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Performance Analysis of 16 × 2.5Gb/s FSO System for the Most Critical Weather Conditions

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Abstract: Free space optics (FSO) uses air as a transmission medium and is significantly affected by the various weather conditions such as haze, rain, fog, snow, wind, etc. In this paper, the behaviour of 16 × 2.5Gb/s FSO system under the effect of the most critical weather conditions using RZ format has been investigated. The operating channel frequencies range from 193.4THz to 189.7THz with the frequency spacing of 100GHz.The performance of the 10th channel has been considered being the worst case scenario to analyse the system. The FSO system is evaluated by varying attenuation from 4.2850dB/km to 116dB/km under different weather conditions. It has been found that as attenuation increases the performance drastically degrades owing to scattering, absorption, free space path loss, geometric losses and other losses suffered by the FSO system. The faithful transmission distance achieved is 9000m in clear weathers and has reduced to 2000m and 100m in case of heavy rain and dense snow respectively. Further, it is shown that channel 2 operating at 193.16THz, gives best results for the FSO system at 40Gb/s where the highest value of Q factor is 29.16dB and OSNR is 80.060dB and 4.9dB value of OSNR for heavy rain has been achieved thus, dense snow, fog and heavy rain are the worst weather conditions which intensely degrade the performance of FSO system.

Keywords : BER, RZ, MZM, Q-Factor, FSO,PD.

I. INTRODUCTION

The increasing demand for bandwidth needs technology that leads beyond conventional copper wires and technology that succeeded to meet demands of increased bandwidth, speed and wireless communication is called FSO (Free space optics) technology. FSO is a communication that use low power modulated laser beam to transmit data, between transmitter and receiver with air as transmission medium. Mazin Ali et al [1] describes major difference between FOC (Fiber optical communication) and FSO. In FOC pulses of light through an optical or glass fiber carry information from one point to another whereas FSO system uses sources of visible light to transfer data through the clear air, space or atmospheric channel. As light travels faster in air than it does in glass, so FSO can also be called as *communication at the speed of light*. Prabhmandeep kaur et al. [2] describes the basic difference between FOC and FSO system. In FOC channel radiation is confined within their guiding structure and in FSO channel radiation diffracts as it propagates from the source outwards. FSO technology is also known as Open air photonics, Free space photonics (FSP), Optical wireless technology or Infrared broadband technology [1-2]. FSO system operates in the near Infrared (IR) wavelength between 399THz to 352.6 THz and between 199.8THz to187.3THz. FSO link are adversely affected by some weather conditions such as haze, fog, snow, rain, smoke, clear sky/drizzles *etc*. [3-4]. The other situations which are unfavourable for FSO system are building sway and swing in case of earthquakes and temporary blockage in case of line-of-sight (LOS) connections required for data transmission between transmitter and receiver [4].The fundamental problem related to FSO system is atmospheric disturbances and effect of attenuation under different weather conditions, which depends upon temperature and pressure of the atmospheric region through which the signal has to pass. [1-4].

Mazin Ali et al. [1] analyzed data rate for FSO System, the paper showed that the data rate decreases with increasing divergence angle and link distance and data rate has very close behavior curve when divergence angle increases and very different behavior curves as range increases for given parameters. Prabhmandeep kaur et al. [2] evaluated the performance of a FSO link using an array of direct detection receivers under the influence of various atmospheric conditions and turbulence strengths. In this paper expression for BER is derived by modeling the turbulence as a gamma–gamma distribution and the effect of weather conditions is incorporated using Beer–Lambert’s law. Hilal A. Fadhil et al. [3] evaluated the quality of data transmission using Wavelength Division Multiplexing, based on the analysis of the paper, it is recommended to develop an FSO system of 2.5 Gbps with 1550 nm wavelength and link range up to 150 km at the clear weather condition of bit-error-rate (BER) 10^{-9}. Nazmi et al. [4] In this paper evaluation for FSO link with latest WOC vendor’s networks specifications is presented and analysis is performed for NRZ, RZ line codes with various operating wavelengths using APD and PIN photodiodes receivers. Results showed that in the presence of moderate fog weather condition, 11.85 µrad is the maximum pointing error and - 41.09 dBm is achieved for

