens can be used as collimator. But mirrors larger than 3 inch size are too heavy. Thus it is best to used fat/Fresnel lens as collimators when beyond 3 inch size is needed. Figure 2. Given below illustrates the role of collimator where θ is transmitter’s divergence half angle, Φ is emitter divergence, emitter diameter (d) and lens diameter (L).

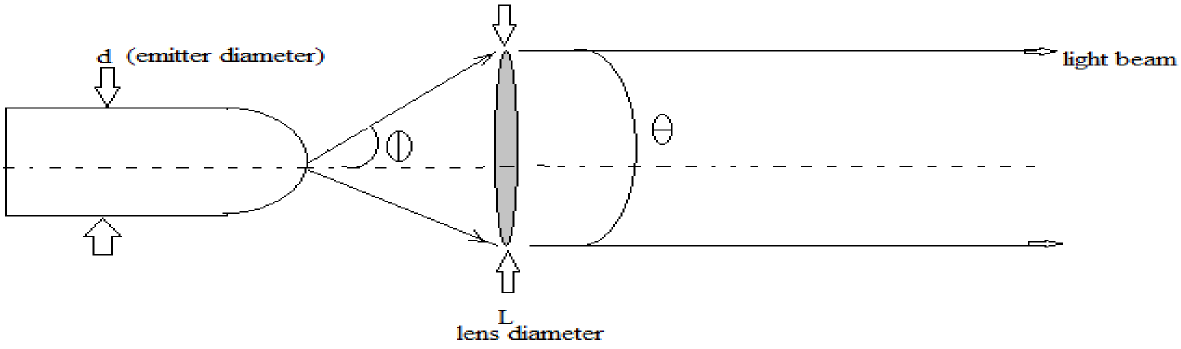

Fig. 1: Working of collimator

- Light emitter: I will recommend using Distributed feedback laser (DFB) than VCSEL laser because DFB laser has good stability and high power output with narrow beam width (highly focused).DFB is ideal for long distance communication with data rate supported up to 100Gbps. Below Fig.2, illustrates the power output of various lasers.

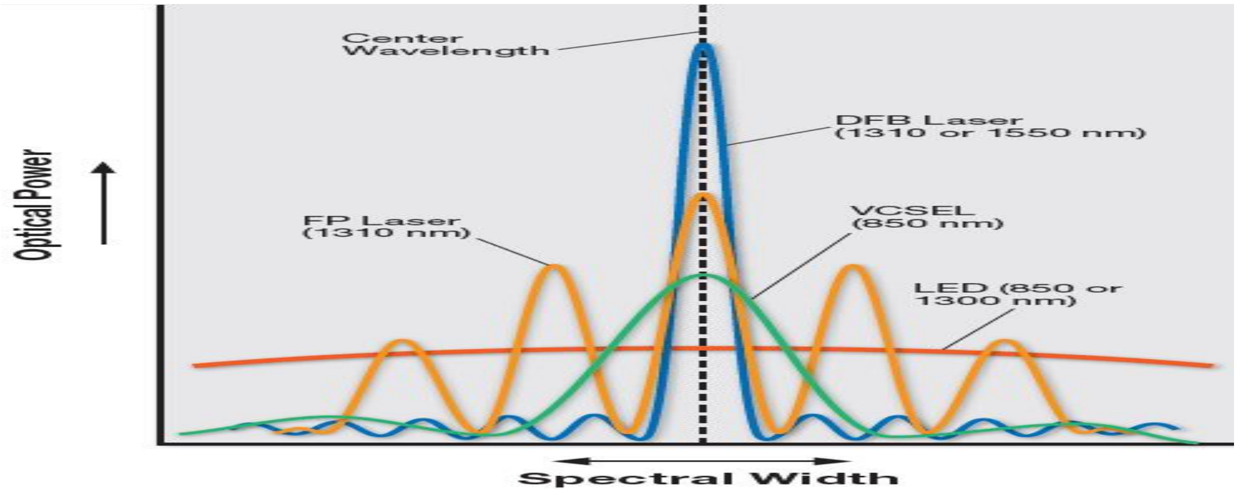

Fig. 2: Power output of various lasers

C. Working and designing of receiver unit:

The overall task of the optical receiver is to extract the information that has been placed on the modulated light carrier by the distant transmitter and restores the information to its original form. The receiver unit can be broken down into 6 sub units or sections. These are: light collector (lens), light detector (PIN), current to voltage converter, signal amplifier and pulse discriminator.

