[Singh*, 5(5): May, 2016]
ISSN: 2277-9655
Impact Factor: 3.785

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERFORMANCE INVESTIGATION OF A FREE SPACE OPTICAL COMMUNICATION LINK OPERATING AT 1550 NM UNDER DIVERSE WEATHER CONDITIONS BY EMPLOYING DIFFERENT MODULATION FORMATS

Salwinder Singh*, Karamdeep Singh, Shivinder Devra

* Department of Electronics Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Department of Electronics Technology, Guru Nanak Dev University, Amritsar, Punjab, India
Department of Electronics Technology, Guru Nanak Dev University, Amritsar, Punjab, India

DOI: 10.5281/zenodo.51463

ABSTRACT

Over the last two and half decades free space optical communication is preferred over microwave and radio frequency communication systems because of its license free long range operations. Also it has many advantages such as low cost, high bandwidth and small size and it has few limitations also like beam dispersion, scintillation. A well-known limitation of FSO is the effect of weather condition on it. In this paper we have designed 10gbps FSO system and analyzed of 10gbps FSO system with different weather condition by power and length varying. From the result it is clear, the transmission distance go on decreasing as the weather condition changes from clear to haze, rain and fog and the BER performance of all received signals is also discussed.

KEYWORDS: Attenuation, Free Space Optics (FSO), Bit Error Rate (BER), Power, Length.

INTRODUCTION

Free space optics is a wireless communication technology which utilizes light for transmission of data through the air in the similar manner as the fiber optics uses a fiber cable. Free space optics is having the same capabilities as that of fiber optics, but at a very lower cost and very fast deployment speed [1]. It has advantages high speed, low cost, high bandwidth, quick installation high security and also license-free longer range spectrum [2]. But in fiber case have problem that is dispersion, nonlinear impacts in a transmission line but not in the FSO channel [3-5-6] and FSO system is also severely limited by the four wav mixing effect [4]. Free space optics work on the principal of laser driven technology which use light source and detectors to transmit and receive information, through the atmosphere same as the Fiber Optic communication cable [2]. The motivation for FSO is to eliminate the cost, time, and effort of installing fiber optic cable, yet to retain the benefit of high data rates for transmission of voice, data, images and video. FSO communication can be used in building to building, ship to ship, aircraft to ground and satellite to ground. The stability quality of the link is highly dependent on atmospheric factors such as Fog, Rain, Haze and Heat [7]. A standard FSO system has range 2-3 times that of the naked eye, which further depends on specific weather condition [8]. FSO links offer same faithfulness and responsibility as the optical fiber communication links and is principally influenced by the weather conditions. In FSO system link, absorption of the laser beam by the atmosphere is very significant; particularly under most critical weather conditions such as dense (haze, rain, fog and snow) [9]. FSO system consists of an optical transceiver at the both ends to provide full duplex capability. FSO is a LOS (Line of sight) technology, where data, video and voice communication is achieved with maximum 10Gbps of data rate by full duplex [10].

An effective FSO system should have the following characteristics [10]:

a) FSO system should have the ability to operate at higher power levels for longer distance.
b) For high speed FSO systems, high speed modulation is important.
c) An overall system design should have small footprint and low power consumption.
d) FSO should have the ability to operate over wide temperature range and the performance degradation would be less for outdoor system.

e) Mean time between failures of system should be more than 10 years.

An effective FSO system should have the following Merits [10];

a) FSO is a flexible network that delivers better speed than Broadband.
b) Installation is very easy and it takes less than 30mintues to install normal locations.
c) It has very low initial investment.
d) It is a secure system because of line of sight operations and so no security system up gradations is needed.
e) There is relatively high bandwidth.
f) High data rate obtained which is comparable to the optical fiber cable data rate but error rate is very low.

An effective FSO system should have the following Limitations [11]:

a) Physical obstructions:-flying birds, tree and tall building can temporary block a single beam, when it appears in the LOS of transmission of FSO system.
b) Geometric losses: - Geometric losses which can be called optical beam attenuation are induced due to the spreading of beam.
c) Absorption: - It is caused by the water molecule which is suspended in the terrestrial atmosphere.
d) Atmospheric turbulence: - It is caused by weather and environment structure.
e) Atmospheric Attenuation: - It is the result of fog and haze normally.
f) Scattering: - Scattering phenomena happen when the optical beam and scatter collide.

In the section 2, literature survey is discussed. In the section 3, different modulation formats along with their optical spectrum are described. In section 4, explains different weather condition. In section 5, simulation setup project and parameters. In section 6, results have been reported for various formats. In section 7, conclusions are made.

LITERATURE SURVEY

Ajay K. Sharma et al. (2009) studied robustness of various modulation formats at 40Gbps. The performance is categorized using Q-factor. They investigated non linearity and noise show robustness up to 450 km at 40Gbos. At high rate, CRZ show better results than NRZ, RZ and CSRZ [12].

Farukh Nadeem et al., (2009) investigate the weather effects on Hybrid FSO/RF Communication Link. FSO is the most prefer among different communication technologies when a high data rate link is required but suffers from different weather effects like fog, rain, snow and clouds in the earth atmosphere. Hybrid network, a combination of FSO main link and radio frequency back up link, is a used to overcome the atmospheric attenuations. The simulation results show that for frequencies greater than 40 GHz have the rain attenuations are higher for GHz frequency links as compared to the prime FSO link. The combination of FSO with 40 GHz backup link would provide good backup data rates though availability achieved would be under heavy rain [13].

Jagjit Singh Malhotra et al., (2010) investigate the Performance analysis of NRZ, RZ, CRZ and CSRZ data formats in 10Gbps. In this paper investigate the performance of NRZ, RZ, CRZ and CSRZ data formats analyzed on the basis of bit error rate (BER), Q2 (dB), OSNR, eye opening performance metrics. The results show that CRZ and CSRZ modulation format is perform better as compared to NRZ and RZ. The CSRZ has optimal performance according to performance metrics [14].