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NRZ-APD at 1550 nm in order to maintain BER < 10^{-9}. Ales et al. [5] dealed with the construction of a modulator and demodulator for FSO system and examines primarily the appropriate modulation format for FSO and also describes the construction of two types of photo detectors. This paper concluded that for OOK NRZ modulation the, maximum transmission speed achieved the value of 160 Mbps. Wakeel et al. [6] performed evaluation of pointing error for practical Bit Error for an FSO link under different weather conditions at 1.55 μm and it was found that maximum pointing error allowed to achieve bit error rate for clear weather can reach 13.53 μ rad.

Mahdieh et al.[8] presents the numerical evaluation of BER by studying the propagation of an initial Gaussian laser beam through turbulent atmosphere and concluded that BER of FSO in turbulent atmosphere is related closely to beam radius, wavelength, turbulent conditions as well as on propagating distance. Kvicera et al. [9] evaluated Performances of Free Space Optical Links from airport visibility data and concluded that fog events occur sporadically during the spring and summer months and confirms the presumption that the reduced visibility most frequently occur during the sunrise due to the fact that the radiation can cause dense fog events. M. Ijaz et al. [10] demonstrated the impact of fog and smoke on the FSO link performance using the continuous wavelength spectrum range of (0.6 µm < ʎ< 1.6 µm) and proposed a wavelength dependent model for fog and smoke channels, which is valid for the visible—NIR range for the visibility range of 1 km and also experimentally demonstrated that the most robust wavelengths windows (0.83, 0.94 and 1.55 µm) that could be adopted for fog conditions in order to minimize the FSO link failure.M. S. Awan et al. [11] investigated impact of fog, rain and snow effects and evaluate their performance on the basis of attenuation data collected for the optical pulse propagated through the troposphere and it was found that fog is the most limiting factor. Horwath et al. [12] measured the time variation of received optical signal level during continental fog and dry snowfall over a link distance of 80m. Wang et al. [13] studied and compared the BER performance of several widely used modulation formats under different atmospheric turbulence scenarios with and without SDRT. It was found that, in the strongly turbulent scenario, the OOK and DPSK formats can have as large as 19.5 and 20.3 dB of SDRT gains at the BER of 10^{-3}, respectively. Borah et al. [14] studied effects of pointing errors on the performance of a free-space optical laser communication. In this paper log-normal and gamma-gamma irradiance probability density function models have been considered to include the effects of optical turbulence. Nistazakis et al. [15] derived closed-form expressions for the evaluation of the average capacity and the outage probability of a FSO system under weak-to-moderate and moderate-to-strong turbulence atmospheric conditions modeled by the log-normal and gamma–gamma distributions, respectively. Sandalidis et al. [16] investigated the error rate performance of FSO links over strong turbulence fading channels together with misalignment effects. This paper present a novel closed-form expression for the distribution of a stochastic FSO channel model which takes into account both atmospheric turbulence-induced fading and misalignment-induced fading and evaluated the average bit-error rate in closed form of a FSO system operating in this channel environment, assuming intensity modulation/direct detection with on-off keying. Navidpour et al. [17] derived expressions for the outage probability for a variety of atmospheric conditions, for given weather and misalignment conditions, the beam width is optimized to maximize the channel capacity subject to outage. In light fog, by optimizing the beam width, the achievable rate is increased by 80% over the nominal beam width at an outage probability of 10^{-5}. Farid et al. [18] investigated the performance and design of FSO links over slow fading channels. In this paper, a statistical model for the optical intensity fluctuation at the receiver due to the combined effects of atmospheric turbulence and pointing errors is derived.

In this paper, we investigate the performance of 16×2.5Gb/s FSO system under the impact of most critical weather conditions like haze, rain, fog, snow, with each channel operating at a different wavelength starting from 193.4 THz to 189.74THz respectively, by varying transmission distance and attenuation using RZ modulation format. The paper is organized as follows: Section II gives the description of FSO system. Section III describes various critical weather conditions for FSO System. Section IV discusses the results and finally conclusions are drawn in section V.