- Light collector: although mirrors could be used to collect light, glass or plastic lens are easier to use and are less bulky. “Fresnel” lens is the best solution.
- Light detector: many light detectors are available such as photo transistors, photo resistors, photo cells, silicon PIN photodiode, avalanche photodiode (APD). But the best is PIN photo diode because of their advantages like: 100 times faster than photo transistors with same active area, APDs has higher gain which allow them to be used for long distance communication but additional noise produced by the ambient light focused onto the detector cancels much of the gain advantage of APDs, APDs are 20 times more expensive than PIN diodes, PIN is highly sensitive to wavelength ranging from 900nm to 1200nm. Hence very much compatible with DFB laser source.
- Signal amplifier: used for amplifying weak received signal(s).
- Current to voltage converter: current form PIN detector is usually converted to voltage before the signal is amplified.
- Pulse discriminator: is basically used to discriminate between the stray light (noise) and actually transmitted light.

D. Certain considerations while designing this communication system:

- This communication should follow “Rule of thumb” rule. It states that usually data transfer rate is about 1.7times the bandwidth. This rule helps in selecting proper light source in achieving the targeted data rate. For example if DFB laser having a bandwidth of 26GHz can help in achieving data rate of 44Gbps.
- Collector’s diameter should not be more than 100 times detector’s (PIN diode) active area.
- Range Equation: The amount of light captured or collected by the light receiver can be calculated using this equation if the acceptance angle and collector’s area is known. Range equation illustrates how the divergence angle (θ) affects illumination area from the light source and how much should be the separation gap/distance between transmitter and receiver units. Below given equation is the range equation (D) where P is transmitter’s power in watt, A is collector’s area, N represents PIN diode’s noise floor in watt, E represents PIN diode’s conversion efficiency which is typically taken as 0.5 .

$$D = \sqrt{(P.A.E)/(tan^2\theta.32.N)} \qquad (1)$$

Range equation can be represented diagrammatically as below:

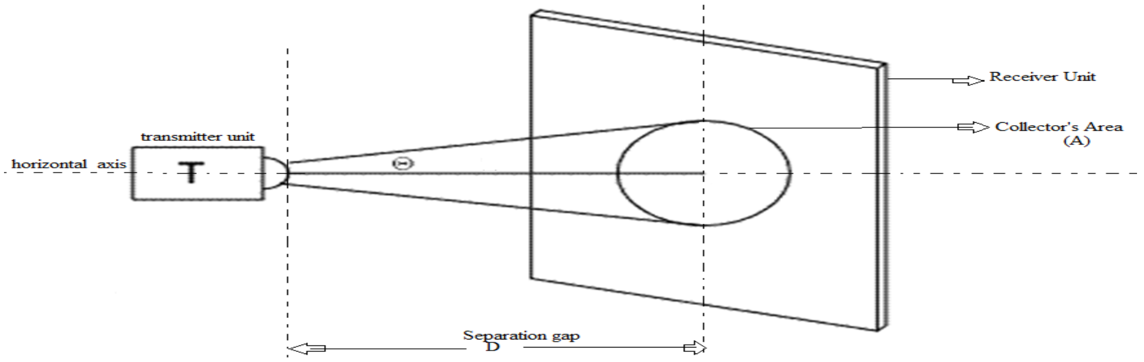

Fig.3: Diagrammatic illustration of the range equation

- Collector should satisfy “forbidden alignment” rule that states that the positioning of the receiver and transmitter should be in north/south alignment for preventing “sun blindness” and stray light effect.
- Equation (1) shows the relation between the divergence half angle (θ) and the separation distance (x) and emitter’s diameter (d).