Alexander Vavoulas et al., (2012) described the Weather Effects on FSO Network Connectivity. In the FSO network some weather phenomena contribute to reduction in significant link performance i.e., fog, rain, and snow. In this paper, the author considers a multiple-hop FSO network, where the nodes are distributed at fixed positions on a given path-link and also find the number of transceivers for a given path-link in order to achieve reliable performance. The results prove that FSO network connectivity can be improved in a number of ways, e.g., by using different path loss models, considering other modulation formats, using forward error correction schemes etc [15].

Malti et al. (2012) studied advance modulation format at different bit rates and observed that MDBRZ show better performance as compared to DBRZ and CSRZ at high bit rates but at 2.5Gbps CSRZ is better than DBRZ and MDBRZ [16].

Jitendra Singh et al., (2013) investigate different modulation format based on the performance analysis of free space optical communication system. In the FSO network some factor play important role i.e. bit error rate (BER), Q factor, forward error correction (FEC), attenuation, absorption, Scattering and scintillation. In this paper investigate the impact of different direct and external modulation formats i.e. RZ, CRZ, CSRZ and NRZ on free space optical communication system. The external modulation has better performance as compare to direct modulation because direct NRZ spectrum has a strong carrier

component compared to external modulated NRZ. The simulation results prove that RZ modulation format is best for long distance, but is complex and costly. Where NRZ is used for short distance and it is less complex, cheaper in comparison to RZ [17].

Jun He et al., (2014) discussed the survey on recent advances in optical communications. The FSO is used in various applications. In this paper investigate the overview of recent research in optical communications and focus on the topics of modulation, switching, add-drop multiplexer, coding schemes, detection schemes, orthogonal frequency-division multiplexing, system analysis, cross-layer design, control and management, free space optics, and optics in data center network. The author aim is provide the knowledge about the advances in optical communications. Hence from this survey conclude that optical communication plays important role in telecommunication and data center communications [18].

Ajay K. Sharma et al. (2009) studied robustness of various modulation formats at 40Gbps. At high rate, CRZ show better results than NRZ, RZ and CSRZ. Farukh Nadeem et al., (2009) investigate the weather effects on Hybrid FSO/RF Communication Link. The combination of FSO with 40 GHz backup link would provide good backup data rates though availability achieved would be under heavy rain. Jagjit Singh Malhotra et al., (2010) investigate the Performance analysis of NRZ, RZ, CRZ and CSRZ data formats in 10Gbps. The results show that CRZ and CSRZ modulation format is perform better as compared to NRZ and RZ. The CSRZ has optimal performance according to performance metrics. Alexander Vavoulas et al., (2012) described the Weather Effects on FSO Network Connectivity. The results prove that FSO network connectivity can be improved in a number of ways, e.g., by using different path loss models, considering other modulation formats, using forward error correction schemes, etc. Malti et al. (2012) studied advance modulation format at different bit rates and observed that MDBRZ show better performance as compared to DBRZ and CSRZ at high bit rates but at 2.5Gbps CSRZ is better than DBRZ and MDBRZ. Jitendra Singh et al., (2013) investigate different modulation format based on the performance analysis of free space optical communication system. The simulation results prove that RZ modulation format is best for long distance, but is complex and costly. Where NRZ is used for short distance and it is less complex, cheaper in comparison to RZ. Jun He et al., (2014) discussed the survey on recent advances in optical communications. The FSO is used in various applications. Hence from this survey conclude that optical communication plays important role in telecommunication and data center communications.

DIFFERENT MODULATION FORMATS

1)Carrier Suppressed Non return to Zero (CSNRZ) Format: - CSNRZ format has high tolerance to the mixed effect of the self-phase modulation and group velocity dispersion (GVD) and has narrower pedestal shape of the optical spectrum than the conventional RZ format. Fig-(1a) shows the schematic diagram of CSNRZ transmitter. In it the NRZ signal after MZ modulator goes through the phase modulator driven by analog sine wave generator at the frequency equal to half the bit rate. That will introduce zero phase-shift between the two adjacent bits and the spectrum will be modified such that the central peak at the carrier frequency is suppressed as shown in the Fig-(1b).

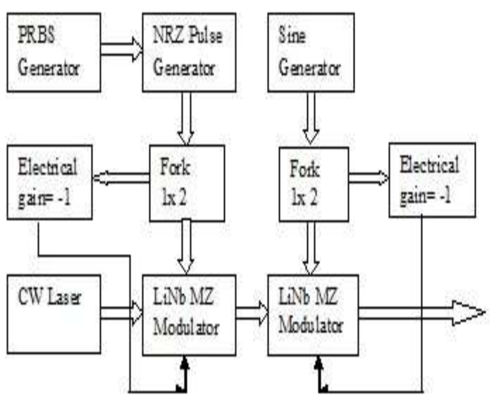
2)Carrier Suppressed Return to Zero (CSRZ) Format: - CSRZ format has high tolerance to the mixed effect of the self-phase modulation and group velocity dispersion. Fig-(2a) shows the schematic diagram of CSRZ transmitter. In it the RZ signal after MZ modulator goes through the phase modulator driven by analog sine wave generator at the frequency equal to half the bit rate and That will introduce 180o phase shift between the two near bits and the spectrum will be modified such that the central peak at the carrier frequency is suppressed as shown in the Fig-(1b) [19].

ISSN: 2277-9655
Impact Factor: 3.785

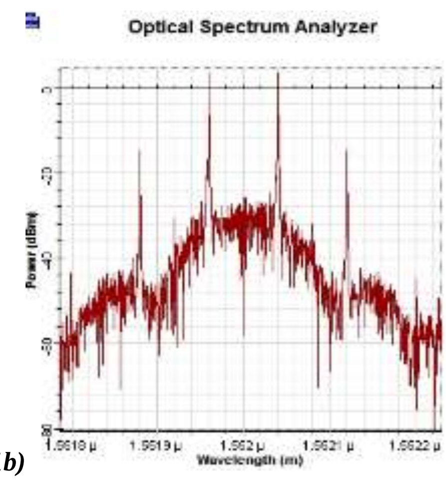
3)Duo-Binary Non return to Zero (DBNRZ) Format: - Fig-(3a) shows the diagram of DBNRZ transmitter. The Duo binary was generated by first creating NRZ duo binary signal using a duo binary precoder, NRZ generator and a duo binary pulse generator. The generator drives the first MZM and then the cascades this modulator with a second modulator that is driven by a sinusoidal electrical signal with the frequency on bit rate and phase= -π/2o. The duo binary precoder used here is composed of an exclusive-or gate with a delayed feedback path and frequency spectrum shown in Fig-(3b) [19].

