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Visibility Performance of FSO Transmission In Between Light Fog & Thin Fog (Delhi Zone, India)

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Abstract: Free-space optical communication (FSO) has taken the world into the technological peak where we can fulfil our rapid demand through transmission of optical signals through the atmosphere to provide high data rate and is termed as optical wireless communication. Generally lasers or led are used as transmitters and among which lasers are preferred because of their coherence nature. This paper presents the effects of light and thin fog atmospheric attenuations on a Free Space Optics (FSO) transmission system. We have considered NEW DELHI, INDIA as the place for our study. The real data analysis was collected from INDIAN METROLOGICAL DEPARTMENT (IMD) from the year of 2006 to 2015. We have calculated the average lowest visibility value in kilometres. Overall average value was calculated to be 1.2km. The Optisystem software 7.0 versions were used to simulate and obtain the Q-factor and BER. The transmitted and received power result has been compared for analysis. The maximum Q-factor was obtained i.e.38.8141 for a range of 1km and the attenuation was calculated from the visibility data i.e. 1.7131 dB/km with a data rate of 10Gpbs.

Keywords: FSO, Atmospheric attenuations, visibility, OPTICAL wireless, LASERS, Q-factor, BER, Optisystem etc.

I. INTRODUCTION

With the advancement of science and technology man has reached to an era of wired to wireless communication medium. This evolution has completely solved the last mile problems which are based on microwave communication technology in a point of bandwidth limitation & security.

FREE SPACE OPTIC (FSO) is a line of sight technology which uses laser & photo detectors to provide optical connection between two points without the fiber. Free space" means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable or an optical transmission lin.

The technology is useful where the physical connections are impractical due to high costs or other considerations. Although OPTICAL FIBER CABLE(OFC) has proved itself as the most effective mode of communication due to its low attenuation ,large information capacity, enhanced safety but some of its disadvantages such as delicacy, repeated electrical-optical-electrical conversion has proved FSO as a pioneer to overcome the last mile problems.FSO has high bandwidth, high error bit rate (BER), low SNR, high data security, low cost & easy installation and maintenances has replaced all the other traditional network fiber. Its various applications are LAN-to-LAN connections on campuses at Fast Ethernet or Ethernet speed, LAN-to-LAN connections in a city, a metropolitan area network, to cross a public road or other barriers which the sender and receiver do not own, Speedy service delivery of high-bandwidth access to fiber networks, Converged Voice-Data-Connection, Temporary network installation (for events or other purposes), Re-establish high-speed connection quickly (disaster recovery), As an alternative or upgrade add-on to existing wireless technologies, etc..

II. LITERATURE SURVEY

Recorded data on visibility of New Delhi, India.

Table 1-The above data was collected from Indian Meteorological Department (IMD).

Year	Average lowest visibility month	Average lowest visibility value (km)
2006	January	1.5
2007	November	1.4
2008	December	1.4
2009	January	1.4
2010	January	1.1
2011	December	1.3
2012	November	1.4
2013	January	0.5
2014	January	1.0
2015	January	1.0

Overall average value	1.2 km

Table 2-International visibility codes for weather conditions.

Weather conditions	Visibility
Dense fog	0.0km to 0.05km
Thick fog	0.2km
Moderate fog	0.5km
Light fog	0.77km to 1km
Thin fog	1.9km to 2km
Haze	2.8km to 4km
Light haze	5.9km to 10km
Clear	18.1km to 20km
Very clear	23km to 50km

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III. VISIBILITY DATA

Visibility is characterized by the transparency of atmosphere estimation from the human observer's eye visibility, and it is measured in kilometres. The value of visibility will be high for less attenuation. The value of visibility is measured by transmission meter or diffusion meter, usually measured at airports by the Meteorology Department. It is given mainly by the atmospheric extinction coefficient associated with solid liquid particles; this extinction is primarily caused by scattering rather than absorption of the light. The effect of different atmospheric condition to FSO system can be found by determining the scattering coefficient where it depends on the visibility conditions. Table 2shows the International Visibility Codes for different atmospheric conditions. The fog category falls in between 0km up to 2km of visibility while for haze the visibility is between 2.8km to 10km. The clear weather is when the size of particles in the atmosphere is smaller than the wavelength of light. The data of visibility was collected from Indian Meteorological Department (IMD) for New Delhi, India region from the year 2006 to 2015. Table 1 shows the average highest visibility value and average lowest visibility value along with their months. It shows that the minimum visibility was on January 2013 that falls into moderate fog category while maximum visibility was on January 2006 that falls above light fog category.