$$\tan\theta = \frac{d}{x} \qquad (2)$$

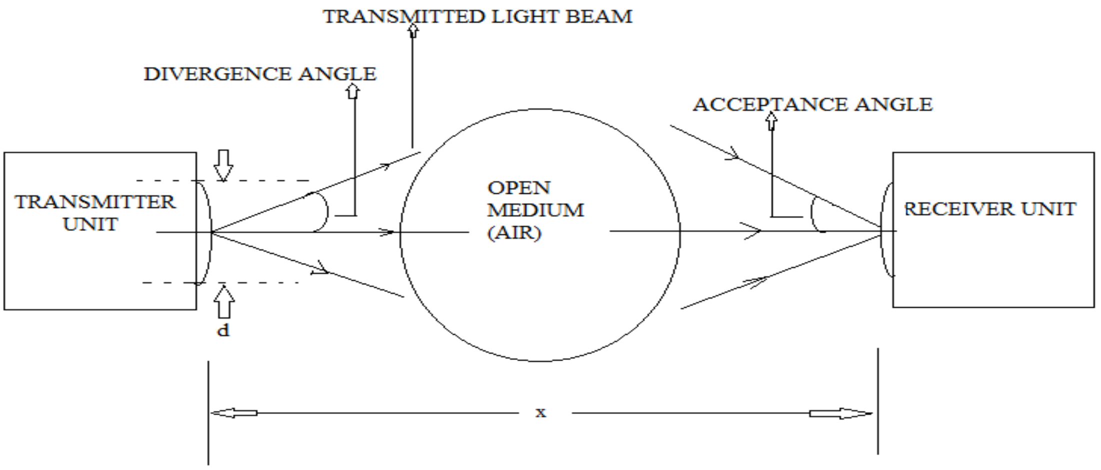

Fig.4: Illustrates relation between θ, x and d

E. Complete block diagram of free space light communication technique (FSLC):

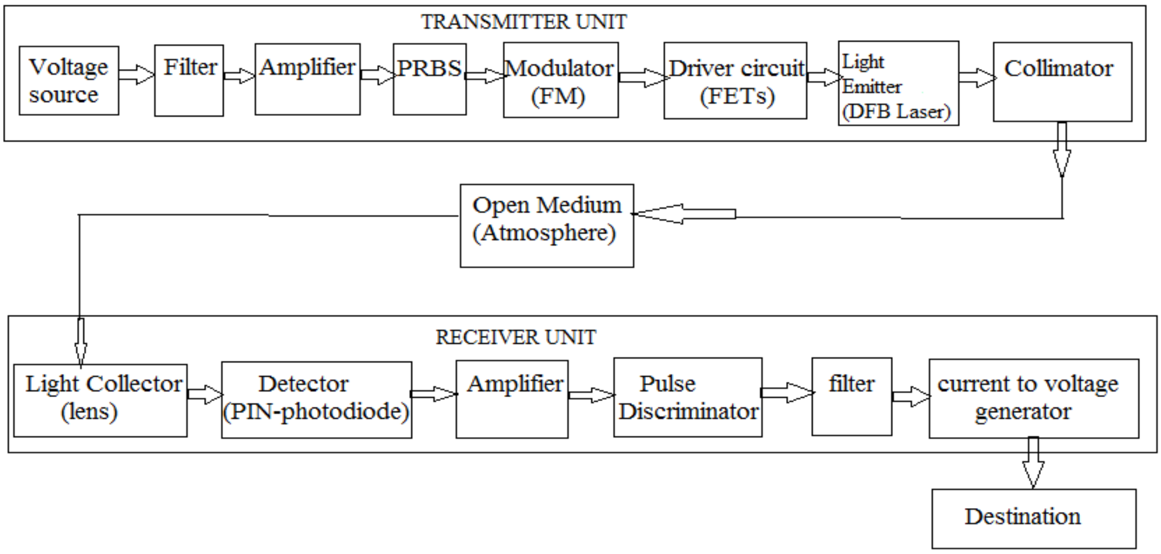

Fig.5: Block diagram of FSLC

IV. IMPROVISING THE SYSTEM'S PERFORMANCE

A. Immunity against stray light (noise) using optical heterodyning technique:

In radio communication, this method mixes the frequencies from the incoming radio signal with another fixed local oscillator frequency. The result is both a sum and difference family of frequencies that can be more easily amplified and used to separate the desired signal form the background noise and interferences .This same principal can applied in the realm of optical frequencies to separate actual light signal form stray light which falls on the same detector unit along with the original data signal.