4)Modified Duo Binary Non return to Zero (MDBNRZ) Format: - Fig-(4a) shows the schematic diagram of MDBNRZ transmitter are called carrier suppressed duo binary format. MDBNRZ was generated by first creating an NRZ duo binary signal using a delay and subtract circuit that drives the first MZM and then concentrating this modulator with a second modulator that driven by a sinusoidal electrical signal with the frequency equal to the bit rate and phase equal to –π/2. The generation of MDBNRZ signal is same as the DBNRZ signal but the delay-and-add circuit is replaced by a delay-and-subtract circuit. In the duo binary signal used earlier where the phase of bits '1' are modified only after a bit '0' appear where as in the modified duo binary signal the phase is alternated 0 and 180 for the bits '1'. Also optical signal spectrum shown in Fig-(4b) that carrier of the duo binary signal has been suppressed.

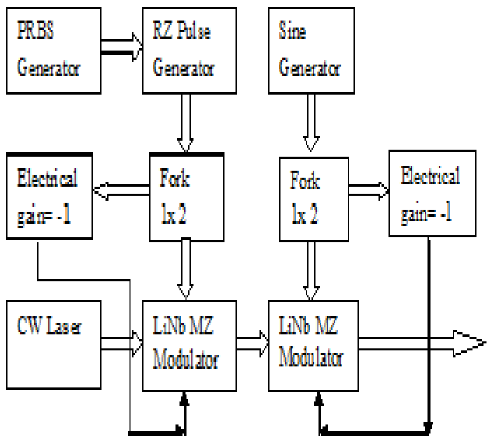
5)Modified Duo Binary Return to Zero (MDBRZ) Format: -Fig-(5a) shows the schematic diagram of MDBRZ transmitter format. MDBRZ was generated by first creating an RZ duo binary signal using a delay and subtract circuit that drives the first MZM and then concentrating this modulator with a second modulator that driven by a sinusoidal electrical signal with the frequency equal to the bit rate and phase equal to –π/2. The generation of MDBRZ signal is same as the DBNRZ signal except the delay-and-add circuit is replaced by a delay-and-subtract circuit. In the duo binary signal used earlier where the phase of bits '1' are modified only after a bit '0' appear where as in the modified duo binary signal the phase is alternated 0 and 180 for the bits '1' frequency spectrum shown in Fig-(5b) [19].



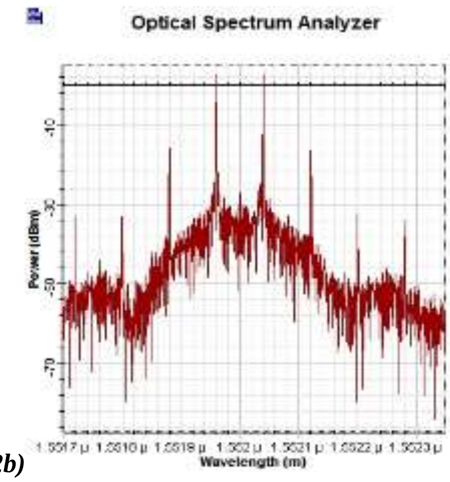
1a)



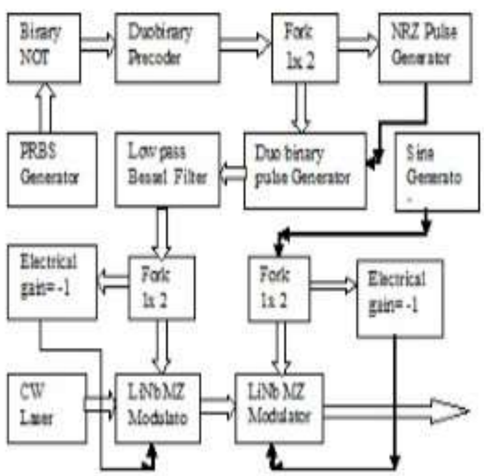
1b)



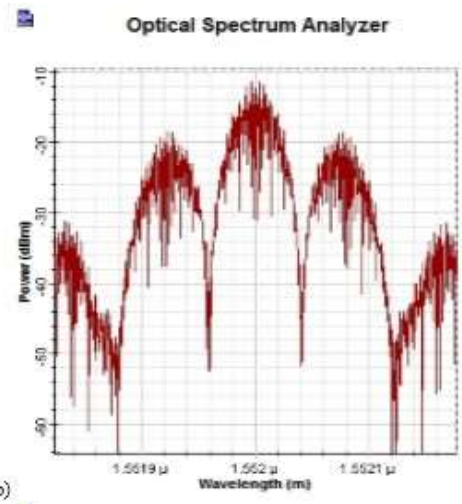
2a)



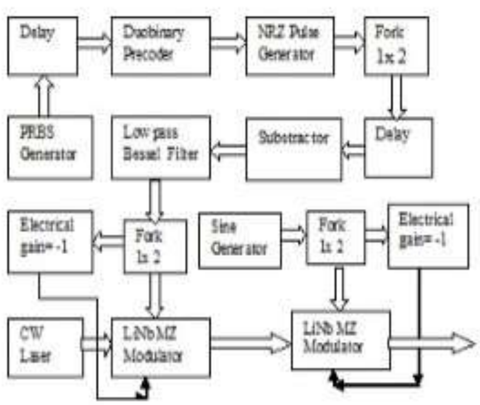
2b)



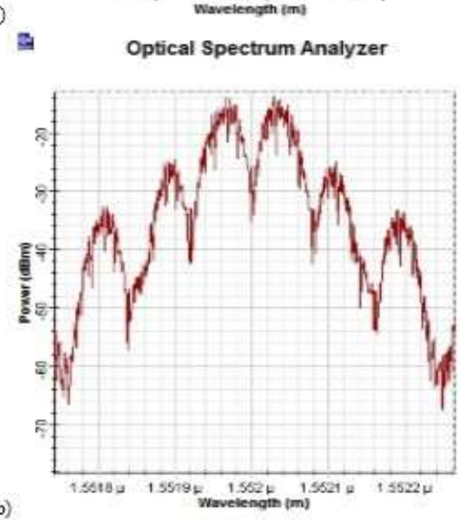
3a)