II. FSO SYSTEM DESCRIPTION

The system for 16 ×2.5 Gb/s FSO system at different values of duty cycle and under the effect of most critical weather conditions is shown in Figure 1.

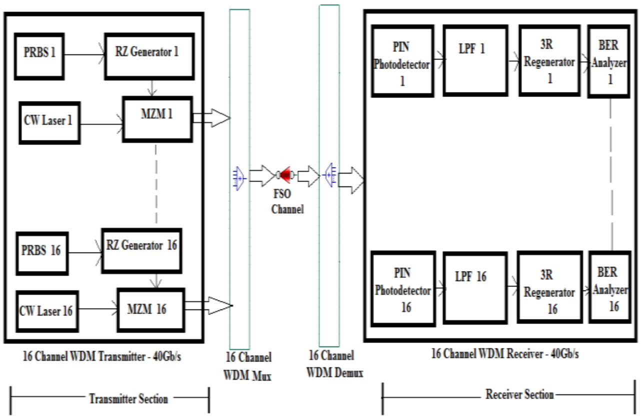

Fig. 1: FSO System

In this system, 16 channels are transmitted by using WDM transmitter at 2.5 Gb/s data rate using FSO system and the operating channel frequencies range from 193.4THz to 189.7THz with the frequency spacing of 100GHz. 16 channel WDM transmitter is made up by using 16 transmitters, in which each transmitter consist of pseudo-random bit generator (PRBS), RZ pulse generator, continuous wave (CW) laser, Mach-Zender Modulator

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(MZM). Pseudo random bit generator, generates the logical signals at 2.5Gb/s in the form of 1010… and order of PRBS is 7, and transmits logical signal to the RZ pulse generator [4]. The function of the RZ pulse generator is to covert the logical signal into the electrical signal and to further pass this signal to the Mach - Zender Modulator. This modulator receives two inputs i.e. electrical signal from the RZ pulse generator and other is from continuous wave (CW) laser as a carrier signal. CW laser source generates 16 laser beams for frequency range from 193.4THz to 189.7THz The primary function of this modulator is to convert the electrical signal into the optical signal because the system is working on the free space optics. Now this modulator passes the optical signal with carrier signal to the photo-detector via a medium called FSO channel. Parameters of laser source are: line-width = 10MHz and power = 10dBm. Mach-Zehander modulator with extinction ratio = 10dB is used as the external modulator to modulate data source signals using laser. Finally, transmitted signals are multiplexed and launched in FSO Channel. Results are evaluated by varying attenuation, duty cycle and transmission distance. Parameters of the FSO system are: attenuation = 4.2dB/km from 116dB/km as mentioned in table 1, range = 1-9000m, transmitter aperture diameter = 10cm, receiver aperture diameter = 20 cm, beam divergence = 0.25mrad and finally transmitter & additional losses = 1dB [3-4-5-6].

Receiver section consists of components such as: PIN photo detector, Low Pass Bessel Filter (LPF), 3R Regenerator, BER Analyzer and spectrum analyzers are used as visualizers to obtain the value of BER, Q-factor, eye diagrams and signal spectrums. Signal reaches photo-dectector after passing through FSO channel and demultiplexer. Photo detector further converts the received optical signal again in the electrical form and passes it to the LPF [5-6-7]. Now the signal is got filtered to remove the unwanted signals from the desired electrical signal. The errors and power in the output signal can be measured by using BER analyzer and electrical power meter respectively. Parameters of the receiver are: Receiver sensitivity = -20dB, responsitivity = 1A/W, dark current = 10nA [6]. Using Opti-system software setup and by using measurement tools such as BER Analyzer, Oscilloscope visualize, Optical power meter, Electrical Power Meter results have been calculated. Evaluation is performed in terms of bit error rate (BER), maximum Q- factor (quality factor), eye height, output power, optical spectrum and range covered by the system for different weather conditions.