In FSLC, special lasers such as VCSEL or DFB must be used that have been carefully constructed to emit light of very high purity (very narrow bean width that means very narrow nearly 1 wavelength).When the light from two of these lasers that emit light of slightly different wavelengths, is focused on to a detector, the detector's output frequency corresponds to a sum and difference of the two wavelengths. In practice, the light from a nearby laser produces a light with a slightly different wavelength than the distant transmitter laser. As in the radio technique, with the help of optical heterodyning technique will allow very weak signals to be processed more easily and permits many more distinct wavelengths of light to be transmitted without interference.

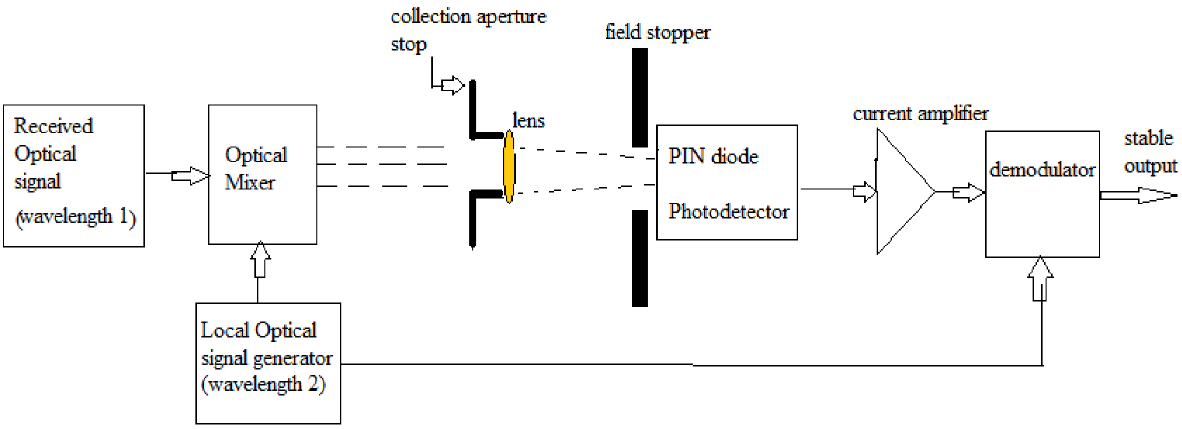

Fig.6: Block diagram illustrating optical heterodyning technique

V. PERFORMANCE

Performance of FSLC depends upon several parameters. These parameters can be divided into two categories: internal parameters and external parameters. Internal parameters are concerned with design of an FSLC system and include optical power, wavelength, transmission bandwidth, divergence angle and optical loss on the transmitter and receiver sensitivity, bit error rate (BER), receive lens diameter, and receive field of view. External parameters are related to the environment in which the system is to show its result. The parameters include visibility or line of sight, atmospheric attenuation, scintillation etc. which come under the effects caused by different atmospheric conditions. It is important to understand all these parameters before designing a system.

A. Scintillation:

The propagating wave sometimes gets defocused from the path leading to a loss because of the solar thermal turbulence which is termed as scintillation. Scintillation will be high when temperature is high. Thus scintillation occurs during midday. FSLC systems operated horizontally in the atmosphere near the surface (in case of terrestrial links), experiencing the maximum scintillation. Scintillation is expresses as below

$$\alpha_{\text{scintillation}} = \sqrt[2]{23.17\left(\frac{2\pi}{\lambda}10^{9}\right)^{\frac{7}{6}} Cn^{2}\, x^{\frac{11}{6}}} \qquad (3)$$

Intensity and speed of scintillation increases with signal frequency. In the above equation (1), λ is the transmitted signal's wavelength in nanometer, x is the separation distance between the transmitter and receiver, Cn^2 is termed as refractive index of the atmosphere which depends on the temperature. Value of Cn^2 is 10^{-16} for low turbulence for high turbulence it is 10^{-13} and 10^{-14} for moderate turbulence.