3b)

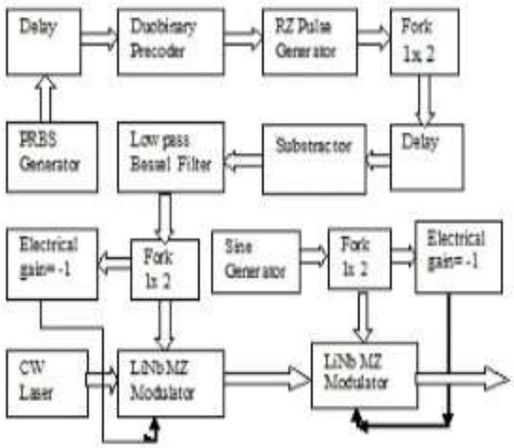


4a)

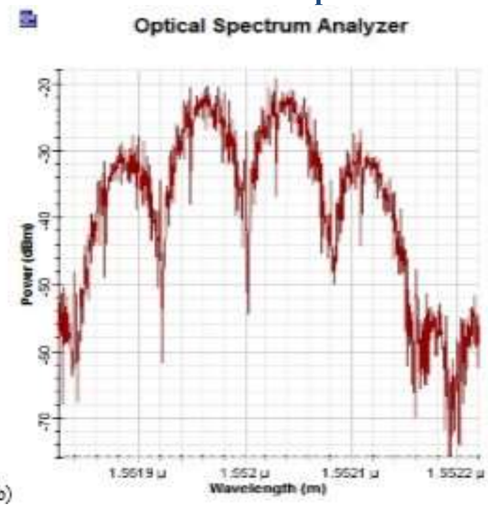


4b)

ISSN: 2277-9655
Impact Factor: 3.785



5a)



5b)

Fig.1. (1a) schematic of CSNRZ transmitter, (1b) frequency spectrum of CSNRZ transmitter, (2a) schematic of CSRZ transmitter, (2b) frequency spectrum of CSRZ transmitter, (3a) schematic of DBNRZ transmitter, (3b) frequency spectrum of DBNRZ transmitter, (4a) schematic of MDBNRZ transmitter, (4b) frequency spectrum of MDBNRZ transmitter, (5a) schematic of MDBRZ transmitter, (5b) frequency spectrum MDBRZ transmitter.

DIFFERENT WEATHER CONDITIONS

Performance of FSO is affected by different weather conditions. There are four different weather conditions like clear, rain, haze and fog etc. and these conditions are explained below.

a) Clear weather condition: when there is a clear weather, as we all know there very less attenuation or its amount is negligible. The amount of attenuation in the clear weather is from 0 to 3dB/km.
b) Rain condition: Rain has a distance-reducing impact on FSO, although its impact is significantly less than that of weather conditions. This is because the radius of raindrops (200-2000μm) is significantly larger than the wavelength of typical FSO light source. Typical rain attenuation values re moderate in nature. There are two conditions of rain i.e. light rain and heavy rain. The amount of attenuation in the rain condition is 19.28dB/km.
c) Fog condition: Fog is the most detrimental 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 degree of fog. The amount of attenuation in the fog condition is 84.91dB/km.
d) Haze condition: Haze weather condition also has a distance- decreasing effect on FSO system performance even though its impact is less as compared to fog and snow. The haze particles are very small and stay longer in the atmosphere, but the rain particles are very large and stay shorter in the atmosphere. This is the primary reason that attenuation via rain is less than haze. The amount of attenuation in the fog condition is 2.37dB/km.

Table 1 Different weather condition

S.no	Weather condition	Attenuation(dB/km)
1	Clear	0.23
2	Haze	2.37
3	Rain	19.28
4	Fog	84.91

SIMULATION SETUP

Figure-2 shows a schematic of simulation setup of a single channel optical communication System at 10Gbps with the central frequency 1552nm. The simulation parameter used in the system model is given in Table 1.

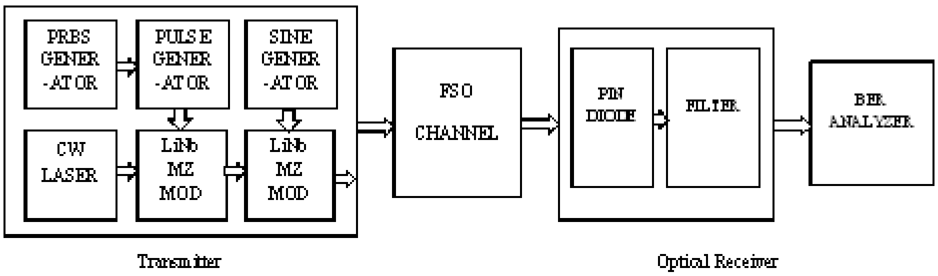


Fig-2-Block-Diagram-of-FSO

The simulation setup is composed of transmitter, free space optical channel and receiver. The transmitter consists of a CW laser, data modulator as shown in Fig-1 and to each output port of the CW lasers a direct modulation lasers. Laser operating wave lengths around 1550nm were developed specially for fiber optic communication because of low attenuation characteristics on this range. The free space between transmitter and receiver is considered as FSO channel which is propagation medium for transmitted light. The receiver is use to regenerate electrical signal of the original bit sequence and the modulated electrical signal as in the optical transmitter to be used for BER analysis.

Table -2 Simulation parameters of FSO

Parameter	Value
Attenuation	Depends upon weather condition
Bit rate (Gb/s)	10Gbps
Sequence length (bits)	128
Samples/bit	64
Central Frequency of channel (nm)	1552nm
Range (m)	1100m
Transmitter Aperture Diameter	5cm
Receiver Aperture Diameter	35cm
Beam Divergence	0.5mrad
Line width	10MHz

RESULT AND DISCUSSION

The result of given FSO system can be taken out in two case. In the first case the transmitter power can be varies from 11dbm to 20dbm with different weather condition and in the second case length is varies different in different weather condition. Different Power and Length can be varies and result discussed below.