III. EFFECT OF CRITICAL WEATHER CONDITIONS ON THE PERFORMANCE OF FSO SYSTEM

The fundamental problem related to FSO system is effect of attenuation under different weather conditions which depends upon temperature and pressure of the atmospheric region through which the signal has to pass. FSO attenuation occurs due to the presence of disturbed atmosphere because atmospheric channel is not ideal [5]. This can probably result in high bit error rates, scattering and absorption of visible and IR optical beams, thus lowering and debasing the FSO system performance. Snow, rain and fog, clouds cause scattering of the pulse and are the most critical weather conditions [7-8]. Table 1 shows visibility and attenuation coefficient for these critical weather conditions and effect of attenuation for these critical weather conditions have been explained as below:

A. Rain Condition: Rainfall rate has a distance-diminishing effect on FSO system, this is because the radius of raindrops (200–2000μm) is significantly larger than the wavelength of typical FSO light sources [5]. Usually rain attenuation values are moderate in nature. For example, for a rainfall of 26 mm/hour, attenuation of 6dB/km can be observed and for a rainfall of 40mm/hour, attenuation of 9.6398dB/km can be observed. But for a rainfall of 80mm/hour, attenuation of 19.2795dB/km can be observed. There are three conditions of Rain i.e. light rain, moderate rain & heavy rain [8].

B. Snow Condition: Snow buntings are ice crystals that come in different shapes and sizes [8]. Typically, snow tends to be larger than rain, fog. Snowfall rate has a very adverse effect on FSO system performance. There are two conditions of snow dry snow and wet snow. For example, for a snowfall of 8mm/hour, attenuation of 115dB/km can be observed with a visibility range of 0.5km and for a snowfall of 4 mm/hour, attenuation of 38.667dB/km can be observed with a visibility range of 1.5km [8-9].

C. Fog Condition: Fog is the primarily disastrous weather phenomenon to FSO because it is composed of small water droplets with radii about the size of near infrared wavelengths. The particle size distribution varies for different degrees of fog [8]. For fog, the attenuation of optical pulse is mainly due to Mie scattering effect and the loss effects due to absorption can be ignored [8-9]. There are five foggy conditions such as: little fog with attenuation of 4.2850dB/km and visibility range of 2km, thin fog with attenuation of 10.55dB/km and visibility range of 1km, moderate fog with attenuation of 15.55dB/km and visibility range of 0.8km, thick fog with attenuation of 25.160dB/km and visibility range of 0.6km, dense fog with attenuation of 84.904dB/km and visibility range of 0.2km [9-10].

TABLE 1
VISIBILITY AND ATTENUATION COEFFICIENT FOR DIFFERENT WEATHER CONDITIONS [2-5-7]

Weather condition	**Visibility (km)**	**Attenuation (dB/km)**
Little Fog	2	4.2850
Moderate Fog	0.8	15.555
Dense Fog	0.2	84.904
Light Rain	1.1	6.2702
Heavy Rain	0.8	19.2795
Dense Snow	0.5	116

Table 1: Shows visibility and attenuation values

Thus from above explanation about weather conditions and from visibility and attenuation coefficient table values it is very much clear that snow, fog and rain are the most

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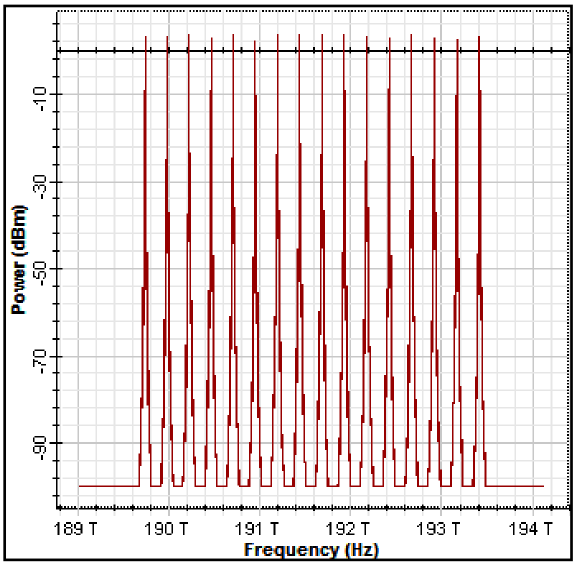
critical weather conditions and snow being the most adverse condition because the effect of snow is more severe than fog and rain because of large size diameter, of the snow droplet.

