Architectural Analysis of Spectrum Sliced Wavelength Division Multiplexed Free Space Optical Communication

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Abstract: **This paper analyzes the performance of spectrum sliced wavelength division multiplexing optical communication system with single mode fiber Kerr effects. At optical transmitter various modulation formats used and corresponding performance is observed in terms of Q-factor, BER and receiver sensitivity. Similarly, performance investigations are carried out by varying optical antenna aperture at transmitter/receiver and beam divergence of optical beam during transmitter to receiver. It has been observed that advanced modulation format DRZ results better Q-factor performance compare to RZ improvement 6 to 7 when transmitter/ receiver antenna aperture diameter increases 5 to 10 cm respectively. Similarly, receiver sensitivity improvements are shown -32 and -35 dBm while transmitter/ receiver antenna aperture diameter increases 5 to 10 cm respectively. Moreover, DRZ modulation format 4 to 6 Q factor improvement is observed compare to RZ while laser light beam divergence increases 0.25 to 1 mrad respectively.**

Keywords: **Free space optics (FSO), highly nonlinear fiber (HNLF), spectrum slicing (SS), Wavelength division multiplexing (WDM), super continuum (SC) generation, duo binary return to zero (DRZ).**

1. Introduction:

Free space optical communication is the advanced technology used widely in now days for short distances which is very cost effective, flexible, license free and high capacity links [1]. Basically, FSO is a communication technology where free space act as medium between transceivers [2]. Free space optical is a line of sight where data, voice and video communication is achieved with maximum data rate by bidirectional connectivity [3]. Wavelength division multiplexed which is used to hold the channels and can carry data in terabits per second with any difficulty [4]. WDM-FSO is a prominent and well competent way out for broadband transmission [5]. WDM are wavelength selective and sensitive routing of each wavelength to specific port [6]. Spectrum sliced technique is very useful for the link rang also bit data rates. So spectrum sliced WDM has identical advantages over the wavelength division multiplexer [7]. Spectrum sliced has many advantages like cost effective, more power efficient, more security, no digging operation, less complex, flexible, high bandwidth [8]. FSO communication link is currently in use for many services at many places. Outdoor wireless access used by wireless services provides for communication and no need of license to use FSO [9]. Free space optical communication capable to providing a backup link in case of failure of transmission through fiber link [10]. FSO service is acceleration to provide instant service to the customer [11]. It can be used to commute between point to point links like two buildings, two ships, and point to multipoint links [12]. It is also used for military access like secure and safely [13]. FSO has some disadvantages are scintillation, geometric losses, atmospheric, turbulences, scattering. The variations of temperature are along different air packets with rising of heat from earth [14]. These temperature variations can cause fluctuation in amplitude of the signal. Geometric losses which can be called optical beam attenuation of the signal.

First of all, it has been seen, refractive index of outer air space continuously varies with atmospheric conditions changes which results in fading of the transmitted signal. It causes the degradation in the performance of FSO links which is generally observed at optical receiver metrics such as bit error rate (BER) increase, SNR deterioration and transmission delays change the transmitter and received aperture diameter (cm) and beam divergence (mrad) [15]. Practically free space optical (FSO) communication system to evaluate Q-factor, bit error rate and received power by different techniques based on SAC OCDMA, high speed OFDM, Optimization. Various physical parameter of FSO also plays an important role in overall transmission communication system [16]. Transmitter and receiver antenna diameter decide to link range and quality of the system. Beam divergence is the major physical parameter which deteriorating factor and needs to be addressed along with attenuation and dispersion [17].

In this paper we have analyzed a spectrum sliced WDM FSO system with various modulation formats such as RZ, NRZ, CSRZ, and DRZ at 2.5 Gb/s bit rate by varying link range 1 to 5 km with clear weather atmospheric turbulence. A Highly Nonlinear Fiber (HNLF) fiber is employed to broaden spectrum of CW laser light by passing through it. Performance is observed in terms of Q-factor, bit error rate and received power by change the physical parameters like beam divergence angle, antenna aperture diameter. The paper is organized as follows: after introduction of FSO links in section 1, section 2 presents architecture of a proposed system set-up SSWDM with HNNF fiber for spectral broadening. In Section 3 the results are shown and discussion is carried out for various performance metrics explorations. At the end section 4 discusses the conclusion drawn from the results and discussions.