CASE 1:- POWER VARIATION FROM 11dbm TO 20dbm

a)Clear weather condition***:*** The result of given FSO system can be taken out by using the above parameters given in table-1. In this case attenuation value is 0.23dB/km, power is varies from 11 to 20dbm, length is set to11km (Kilometer) and bitrate is set to 10Gbps. Clear weather condition can be apply on the FSO channel link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ).The result of clear weather condition shown in fig-3 and CSNRZ and DBNRZ system have better performance than the other modulation system but DBNRZ has also better performance than CSNRZ system. So DBNRZ system better than the other system as shown in fig-3a and performance of BER and transmitter power also shows in fig-3b. From graph it shown that when transmitter power is increased, BER continuously decreased and DBNRZ system is better because this system has BER -136 at 19dBm transmitter power than other modulation formats. So DBNRZ system is better performance.

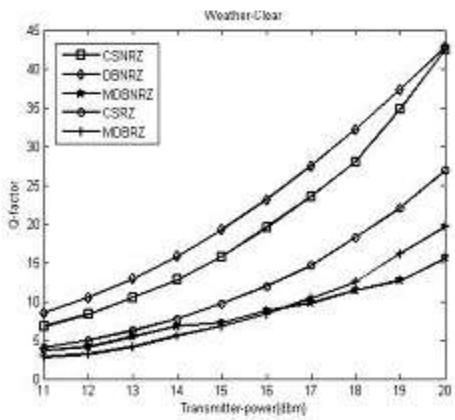


Fig-3a Power variation under clear weather condition

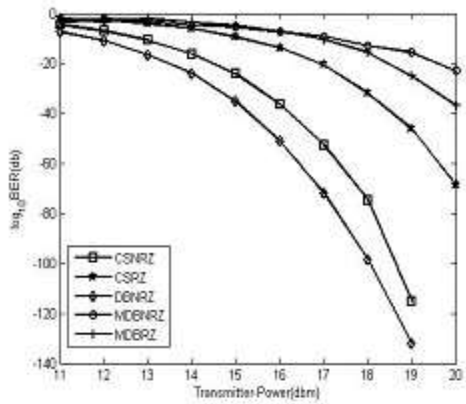


Fig-3b BER v/s Transmitter power in clear weather condition

b)Haze weather condition:- The result of given FSO system can be taken out by using the above parameters given in table-1.In this case attenuation value is 2.37dB/km , power is varies from 11 to 20dbm , length is set to 4km (Kilometer) and bitrate is set to 10Gbps. Haze weather condition can be apply on the FSO channel link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ).The result of haze weather condition shown in fig-4 and CSNRZ and DBNRZ system have better performance than the other modulation system but DBNRZ has also better performance than CSNRZ system. So DBNRZ system better than the other system as shown in fig-4a and performance of BER and transmitter power also shows in fig-4b. From graph it shown that when transmitter power is increased, BER continuously decreased and DBNRZ system is better because this system has BER-129 at 17dBm transmitter power than other modulation formats. So DBNRZ system is better performance.

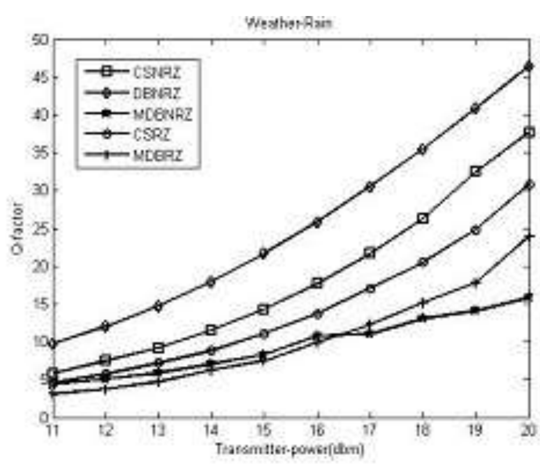


Fig-5a Power variation under rain weather condition

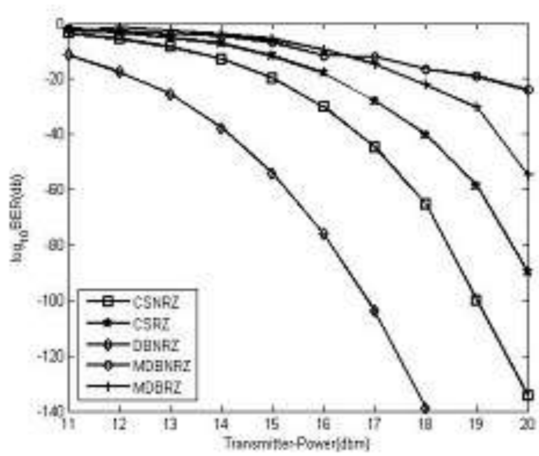


Fig-5b BER v/s Transmitter power in Rain weather condition c)Rain weather condition:- The result of given FSO system can be taken out by using the above parameters given in table-1.In this case attenuation value is 19.28dB/km , power is varies from 11 to 20dbm , length is set to 1100m (meter) and bitrate is set to 10Gbps. Rain weather condition can be apply on the FSO channel link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ).The result of rain weather condition shown in fig-5a and CSNRZ and DBNRZ system have better performance than the other modulation system but DBNRZ has also better performance than CSNRZ system. So DBNRZ system better than the other system as shown in fig-5a.