V. EXPERIMENTAL RESULTS AND DISSCUSIONS

The results for the performance and design of a 16 channels operating at 2.5Gb/s (40Gb/s network capacity) of a FSO system under impact of critical weather conditions like fog, snow and rain using wavelength of 193.4THz to 189.7THz respectively, using RZ modulation format at 0.5 duty cycle can be calculated using following values of the parameters as mentioned above.

A. Optical Spectrum Analyzer Results



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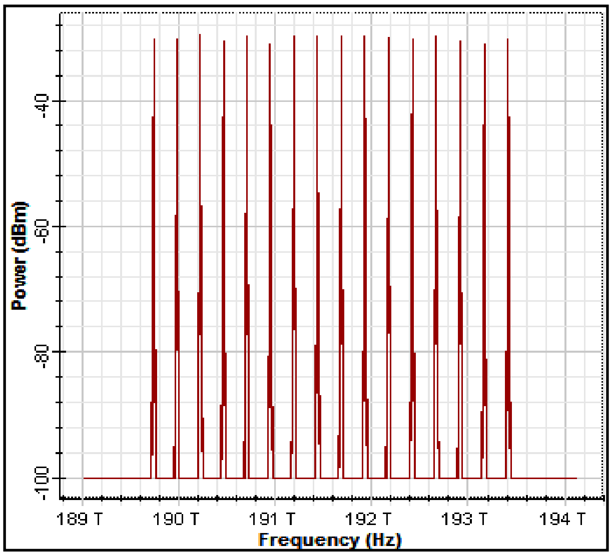

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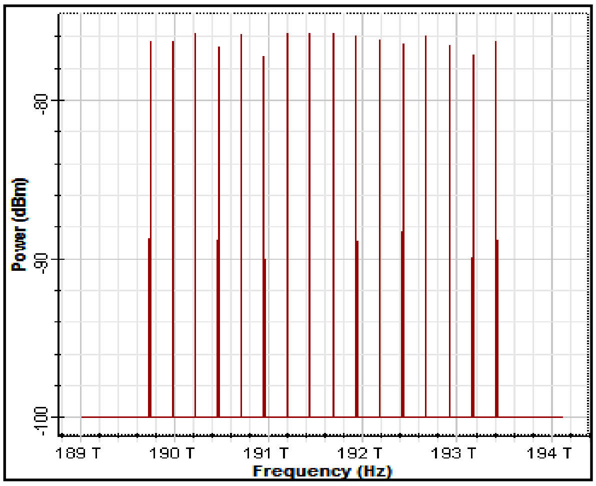

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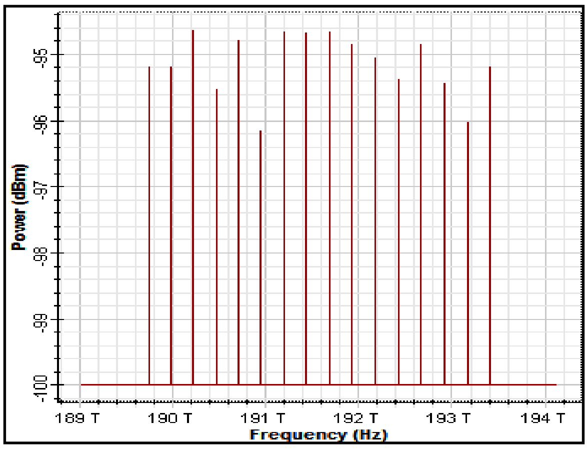

(d)