2. System Set-Up:

A spectrum slicing is an attractive method to diminish the cost of multi wavelength FSO system architectures such as wavelength division multiplexing. In WDM, a numbers of coherent intensity sources are used to generate different frequencies, which increase the total expenditure of the system. Spectrum slicing is an alternative to WDM, because it can also support same data rates and similarly parallel data streams can be transmitted.

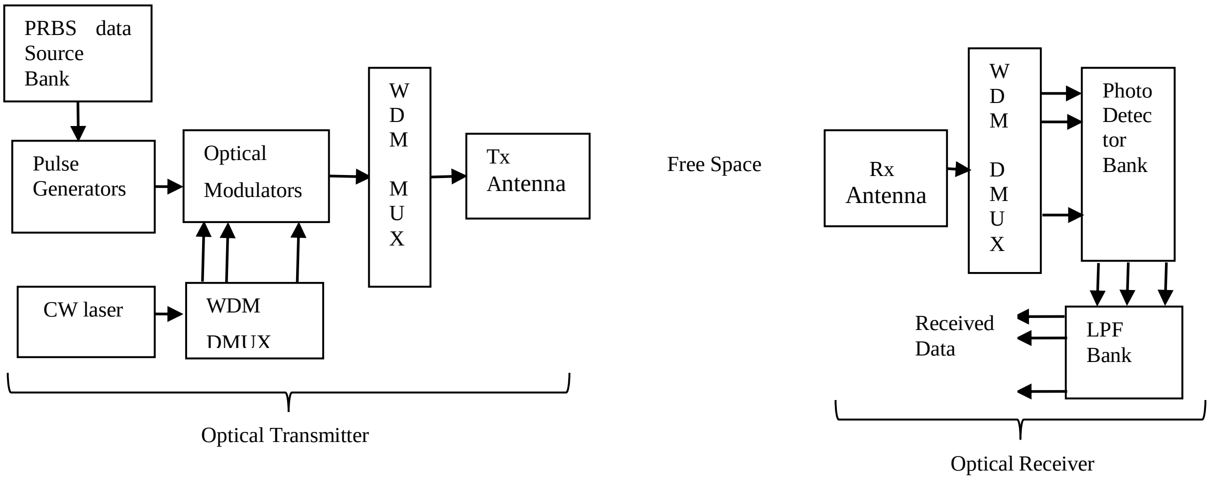


Fig 1. System architecture of SS-WDM-FSO

A proposed spectrum sliced WDM FSO system set-up arrangement is shown in fig. 1. Continuous wave laser generate a carrier wave at 193.54 THz frequency and input power 30 dBm. The laser light is launched into HNLF (highly nonlinear fiber) for super continuum generation using fiber kerr effects. The HNNF fiber output carrier wave spectrum is shown in Fig. 2 (b). The HNLF is specially prepared fiber which due to its high nonlinearity called self-phase modulation (SPM), generates broad optical wave spectrum ready to bed sliced. The principle for the generation of broad spectrum is SPM by highly nonlinear fiber due to very low effective fiber core area (10 μm^2) and coherent high power pulse. The spectral broadening is improved by high nonlinear index coefficient of the fiber using pulses with high peak. Nonlinear coefficient increased by material with high nonlinearity and reduction in fiber effective area. Molecules of the HNLF vibrate due to highly intense laser wave and subsequently there exists varying refractive index [5].

SPM Proportionality constant of HNLF is expressed as

$$\gamma_{SPM} = \frac{2\pi n^2}{\lambda A_{eff}} \qquad (1)$$

Where γ_{SPM} is SPM fiber nonlinearity ($W^{-1}km^{-1}$), n is refractive index of the fiber core, λ is operating wavelength of light wave (m) and A_{eff} (μm^2) effective area of HNLF.