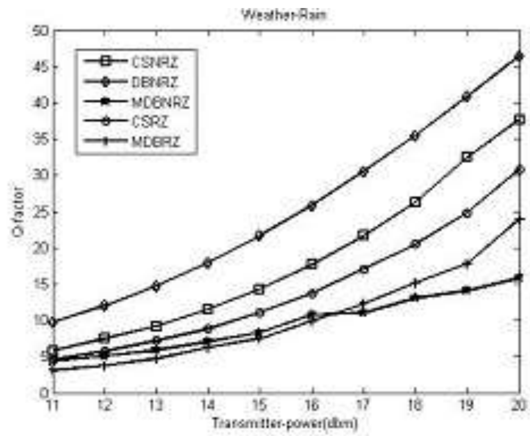


Fig-5a Power variation under rain weather condition

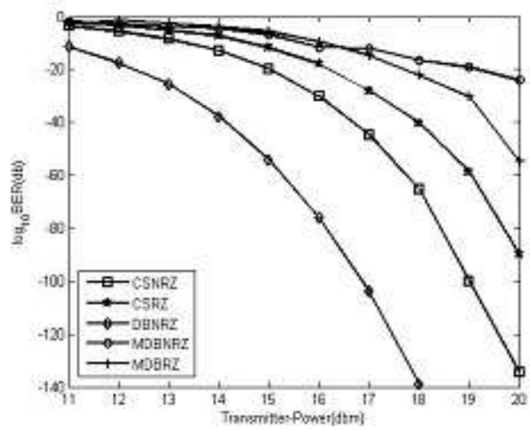


Fig-5b BER v/s Transmitter power in Rain weather condition

The performance of BER and transmitter power also shows in fig-5b. From graph it shown that when transmitter power is increased, BER continuously decreased and DBNRZ system is better because this system has BER-125 at 18dBm transmitter power than other modulation formats. So DBNRZ system is better performance

d)Fog weather condition:- The result of given FSO system can be taken out by using the above parameters given in table-1.In this case attenuation value is 84.90 dB/km , power is varies from 11 to 20dbm , length is set to 345m (meter) and bitrate is set to 10Gbps. Fog weather condition can be apply on the FSO channel link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ).The result of fog weather condition shown in fig-6a and CSNRZ and DBNRZ system have better performance than the other modulation system but DBNRZ has also better performance than CSNRZ system. So DBNRZ system better than the other system as shown in fig-6a and performance of BER and transmitter power also shows in fig-6b. From graph it shown that when transmitter power is increased, BER continuously decreased and DBNRZ system is better because this system has BER-139 at 18dBm transmitter power than other modulation formats. So DBNRZ system is better performance.

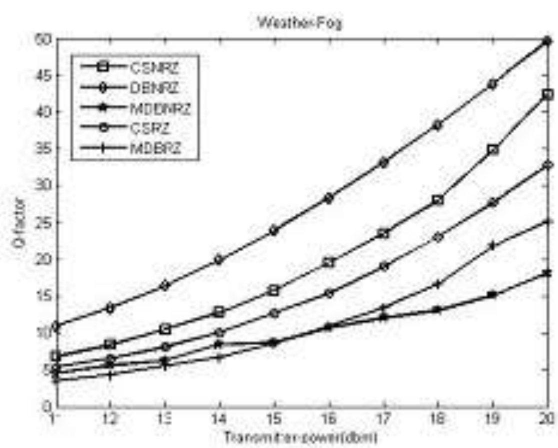


Fig-6a Power variation under Fog weather condition

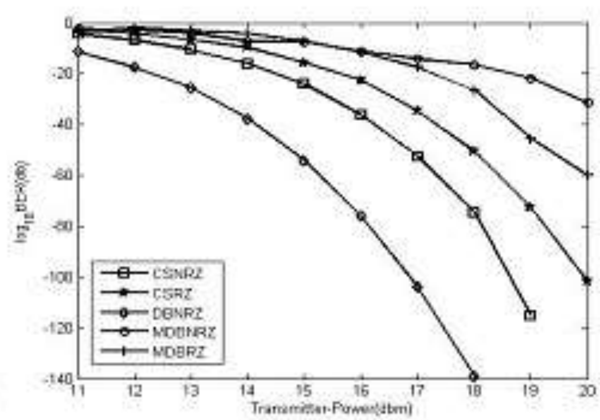


Fig-6b BER v/s Transmitter power in Fog weather condition

ISSN: 2277-9655
Impact Factor: 3.785

CASE 2:- DIFFERENT LENGTH VARIATION IN DIFFERENT WEATHER CONDITION

a)Clear weather condition: The result of given FSO system can be taken out by using the above parameters given in table-1. In this case attenuation value is 0.23dB/km, power is set to 20dbm , length is varies from 0 to 33 km and bitrate is set to 10Gbps. Clear weather condition can be apply on the FSO system link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ). The result of clear weather condition shown in fig-7 and CSNRZ and CSRZ system have better performance than the other modulation system but CSRZ has also better performance than CSNRZ system. So CSRZ system better than the other system as shown in fig-7. It has been observed that Q factor reduce from 857.01 to 0 in the transmission range 0 to 33km (Kilometer) at attenuation 0.23dB/km.