B. Signal to noise ratio (SNR):

SNR becomes progressively worse with increase in the distance. Below plot illustrates SNR versus distance for a various values of Cn^2 .

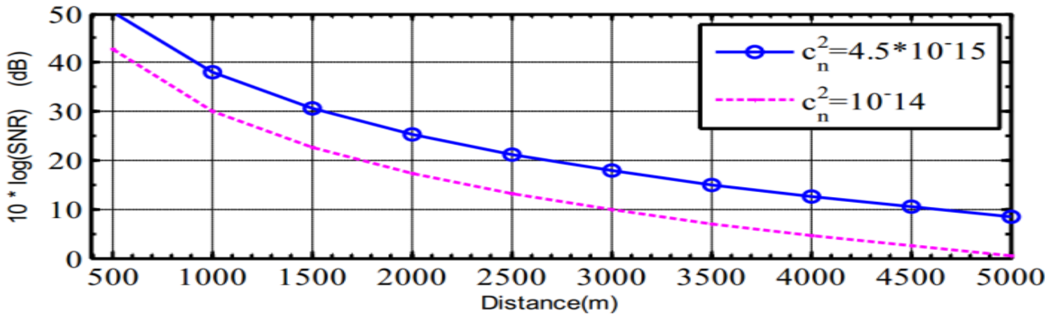

Fig.7: Plot of SNR versus distance

C. Noise equivalent power (NEP):

It is the measure of the sensitivity of an optical detector or detector system. It is defined as the signal power which gives a signal to noise ratio of 1 for an integration time of half a second, or more technically the radiant power that produce a SNR of unity at the output of a given optical detector. NEP is expressed below where (η) is quantum efficiency, (h) is planks constant, (c) is speed of light in air and (λ) is operation optical signal wavelength.

$$\mathrm{NEP} = \frac{2hc}{\lambda\eta} \text{ , watt} \tag{4}$$

D. Absorption:

Absorption is the conversion of light rays into heat as they interact with the molecules of impurities present in the atmosphere. The absorption coefficient ($\alpha_{\text{absorption}}$), refractive index of atmosphere (k) and wavelength of the signal are related to each other as shown below:

$$\alpha_{\text{absorption}} = \frac{4\pi k}{\lambda} \tag{5}$$

E. Free space path loss:

In the field of communication, free-space path loss (FSPL) is the loss in signal strength that would occur in a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. The equation for free space path loss (FSPL) and the effect of link length are given below where x is the separation distance between the transmitter and receiver, λ is the transmitted signal's wavelength in nanometer:

$$\mathrm{FSPL} = \left(\frac{4\pi x}{\lambda}\right)^2 \tag{6}$$

F. Geometric loss:

Geometric losses (GL) in dB are those losses that occur due to the spreading of transmitted beam between transmitter and the receiver. The beam spreads to a size larger than the receive aperture and the sufficient amount of energy is lost given by the below formula where R_A is Receiver's aperture diameter(m) , T_A is transmitter's aperture diameter (m) , x is distance between the transmitter and receiver and θ is divergence angle (in radian (rad)) .

$$\mathrm{GL\ (dB)} = 10\log\left(\frac{RA}{TA+[x\mathrm{X}\theta\,]}\right)^2 \tag{7}$$

G. Attenuation:

Attenuation is the loss of light or signal power, often expressed as dB/Km for loss per kilometer (Km).Scattering and absorption are two primary causes of attenuation. Scattering: change of direction of light beam or photons after striking small particles present on the atmosphere. Absorption: conversion of light rays into heat as light beam interacts with small particles present on the atmosphere.