IV. KRUSE AND KIM RELATIONS

Thus, the attenuation coefficient is approximated by the following relation (Kruse relation):

$$\gamma(\lambda)\ ;\ \beta_{\alpha}(\lambda) = \frac{3.912}{v}\left(\frac{\lambda_{nm}}{550}\right)^{-q}$$

The coefficient q depends on the particle size distribution. It is given by [1]:

$$q = \begin{cases} 1.6 & \text{si } v > 50\text{km} \\ 1.3 & \text{si } 6\text{km} < v < 50\text{km} \\ 0.585\, v^{1/3} & \text{si } v < 6\text{km} \end{cases}$$

This relation was largely used in the literature with the aim of determining the FSO equipment link budget. From the last two equations, it is clear that, for any meteorological conditions, more the wavelength increases, more the attenuation decreases.

Thus, a recent study proposes another expression for the parameter q. This expression, not yet experimentally checked, is the following one [2]:

$$q = \begin{cases} 1.6 & \text{si } v > 50\text{km} \\ 1.3 & \text{si } 6\text{km} < v < 50\text{km} \\ 0.16v + 0.34 & \text{si } 1\text{km} < v < 6\text{ km} \\ v - 0.5 & \text{si } 0.5\text{km} < v < 1\text{km} \\ 0 & \text{si } v < 0.5\text{km} \end{cases}$$

This last equation implies independence between the atmospheric attenuation values and the wavelength in presence of a dense fog reducing the visibility below 500 m. Beyond 500 m of visibility, this relation respects the conclusion deduced from the previous relations, namely a smaller attenuation for increasing wavelengths.

Therefore using the **Kim & Kruse** relationship and the following recorded data of IMD, we get the value of q=0.6216 [1] (Visibility< 6Km) or q=0.532 [2] (1Km <Visibility< 6Km) and attenuation to be 1.7131dB/km or 1.8785dB/km. Here we will be considering 1.7131dB/km obtained from [1] which was largely used for FSO application.

V. METHODOLOGY

Components that we have used in our simulations are basic Analog, digital & optical circuitry that can be found in any simulation tool & software. They listed below as below:

- **Pulse generator:**
- Pulse generator is to represent the information or data that wants to be transmitted; in our simulation we have used a pseudo-Random bit sequence generator as source of binary information. The output from a generator is a bit stream of binary pulses; a sequence of "1"s (ON) or "0"s (OFF), of a known and reproducible pattern.
- **NRZ pulse generator :**
- Non-Return-to-Zero (NRZ) electrical pulse generator. This subsystem encodes the data from the user defined bit sequence pulse generator by using the NRZ encoding technique. A NRZ line code is a binary code in which 1's are represented by one significant condition and 0's are represented by some other significant condition.

- **LOW Pass GAUSSIAN filter:**
- An ideal low pass filter will keep all spatial frequencies below a nominal spatial frequency, and remove all spatial frequencies above it. Unfortunately, a true ideal low pass filter has infinite support (i.e., has an infinitely large non-zero spatial extend). Even a practical approximation to an ideal low pass filter has large spatial support.
- A Gaussian, on the other hand, isn't ideal in terms of which frequencies it filters out. A Gaussian in the spatial domain turns out to be a Gaussian in the spatial frequency domain. That is, it doesn't produce very sharp spatial frequency selectivity. The advantage though is that the spatial support of the filter is small. People use Gaussian filters for this because they are convenient mostly. Filtering with a Gaussian tends to look "natural" compared to ideal low pass filters, which can generate ringing artifacts.
- Gaussian filters have the properties of having no overshoot to a step function input while minimizing the rise and fall time. This behavior is closely connected to the fact that the Gaussian filter has the minimum possible group delay.
- Mathematically, a Gaussian filter modifies the input signal by convolution with a Gaussian function, and the Gaussian function converges to zero so rapidly that a causal approximation can achieve any required tolerance with a modest delay.
- As well as it is more efficient in case of white noise filtering.