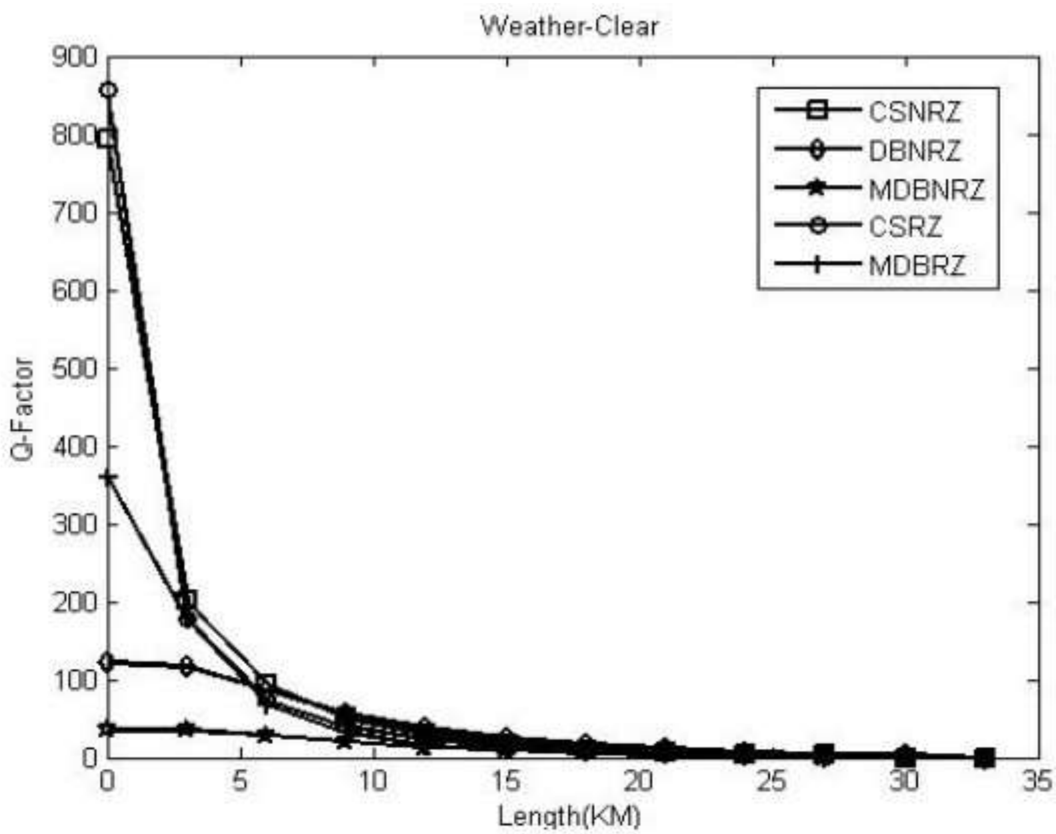


Fig-7 Length variation under clear weather condition

b)Haze weather condition: The result of given FSO system can be taken out by using the above parameters given in table-1. In this case attenuation value is 2.37dB/km, power is set to 20dbm , length is varies from 0 to 8500m (Meter) and bitrate is set to 10Gbps. Haze weather condition can be apply on the FSO system link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ). The result of haze weather condition shown in fig-8 and CSNRZ and CSRZ system have better performance than the other modulation system but CSRZ has also better performance than CSNRZ system. So CSRZ system better than the other system as shown in fig-8. It has been observed that Q factor reduce from 844.90 to 0 in the transmission range 0 to 8500m (Meter) at attenuation 2.37dB/km.

 ISSN: 2277-9655
Impact Factor: 3.785

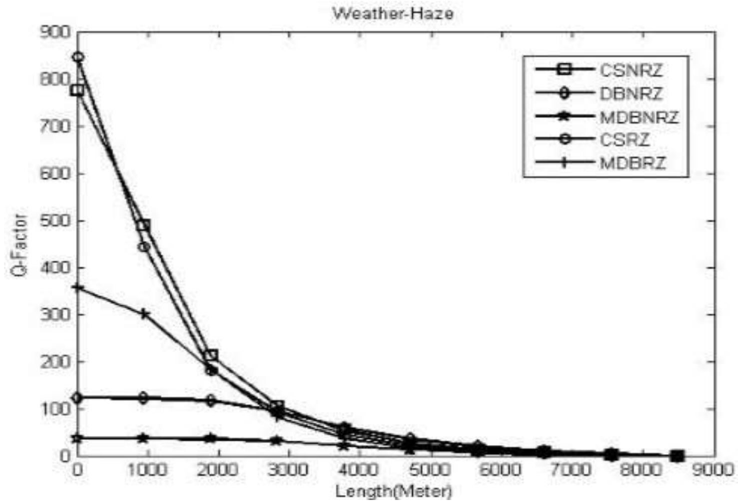


Fig-8 7 Length variation under haze weather condition

c)Rain weather condition: The result of given FSO system can be taken out by using the above parameters given in table-1. In this case attenuation value is 19.28dB/km, power is set to 20dbm, length is varies from 0 to 1800m (Meter) and bitrate is set to 10Gbps. Rain weather condition can be apply on the FSO system link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ). The result of rain weather condition shown in fig-9 and CSNRZ and CSRZ system have better performance than the other modulation system but CSRZ has also better performance than CSNRZ system. So CSRZ system better than the other system as shown in fig-9. It has been observed that Q factor first increase from 855.01 to 1250.8 and then reduced from 1250.8 to 0 in the transmission range 0 to 1800m (Meter) at attenuation 19.28dB/km.

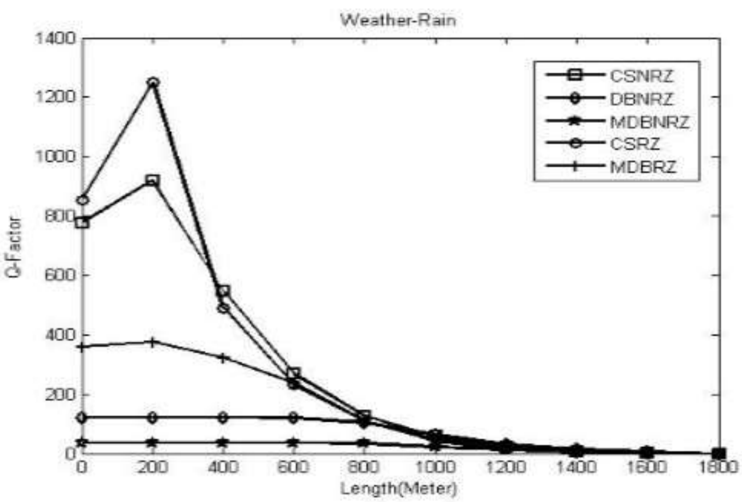


Fig-9 7 Length variation under rain weather condition

d)Fog weather condition: The result of given FSO system can be taken out by using the above parameters given in table-1. In this case attenuation value is 84.90dB/km, power is set to 20dbm, length is varies from 0 to 500m (Meter) and bitrate is set to 10Gbps. Fog weather condition can be apply on the FSO system link with different transmitter modulation (CSNRZ DBNRZ MDBNRZ CSRZ MDBRZ). The result of fog weather condition shown in fig-10 and CSNRZ and CSRZ system have better performance than the other modulation system but CSRZ has also better performance than CSNRZ system. So CSRZ system better than the other system as shown in fig-10. It has been observed that Q factor first increase from 875.06 to 2296.46 and then reduced from 2296.46 to 0 in the transmission range 0 to 500m (Meter) at attenuation 84.90dB/km.