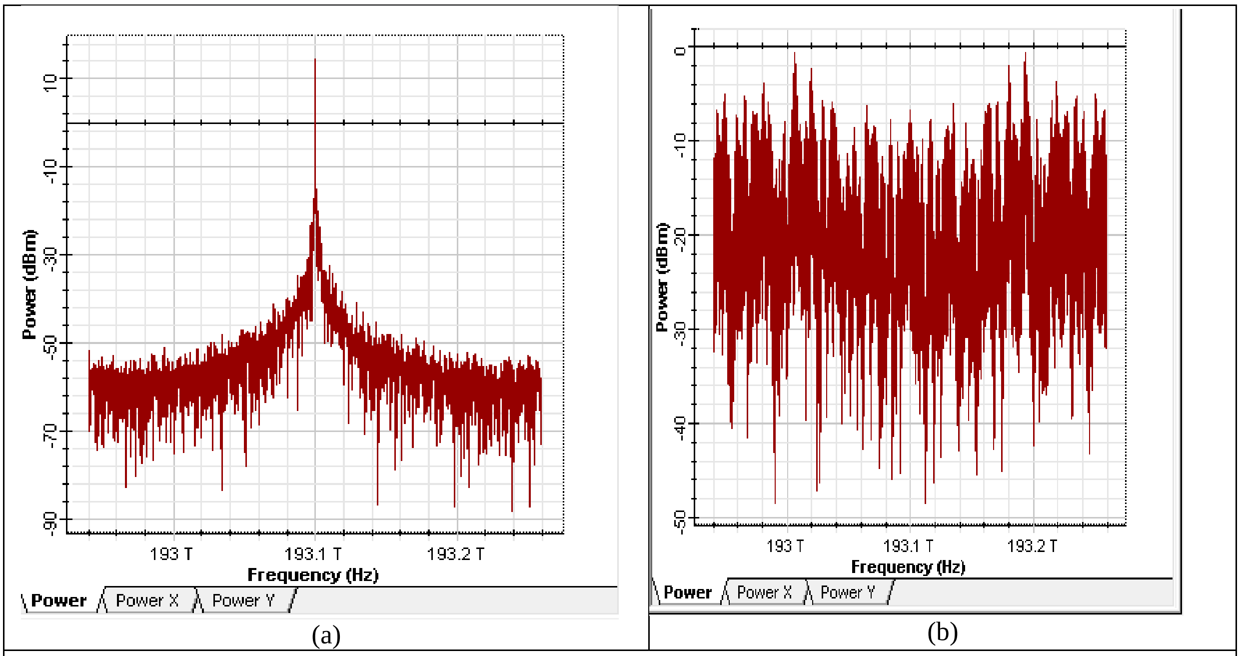
The actual generation of super continuum in HNLF can be altered, varying fiber length, the time of pulse; maximum intensity and wavelength of pump [5].

The HNNF generated light is spectrum sliced into eight wavelength channels having frequency range equally spaced such as 193.0 to 193.2 THz with continuous wave optical de-multiplexer (DEMUX). Channel spacing is 100 GHz to make system bandwidth efficient. A data source bank consisting of 4 individual pseudo random bit sequence (PRBS) generators are used for four independent non- return to zero (NRZ) pulse generators. The sliced channels are optically modulated at peak point eight optical Mach- Zehnder modulators (MZM). These modulated optical waves are on wavelength division multiplexed (WDM) and to transmit waves in free space by optical antenna. Selected parameters during investigations are shown in Table 1.

Table 1. Parameter selected for simulation

S. No.	Name	Value selected
1.	Frequency (THz)	193.54
2.	Laser power (dBm)	30
3.	Numbers of channels	4
4.	Channel frequency range (THz)	193.000-193.22
5.	Channel bandwidth (GHz)	100
6.	HNLF attenuation (dB/km)	0.1
7.	HNLF Beta$_2$ (ps^2/km)	191.9
8.	Nonlinear refractive index (m^2/w)	2.35×10^{-20}
9.	HNLF effective core aperture (μm^2)	10
10.	Transmitter/Receiver aperture diameter (cm)	5 to 20
11.	Beam divergence Angle (mrad)	0.25 to 1
12.	Link distance (km)	1 to 5

Through FSO channel waves reached at the receiver optical antenna end of the system. To connects all the 8 channels at demultiplexer with WDM demultiplexer. AT receiver end each optical receiver consists of a photo detector that converts the light signal into electric signal. PIN photodiode with dark current 10nA and 1 A/W responsibility is followed by a low pass Bessel filter. LPF is used for removing noises from the received signals. A 3-R regenerator placed after LPF for retiming, re-shaping and re-amplification followed by BER analyzer. Bit error rate analyzer is used a decision component that shows the final values of Q-factor, bit error rate, eye closer penalty etc. OSA (optical spectrum analyzers) is placed to access the spectrum frequencies and power of each slices of wavelength. Optical time domain visualizes represents data bits with respective to time of each bit slot.