Figure 2: Shows input and output spectrums at different values of attenuation: (a) Power vs Frequency at the input of the FSO channel (b)) Power vs Frequency at output of FSO channel for light rain at attenuation = 6.2dB/km (c) Power vs Frequency at output of FSO channel for moderate fog at attenuation = 15.5dB/km (d) Power vs Frequency at output of FSO channel for heavy rain at attenuation = 19.27dB/km

Figure 2 shows relation between power and frequency of the spectrum analyzer for different values of attenuation at the input and output of the FSO channel, Figure 2 (a) shows that maximum power range at the input is between -90dB to 0dB. Figure 2 (b), (c), (d) shows power at the output of the FSO channel under light rain, moderate fog, heavy rain condition and it is seen that maximum power has reduced from 0dB to -40dB, -80dB, -95dB respectively**.** The reason for the reduction in the value of power from 0 to -95dBm at the output of the FSO channel is due to the effect of high attenuation and geometric losses, scattering, absorption, transmitter losses and additional losses, wavelength and other losses suffered by the system. In practical cases free space path loss (FSPL) along with several other losses severely affects the performance of the FSO system. Figure 2 (d) shows that in case of heavy rain value of power is not constant at the output because under heavy rain due to high attenuation energy is transferred from one frequency to another which results in unequal power distribution at the output. Thus degrades the performance of the FSO system.

B. Performance of Channels under critical weather Conditions:

Evaluation of Q-factor vs transmission distance for a distance range of 1m to 9000m with different values of attenuation such as: Light Fog = 4.2850 dB/km, Moderate Fog = 15.555dB/km, Dense Fog = 84.904 dB/km, Light Rain = 6.2702 dB/km, Heavy Rain = 19.2795 dB/km, and Dense Snow = 116 dB/km for channel 2, 8, 16 have been calculated.