- **MACH Zehnder Modulator:**

It is an optical modulator that the function is to vary intensity of the light source from the laser according to the output of the NRZ pulse generator.

- The output of a NRZ driver is given to a subsystem Mach-Zehnder modulator which has two input ports, one is electrical input and another is optical input port. A CW laser is connected to optical input port of Mach-Zehnder modulator. The operating wavelength of CW laser is 1550 nm.
- Output of Mach-Zehnder modulator is given to optical amplifier to increase the gain and traverse through FSO channel.
- **Cw laser :**
- Continuous-wave (cw) operation of a laser means that the laser is continuously pumped and continuously emits light. The emission can occur in a single resonator mode (→ single-frequency operation) or on multiple modes.
- The operating wavelength of CW laser is 1550 nm. The 1550nm band is attractive due to its compatibility with the third window and eye safety.

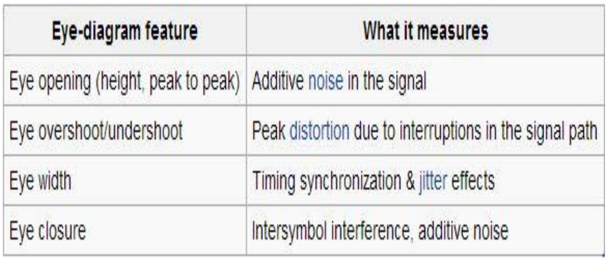
- **Photo Detector(APD):**
- The APD (avalanche photodiode) is a high sensitivity photodiode that operates at high speeds and high gain by applying a reverse bias. Delivers a higher S/N than PIN photodiodes and is widely used in optical rangefinders, spatial light transmission, scintillation detectors, etc.
- The optical receiver consist of an avalanche photodiode (APD) (having gain=10), APD must be capable of matching the system bandwidth.

- **Low Pass Bessel Filter:**
- The Bessel filter is a linear form of filter that provides a maximally flat group delay or propagation delay across the frequency spectrum, but offers a slower transition from pass-band to stop-band than for other forms of filter of the same order.
- A bessel Low Pass Filter (LPF) is used to filter out the unwanted higher frequency signals. Bessel LPF is used with a cut-off frequency of 0.75 x bit rate of the signal.

- **3R regenerator:**
- 3R regeneration includes three regenerating operations with a signal: regeneration of amplitude (amplification), regeneration of signal waveform and regeneration of synchronization (relative time delay deviation).
- Detect optical signals, convert them into electric signals, completely regenerate the signal in its electric waveform and transmit it in the form of an optical signal.

- **EYE Diagram analyser:**
- It is an experimental tool for the evaluation of the combined effects of channel noise on the performance of a baseband pulse-transmission system.
- Eye diagram is an oscilloscope display in which a digital signal from a receiver is repetitively sampled and applied to the vertical input, while the data rate is used to trigger the horizontal sweep.

- **OPTICAL SPECTRUM ANALYZER:**
- An Optical Spectrum Analyzer (or OSA) is a precision instrument designed to measure and displays the distribution of power of an optical source over a specified wavelength span. An OSA trace displays power in the vertical scale and the wavelength in the horizontal scale.It uses reflective and/or refractive techniques to separate out the wavelengths of light. An electro-optical detector is used to measure the intensity of the light, which is then normally displayed on a screen in a similar manner to a radio- or audio-frequency spectrum analyzer.
- It is also a wavelength-selective optical power meter that measures signal power versus wavelength (or frequency),tunable over a specified wavelength range somewhere between the ultraviolet and the infrared, depending on the application. The most common application of an OSA is characterizing optical components and testing optical signals in telecommunication networks.
- These are similar to wavelength meters in that they produce a spectrum of intensity versus wavelength, but each has a slightly different specialty. While wavelength meters pinpoint the wavelength of a laser to an extremely high accuracy, optical spectrum analyzers measure both wavelength and of a laser at a high accuracy, often across a much wider dynamic range of wavelengths. This makes OSAs useful for analyzing transmitted signals—in particular, for discriminating a desired signal from unwanted noise, known as the optical signal-to-noise ratio (OSNR).In dense wavelength division multiplexing (DWDM) systems, OSAs are the key instruments for testing (channel) power levels, wavelength, and OSNR over a specified wavelength range.
- Optical spectrum analyzers typically use either direct spectral measurement or fast-Fourier transform (FFT)-based measurement. An OSA that incorporates fast-Fourier transform (FFT)-based measurement is often called a multi wavelength meter. Another type of OSA is the heterodyne OSA, which uses inverse Fourier transforms to achieve very high resolution bandwidth