(a) (b)

Fig 2. CW laser spectrum (a) at laser output (b) After passing through HNLF

3. Results and discussion

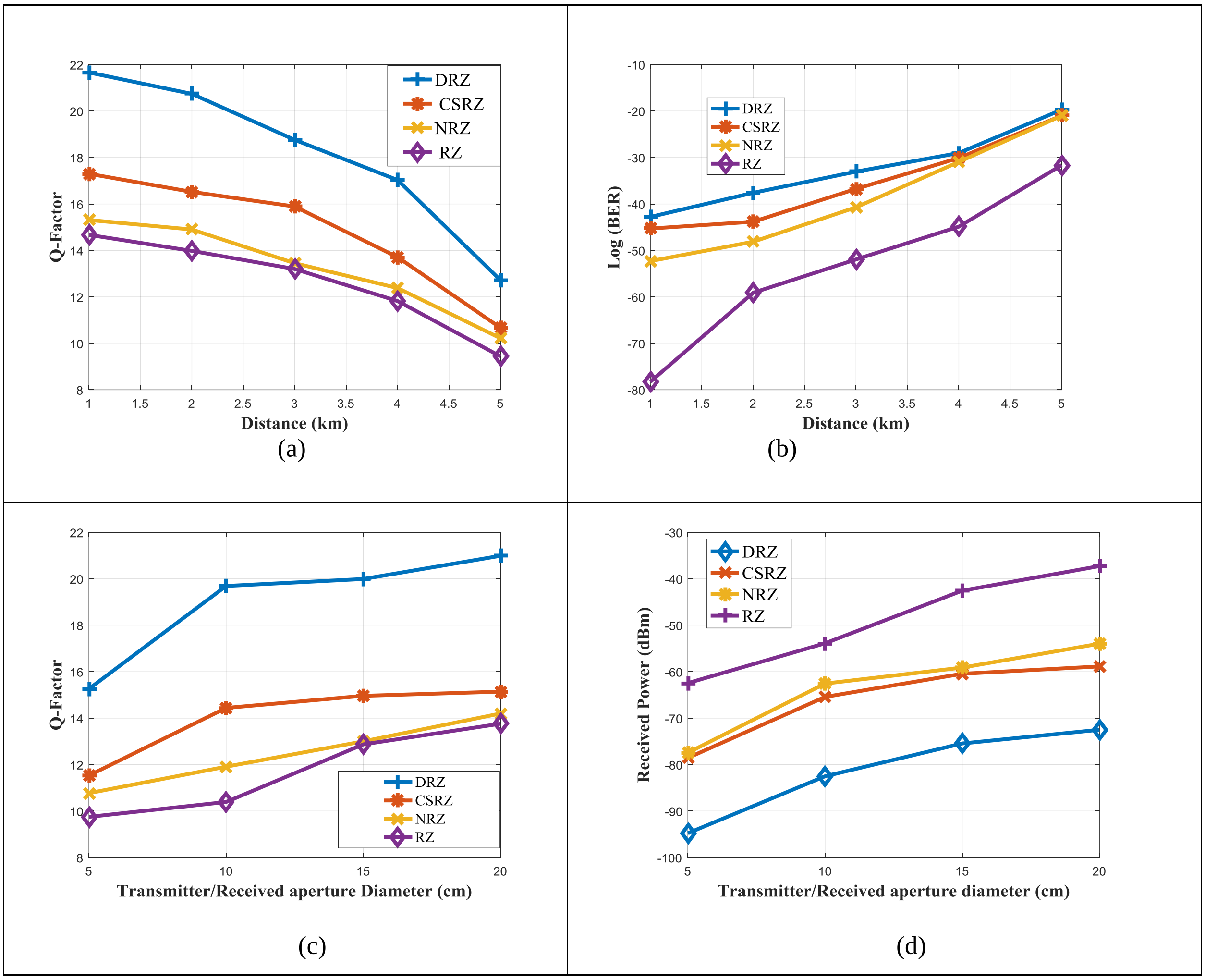
The investigations of spectrum sliced wavelength division multiplexer free space optical system is based on self-phase modulation (SPM) using highly nonlinear fiber. The system performance of the set-up is observed by varying architecture parameters such as modulation formats (RZ, NRZ, CSRZ, and DRZ), link range distance, and beam divergence angle of propagating beam and transceiver antenna aperture diameter. The system link range is varied 1 to 5 km under clear weather atmospheric turbulence. The results are observed in terms of Q-factor, bit error rate and optical receiver power vs. link transmission distance, transmitter/receiver aperture diameter (cm) and beam divergence at 2.5 bit rates.