CASE 1: Evaluation of Channel 2 Operating at 193.1 THz

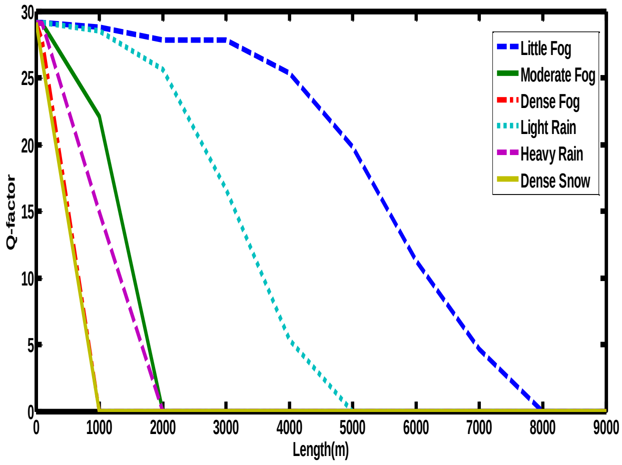

Fig. 3: Evaluation of Length vs Q-factor at 193.1 THz

Case 2: Evaluation of Channel 8 Operating at 191.6 THz

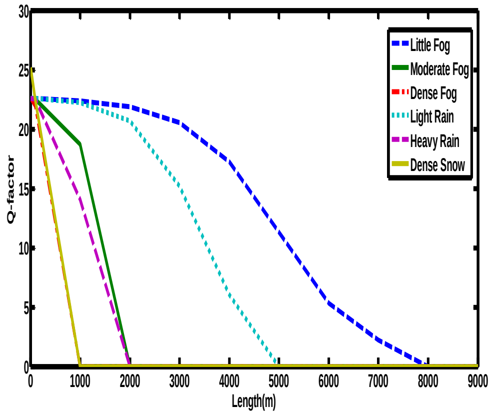

Fig. 4: Evaluation of Length vs Q-factor at 191.6 THz

CASE 3: Evaluation of Channel 16 Operating at 189.7 THz

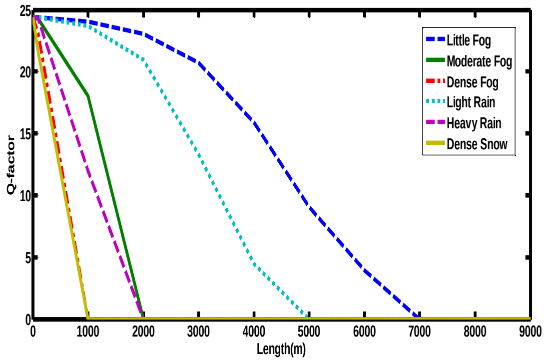

Fig. 5: Evaluation of Length vs Q- factor at 189.7 THz

Figure 3, 4, 5 shows that at 0.5 value of duty cycle best values of Q-Factor and BER are achieved, moreover in little Fog weather RZ covers maximum distance of 7 kms and 5 kms and the curve decreases slowly in light rain with high values of Q-factor and curve decreases slowly and a distance of 2 kms in moderate fog and heavy rain and 1 kms in dense fog and dense snow further simulation results showed that channel 2 operating at 191.6 THz gives highest values of Quality factor with reasonable value of BER and eye height. Thus 191.6THz frequency gives the best evaluation results under critical weather conditions.

C. WDM Analyzer Results and Analysis

Values of Frequency (THz) and OSNR (dB) at the input and output of the FSO Channel under different weather condition

Frequency (THz)	**OSNR At Input**	**OSNR At 4.2 dB/km**	**ONSR At 6.2 dB/km**	**OSNR At 15.5 dB/km**	**OSNR At 19.2 dB/km**
193.16 (Channel 2)	90.76	88.12	69.62	23.48	4.98
191.68 (Channel 8)	90.00	87.65	67.15	22.50	3.50
189.74 (Channel 16)	90.68	89.06	70.56	24.41	5.91

Table 2 : shows values of ONSR for different values of attenuation

Results are also supported by OSNR values of the output of the FSO channel for different weather conditions as given in Table 2. Very high values of OSNR are achieved at the input of the FSO channel but significant decrease in the values of OSNR is observed at the output.

Further, it is observed that middle channels under all attenuations have lowest value of OSNR as compared to all other channels because four wave mixing (FWM) affect the middle channel most strongly, so its effect is maximum at the middle channels as compared to other channels.

This is because the number of FWM signals at the middle channel is maximum [19]. Thus high values of attenuation severely reduces OSNR values to as low as 4.9dB from 80.89dB.

D. Eye Diagram Analysis

Comparison of values of eye height at 3000m distance for different values of attenuation 4.2850dB/km, 6.2702dB/km, 15.55dB/km, 19.2795dB/km, 38.667dB/km are observed.

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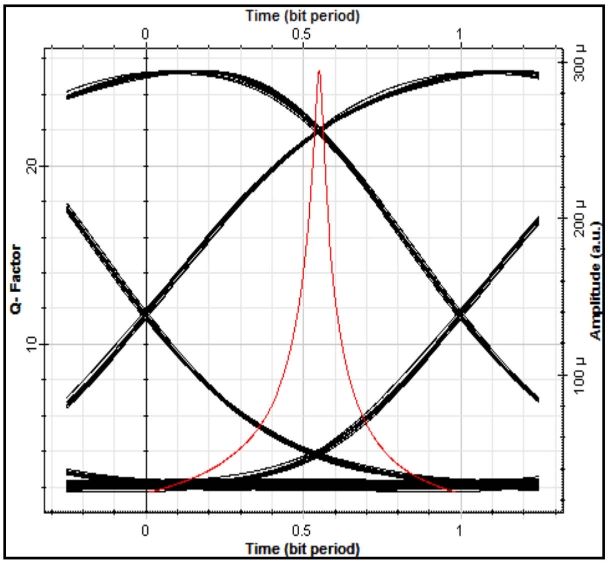