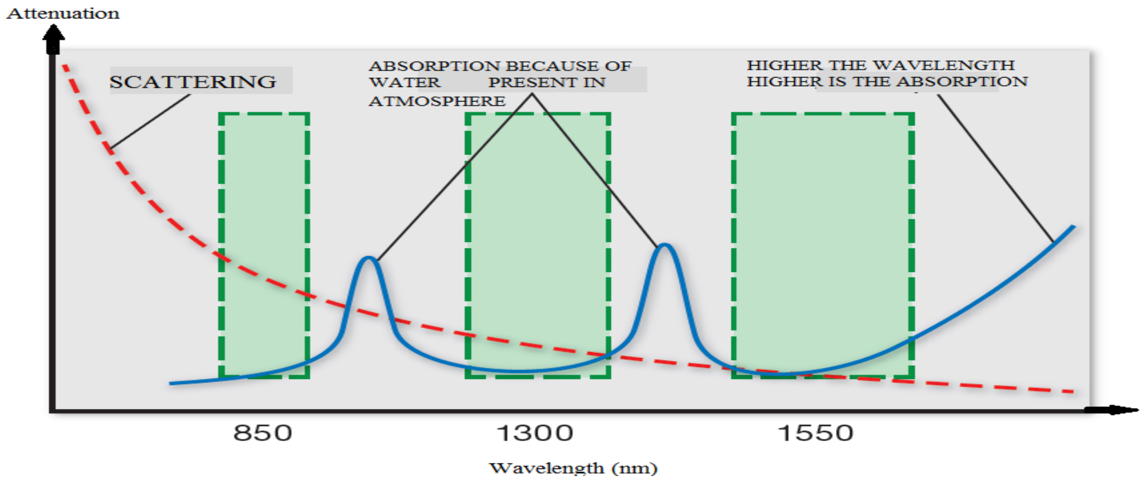

Fig.8: Illustrates Attenuation faced by the transmitter light wave in atmosphere

TABLE I: COMPARISON OF ATTENUATION LEVEL OF VARIOUS TECHNOLOGIES

Technologies	**Level of attenuation**
Coaxial cable	25dB/Km
Twisted pair cable	18dB/Km
Glass fiber	5dB/Km
Free space light communication (FSLC)	0.13 dB/Km to 0.01 dB/Km

VI. COMPARISON WITH OTHER COMMUNICATION TECHNOLOGIES

TABLE II: TECHNICAL COMPARISON OF FSLC WITH OTHER EXISTING TECHNOLOGIES

Technology	**Data Rate**	**Transmission Distance**	**Core size**
Thinnet Coax Cable	10Mbps	185m	0.35cm
Thicknet Coax Cable	10Mbps	500m	1cm
Shielded Twisted Pair cable (STP)	10Mbps	300ft	0.51mm
Unshielded Twisted Pair ategory1 (UTP1)	1 Mbps	100m approximate	1cm
Unshielded Twisted Pair category2 (UTP2)	4 Mbps	100m approximate	1cm
Unshielded Twisted Pair category3 (UTP3)	10 Mbps	100m approximate	1cm
Unshielded Twisted Pair category4 (UTP4)	16 Mbps	100m approximate	1cm
Unshielded Twisted Pair category5 (UTP5)	100 Mbps	100m approximate	1cm
Unshielded Twisted Pair category5e (UTP5e)	1Gbps	100m approximate	1cm
Unshielded Twisted Pair category6 (UTP6)	1/10Gbps	100m approximate	1cm
Optical multimode fiber generation 1(OM1)	100Mbps	300m	62.5µm
Optical multimode fiber generation 2 (OM2)	100Mbps	1000m	50µm
Optical multimode fiber generation 3 (OM3	< 10Gbps	2000m	50µm
Optical multimode fiber generation 4 (OM4)	10Gbps	>2000m	50µm
Optical single mode fiber generation 1 (OS1)	< 100Gbps	30Km	9µm
Optical single mode fiber generation 2 (OS2)	100Gbps	30Km	9µm
Free space light communication (FSLC)	>100Gbps	2.3Km	-

VII. CONCLUSION

In this work, I have illustrated ways to analyze the free space light communication (FSLC) and atmospheric factors affecting this communication technique. Designing of transmitter and receiver sections of OMOC is explained here. Also I have explained all advantages of FSLC over other communication techniques in the form of tables.

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