Fig 3(a) shows Q-factor performance of the link for various modulation formats such as 14.67 to 9.44 (RZ), 15.31 to 10.22 (NRZ), 17.30 to 10.67 (CSRZ), 21.66 to 12.72 (DRZ) with link range 1 to 5 km at clear weather turbulence. Evidently compare to other, DRZ format results highest Q- factor and better performance with at all observed link range of the system. DRZ format performs better due to dispersion tolerance, power efficient and limited effect of scintillation noise on it. The Q- factor analysis is also indicated in Table 2 for various modulation formats.

Similarly, Fig 3(b) and Table 2, show BER performance with varying link rang distance (km) 1 to 5. Duo binary return to zero (DRZ) modulation format results better performance compared to other. Clearly, BER parameter of the system vary from 1.6×10^{-43} to 1.9×10^{-20} (RZ), 5.13×10^{-46} to 9.7×10^{-22} (NRZ), 4.9×10^{-53} to 1.7×10^{-22} (CSRZ) and 5.262×10^{-79} to 2.239×10^{-32} (DRZ). It is evident that DRZ format results less BER compared to other formats. This is in accordance with Q- factor analysis and the proposed design performs better at this format.

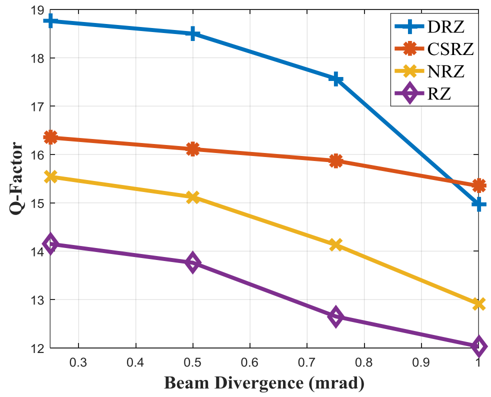
Table 2. Q-factor and BER vs. link range (km)

Link Range (km)	Q- factor				BER			
	RZ	NRZ	CSRZ	DRZ	RZ	NRZ	CSRZ	DRZ
1	14.67	15.31	17.30	21.66	1.6×10^{-43}	5.1×10^{-46}	4.9×10^{-53}	5.3×10^{-79}
2	13.98	14.9	16.52	20.74	2.5×10^{-38}	1.5×10^{-44}	7.4×10^{-49}	7.7×10^{-60}
3	13.2	13.45	15.89	18.76	9.1×10^{-34}	1.7×10^{-37}	1.2×10^{-41}	1.2×10^{-52}
4	11.82	12.38	13.71	17.03	9.1×10^{-30}	7.8×10^{-31}	1.1×10^{-31}	1.4×10^{-45}
5	9.44	10.22	10.67	12.72	1.9×10^{-20}	9.7×10^{-22}	1.7×10^{-22}	2.3×10^{-32}



(a) (b)

(c) (d)



(e)

Fig 3.(a) Q-factor (b) BER vs. varying link range 1 to 5 km (c) Q-factor (d) Optical receiver power vs. TX/Rx aperture diameter 5 to 20 cm, (e) Q-factor vs. Tx/Rx beam divergence 0.25 to 1 (mrad).