Eye-diagram feature	What it measures
Eye opening (height, peak to peak)	Additive noise in the signal
Eye overshoot/undershoot	Peak distortion due to interruptions in the signal path
Eye width	Timing synchronization & jitter effects
Eye closure	Intersymbol interference, additive noise

VI. WORKING PRINCIPLE

The fundamental elements that form a FSO system are the FSO transmitter, a FSO channel and the FSO receiver. Here TX and RX represent transmitter and receiver respectively. Transmitter includes the User Defined Bit Sequence Generator, NRZ pulse generator, a laser source and MZM (Mach Zehnder Modulator). In the simulation shown , data generated by the User Defined Bit Sequence generator at a bit rate of 10000000000 bits/s is encoded and light modulated using MZM, where laser source acts as the carrier source with wavelength 1550 nm and power 0dBm. This modulated light is transmitted to a range of 1km. The apertures of transmitter and receiver are set to 5 cm and 20 cm. The beam divergence is 2 mrad. There is attenuation in the received signal due to atmospheric conditions of the channel, which is calculated on the basis of visibility conditions (of the New Delhi, region of our

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study) between light Haze and fog using Kim and **Kruse relations** (see Literature survey section) and found to be 1.7131 dB/km. The optical signals from the FSO channel are received by photodetector APD. A low pass Bessel filter is used to filter the signal from noise. This simulations uses three visualizers namely optical power meter, optical spectrum analyser and BER analyser. Optical spectrum analysers provide the facility to analyse the optical spectrum. Optical power meters gives the power received in both dBm and Watts. BER analyzer automatically calculates the BER value, Q factor and display eye diagram.

VII. SIMULATION SETUP

The design of a FSO transmission link consists of a transmitter, atmosphere channel and a receiver. FSO system spans from a random bit sequence (or PBRS) at 10Gbps data rate to other component, the electrical signal generator and then modulated with laser at wavelength 1550nm and 20dBm of power transmit using Mach Zehnder Modulator (MZM) modulator before the modulated signal went through the atmosphere channel and reached at reception that contains APD with a gain of 10 and Responsively of 9 A/W and filter with a 0.75GHz Bessel electrical low pass filter and also low pass Gaussian filter with a cut off frequency of 0,75GHz in the transmitter side. Analyser and visualizer have been used such as Eye diagram analyser, oscilloscope visualizer and optical power meter to study the simulation setup. Figure 3 depicted the FSO system transmission design in a range of 1km using OptiSysTMsoftware.

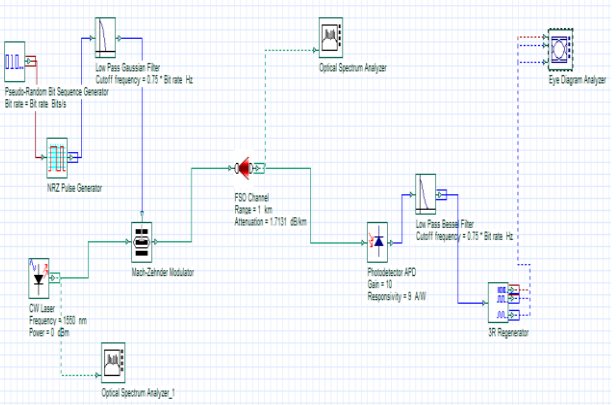

Figure:-3

VIII. RESULTS AND DISCUSSIONS

By using the Optisystem software the simulation output has been taken as shown in the figure.

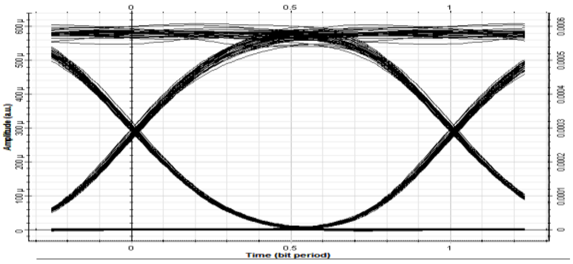

Fig 1:The eye diagram

Fig-1 shows the actual eye diagram of the simulation. This eye diagram can be defined as an oscilloscope display in which a digital signal from a receiver is repetitively sampled and applied to the vertical input, while the data rate is used to trigger the horizontal sweep. Here we have taken the range upto 1km.