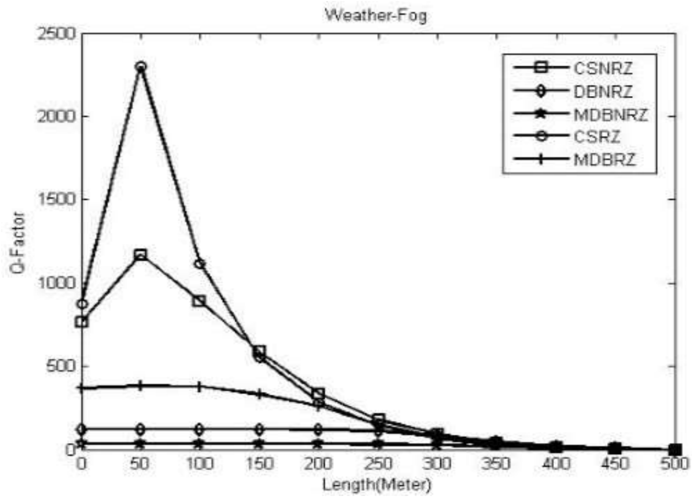


Fig- 10 7 Length variation under fog weather condition

CONCLUSION

In this paper we have presented the results of a 10Gbps FSO system on different weather conditions under different transmitter power and transmission distance. From the results it is concluded that when the power is varied from 11 to 20dBm, the transmission distance go on decreasing as the weather condition changes from clear to fog and DBNRZ transmitter gives better performance under all the different weather conditions and when the transmission length is varied under different weather conditions, the CSRZ system provides the better performance. The BER performance of all received signals is also discussed and it seen that DBNRZ transmitter is better result than other transmitter.

REFERENCES

[1] Kolka, Z., Wilfert, O., Kvicala, R., Fiser, O. Complex Model Of Terrestial FSO Links. Proceedings Of Spie,2007, VOL.6709,P.67091J.
[2] David, F. Scintillation Loss In Free-Space Optic Im/Dd Systems. In Lase 2004, Vol.5338. San Jose(U.sa),2004.
[3] Shivinder Devra, Gurmeet Kaur, “Different Compensation Techniques to Compensate Chromatic Dispersion in Fiber Optics”, International Journal of Engineering and Information Technology, vol. 3, no. 1, pp. 1-4, 2011 (ISSN 0975-5292 (Print), ISSN 0976-0253.
[4] Karamdeep Singh, Gurmeet Kaur, Maninder Lal Singh, “A single As2Se3 chalcogenide Highly Non-Linear Fiber (HNLF) based simultaneous all-optical half-adder and half-subtracter”, locate, vol. 24, pp. 56-63, April 2015.
[5] Shivinder Devra, Gurmeet Kaur, “Dispersion Compensation using Raised Cosine Filter in optical fibers”, International Journal on Information and Electronics Engineering, vol. 1, no. 1, pp. 47-51, July 2011 (ISSN: 2010-3719)
[6] Shivinder Devra, Gurmeet Kaur, “Dispersion Compensation using All Pass Filters in Optical Fibers”, Proc. 2011 International Conference on Information and Electronics Engineering, IACSIT press, vol. 6, no. 5, pp. 218-222, 2011.
[7] Ashish Kumar, Aakash Dhiman, Devender Kumar, Naresh Kumar, “ Free Space Optical Commmunication System under Different Weather Conditions”,IOSR Journal of Engineering, e-ISSN: 2250-3021, p-ISSN:2278-8719, VOL. 3, ISSUE 12, V2, PP. 52-588, 2013.
[8] Michael Cheffena, “The effect of rain attenuation on the performance of BFWA around Kjeller, Norway”, IEEE photonic Journals, vol. 2, no. 3, pp. 121-128, December 2008.
[9] D. K. Borah and D. G. Voelz, “Pointing Error Effects on Free- Space Optical Communication Links in The Presence of Atmospheric Turbulence”, Jornals of Lightwave Technolgy, vol. 27, no. 18, pp. 3965-3973, September. 2009.
[10] http://www.laseroptronics.com/index.cfm/id/57-66.htm.

 ISSN: 2277-9655
Impact Factor: 3.785

[11] Aditi Malik, Preeti Singh, "Free Space Optics: Current Applications and Future Challenges", Hindawi Publishing Corporation, Interntionl journal of Optics, vol.2015, Article ID 945483, 7 pages.

[12] Ajay K. Sharma, S.K. Wadhwa, T.S. Kamal," Robustness of NRZ , RZ, CSRZ modulation on fiber Nonlinearities and amplifier noise at 40Gbps for Long Haul Link", Optik International Journal for Light and Electron optics, vol. 120, pp. 614-618, 2009.

[13] Farukh Nadeem, Vaclav Kvicera, Muhammad Saleem Awan, Erich Leitgeb, Sajid Sheikh Muhammad, Gorazd Kandus, "Weather Effects on Hybrid FSO/RF Communication Link," IEEE journal on selected areas in communications, vol. 27, no. 9, December 2009.

[14] Jagjit Singh Malhotra, Manoj Kumar, Ajay K. Sharma, Alok Kumar, "Performance evaluation of 16 channel DWDM radio-over-fiber link", International Journal for Light and Electron optics, vol. 124, pp. 4120-4122, 2013

[15] Alexander Vavoulas, Harilaos G. Sandalidis, Dimitris Varoutas, "Weather Effects on FSO Network Connectivity," J. Opt. Commun. Netw., vol.. 4, no. 10, October 2012.

[16] Malti, Meenakshi, Anu Sheetal," Comparison of CSRZ, DRZ and MDRZ Modulation Formats for High Bit Rate WDM-PON System Using AWG, " International journal of Emerging Technology and Advances Engineering., vol. 2, issue 6, 2012.

[17] Jitendra Singh, Naresh Kumar, "Performance analysis of different modulation format on Free Space optical communication system", International Journal for Light and Electron optics, vol. 124, pp. 4651-4654, 2013.

[18] Jun He , Robert A. Norwood , Maïté Brandt-Pearce , Ivan B. Djordjevic , Milorad Cvijetic ,Suresh Subramaniam , Roland Himmelhuber , Carolyn Reynolds , Pierre Blanche ,Brittany Lynn , Nasser Peyghambarian , "A survey on recent advances in optical communications", Computers and Electrical Engineering, vol.40, pp.216-240, 2014

[19] Anu Sheetal, Ajay K.Sharma, R.S. Kaler, "Simulation of high capacity 40 Gb/s long haul DWDM system using different modulation formats and dispersion compensation schemes in the presence of Kerr's effect", International Journal for Light and Electron optics, vol. 121, pp.739-749, 2010