Table 3 shows the performance analysis by varying transmitter/receiver aperture diameter varying 5 to 20 cm at clear weather in terms of Q-factor from 9.78 to 13.84 (RZ), 10.73 to 14.35 (NRZ), 11.56 to 15.18 (CSRZ), 15.29 to 20.99 (DRZ). Evidently, Q-factor improves by increasing the Tx/Rx aperture diameter. This improvement is due to the higher optical antenna gain and tolerant to beam divergence with aperture. But in real system antenna aperture is somewhat less variant parameter. Moreover, DRZ modulation format have good performance in accordance with link range analysis.

Theoretically, let power transmitted and received at the antennas is represented as P_{TX} and P_{RX} respectively. Similarly, A_{TX} *and* A_{RX} represent aperture area of the antenna respectively. Moreover, if R is the link range at is the wavelength (λ). Assuming the far-field beam diameter is much larger than the receiver diameter. Then received power at the optical receiver antenna can be expressed as

$$P_{Rx} = \frac{P_{Tx}A_{Tx}A_{Rx}}{R\lambda^2} \tag{2}$$

Table 3. Q-factor with Tx/Rx aperture diameter (cm)

Sr. No.	Tx/Rx aperture (cm)	Q-factor				Optical Received Power (dBm)			
		RZ	NRZ	CSRZ	DRZ	RZ	NRZ	CSRZ	DRZ
1	5	9.78	10.73	11.56	15.29	-94.77	-78.56	-77.45	-62.45
2	10	10.45	11.85	14.48	19.75	-82.51	-65.43	-62.56	-53.89
3	15	12.97	13.04	14.92	19.94	-75.45	-60.45	-59.12	-42.56
4	20	13.84	14.35	15.18	20.89	-72.51	-58.87	-53.98	-37.27

Further, optical receiver sensitivity has been analyzed with modulation formats at 2.5 Gb/s bit rate with Tx/Rx antenna aperture diameters at clear weather turbulence. The analysis is shown in fig. 2(d) by plotting of received power by varying the transmitter and receiver aperture diameter (cm) from 5 to 20. It can be elaborated that, at clear weather condition the received optical power is decreased -94.77 to -72.51 (RZ), -78.56 to -58.87 (NRZ), -77.45 to -53.98 (CSRZ), -62.45 to -37.27 (DRZ) dBm. Moreover, DRZ modulation format performs better with varying Tx/Rx aperture diameter (cm) and results comparatively less deteriorations. As per the optical received power indicated in Table 3 and fig. 3 (d) the proposed system should work full range up to 1 to 5 km with Tx/Rx aperture diameter (cm).

Analytically single mode Gaussian beam FSO system can be represented beam divergence angle θ in a link range L. If P_{Tx} and P_{Rx} are represent transmitter and receiver powers respectively, α is the attenuation coefficient along the observed path and A is antenna effective area of antenna. Then investigations for different beam divergences due to the link range and other parameters can be expressed as.

$$\theta = \sqrt{\frac{2P_{Tx}A_r e^{-\alpha L}}{P_{Rx}\pi L^2}} \tag{3}$$

Fig. 3(e) and table 4 show beam divergence angle analysis by varying it as 0.25 to 1 (mrad). The observed Q- factor analysis indicate variations such as 14.15 to 12.03 (RZ), 15.54 to 12.91 (NRZ), 16.35 to 15.35 (CSRZ), and 18.76 to 14.97 (DRZ). Whereas, a beam divergence angle is small, the propagation of light affected more by scintillation noise and consequently Q-factor degrades. However, these degradations are less with DRZ format and improved Q- factor results. Here again it have been elaborated that DRZ modulation format have better Q- factor when beam diverges more with propagation through the space.

Table 4. Q-factor with Beam divergence angle (mrad)

Sr. No.	Beam divergence (mrad)	Q-factor			
		RZ	NRZ	CSRZ	DRZ
1	0.25	14.15	15.54	16.35	18.76
2	0.5	13.76	15.12	16.11	18.5
3	0.75	12.65	14.13	15.87	17.57
4	1	12.03	12.91	15.35	14.97