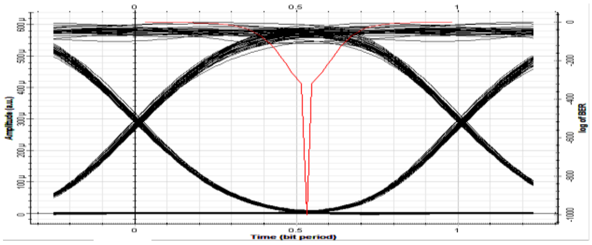

Fig 2: The minimum BER

Fig-2 indicates the minimum BER of the simulation. Here the minimum BER (bit error rate) is 0 bit/sec as we have taken the range to be 6.5km. If the range is increased above 1.008Km, the BER is introduced in the channel.

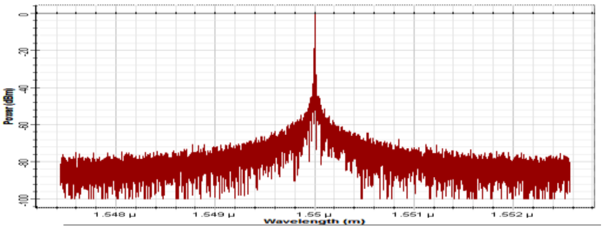

Fig 3:The transmitted power

Fig-3 shows the transmitted optical power of the transmission system. Here the wavelength range started from 1.54719e-006micron to 1.55283e-006micron and the centre range of 1.55001e-006micron. The maximum power and minimum power transmitted is 4.35437dBm and -104.969dBm respectively.

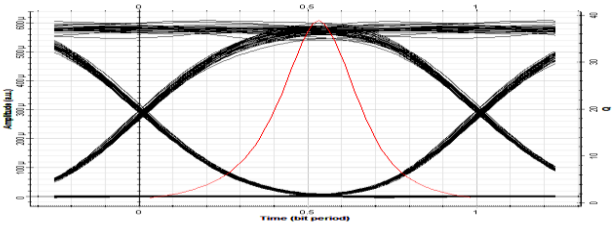

Fig 4: The Q factor

The Q factor (fig-4) lies within the 0-1 time bit period which is approximately at 0.6 time bit period. At 1km range the maximum Q factor is 38.8141.If the range will increases the maximum Q factor decreases.

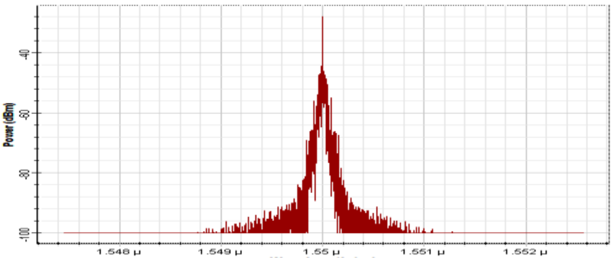

Fig 5: The received power

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Fig-5 shows the received optical power of the receiving system. Here the wavelength range started from 1.54719e-006micron to 1.55283e-006micron and the centre range of 1.55001e-006micron. The maximum power and minimum power transmitted is -24.393dBm and -103.6dBm respectively.

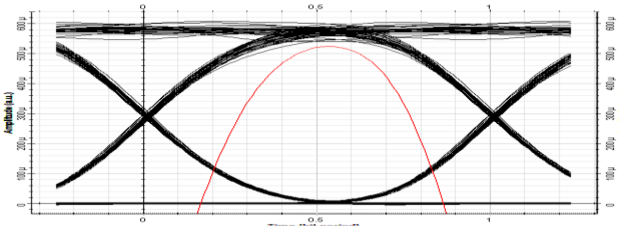

Fig 6: The eye height.

Fig-6 tells about the eye height of the simulation. Here the eye height was found to be 524.91 x 10-6 at the range of 1km and by increasing the range the eye height value will be decreased.

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