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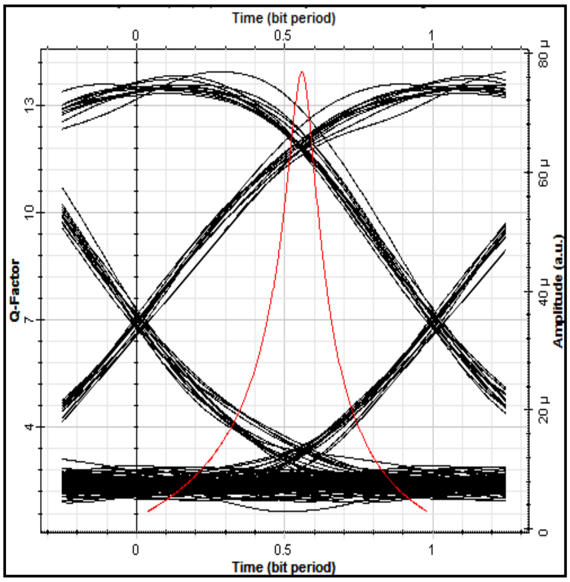

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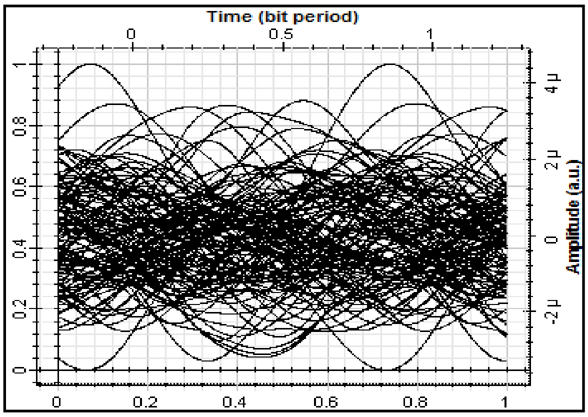

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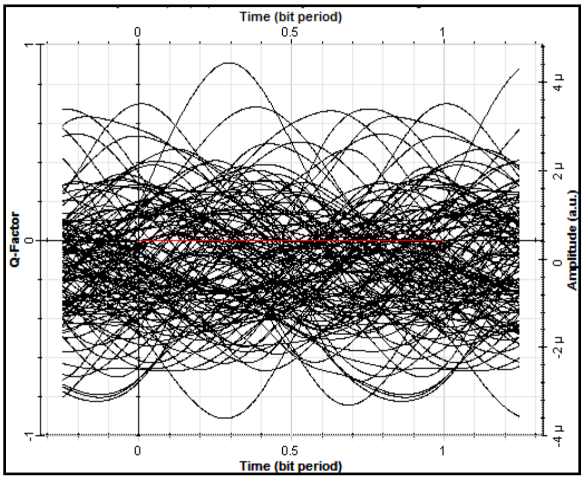

(d)

Figure 6: Showing eye diagrams for different weather conditions at 0.5 duty cycle at distance of 3000m: (a) attenuation = 4.2850dB/km (b) attenuation = 6.2702dB/km (c) attenuation = 15.55, 19.2795dB/km (d) attenuation = 84.9,116dB/km

The results are also supported by the eye diagrams for different weather conditions obtained at the BER analyzer, as attenuation increases eye height decreases, BER increases and Q-Factor decreases. Further, best eye opening is obtained in case of little fog as shown in Fig. 6 (a) and worst eye opening is obtained in case of dense snow and dense fog at 84.9dB/km and 116dB/km as shown in Fig. 6 (d).

V. CONCLUSION

FSO system presents a practical way for establishing optical integration in a profitable, fast, compact, low power and less complex system in a definite situation. In this paper, 16×2.5Gb/s FSO system has been analyzed using RZ format for different weather conditions. The attenuation values for various weather conditions range from 4.2850dB/km to 116dB/km. The system performance has been analyzed on the basis of Q-Factor, BER for transmission distance in range 1m to 9000m for the frequency range 193.41449 to 189.74206THz and 100GHz channel spacing. The results show that as attenuation increases distance covered, Q factor, and eye height decreases but BER increases. Further, it is found that achieved Q factor and BER are outstandingly good for RZ format with 0.5 duty cycle and system covers a maximum distance of 7 kms in little fog and a minimum distance of 1 kms in dense fog and dense snow. Thus, it is reported that FSO system using 16 channels can even be preferred for long haul communication under most critical weather conditions.

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