4. Conclusion

The purposed system have also been investigated by different modulation formats at the optical transmitter such as RZ, NRZ, CSRZ and DRZ with changes the physical parameter such as beam divergence angle, transmitter and receiver antenna aperture diameter at 2.5 Gb/s bit data rate with link range varying 1 to 5 km. The performance metrics are observed such as Q- factor, BER and optical receiver sensitivity at the system outputs. It has been observed that advanced modulation format DRZ results better Q-factor performance compare to RZ improvement 6 to 7 when transmitter/ receiver antenna aperture diameter increases 5 to 10 cm respectively. Similarly, receiver sensitivity improvements are shown -32 and -35 dBm while transmitter/ receiver antenna aperture diameter increases 5 to 10 cm respectively. Moreover, DRZ modulation format 4 to 6 Q factor improvement is observed compare to RZ while laser light beam divergence increases 0.25 to 1 mrad respectively. Theoretically, a laser light diverges more there are degradations of Q-factor but still in this scenario DRZ format performs better. The paper investigations indicate that the system DRZ format performs comparatively better Q- factor, optical receiver sensitivity and bit rate to the work reported under similar conditions.

References

1. M. Kaur, G. Singh, "Analysis of different modulation formats in spectrum slices free space optical communication system", *International Journal of Creative Research Thoughts,* vol. 5, no.3, pp. 448-452, 2017.
2. G. singh, D. Saini, "A radio over free space optical system by mixing radio frequency waves in advance modulation formats", *International research journal of engineering and technology,* vol. 4, no. 6, pp. 2775-2780, 2017.
3. G. Singh, M. Singh, "Investigation and analysis of free space optical link for different atmospheric turbulences, beam divergence and modulation formats," *International journal of engineering research and application,* vol. 7, no. 7, pp. 22–25, 2017.
4. S. Singh, K. Singh, S. Devra, "Simulative performance evaluation of a free space optical communication link operating at 1550 nm using different modulation formats", *International journal of computer application technology and research,* vol. 5, no. 6, pp. 320-329, 2016.
5. S. D. Milner, C. C. Davis, "Hybrid free space optical/RF networks for practical operations", *in Proceedings of IEEE Milcom 1, Monterey*, pp. 409–415, 2004.
6. H. Izadpanah, T. Elbatt, V. Kukshya, F.Dolezal, B. K. Ryu, "High-availability free space optical and RF hybrid wireless networks". *IEEE Wireless Communication*, vol. 2, pp.45–53, 2003.
7. H. Tapse, D. K. Borah, "Hybrid Optical/RF channels: characterization and performance study using low density parity check codes", *IEEE Trans Communication*, vol. 57, pp. 3288–3297, 2009.
8. V. Kukshya, T. S. Rappaport, H. Izadpanah, G. Tangonan, R. A. Guerrero, J. K. Mendoza, B. Lee, "Free-space optics and high-speed RF for next generation networks–propagation measurements", *in Proceedings IEEE VTC-Fall, Vancouver*, vol. 1, pp. 616–620, 2002.
9. D. K. Borah, D. G. Voelz, "Pointing error effects on free space optical communication links in the presence of atmospheric turbulence", *IEEE/OSA Journal Light wave Technology*, vol. no. 27, pp. 3965–3973, 2009..
10. S. Jawla, R. K. Singh, **"**different modulation formats used in optical communication system", *IOSR Journal of Electronics and Communication Engineering*, vol. 8, no. 4 pp. 15-18, 2013.
11. G. Immadi, M. V. Narayana, A. S. Madhuri, V. L. T. Sabbasani, "simulation of free space optical communication under different weather conditions", *International Journal of Pure and Applied Mathematics*, vol. 117, no. 18, pp. 143-148, 2017.
12. A. Abdul Hussein, A. Oka, T. Nguyen, L. Lampe, "Rate less coding for hybrid free-space optical and radio-frequency communication", *IEEE Trans Wireless Communication*, vol.4, no.9, pp.907–913, 2010.
13. S. Vangala, H. Pishro-Nik, "A highly reliable FSO/RF communication system using efficient codes', *in Proceedings IEEE Globe com, Washington, D.C.*, pp. 2232–2236, 2007.
14. R. Luna, D. K. Borah, R. Jonnalagadda, D. Voelz, "Experimental demonstration of a hybrid link for mitigating atmospheric turbulence effects in free space optical communication", *IEEE Photon Techno Letter*, vol. 21, pp.1196–1198, 2009.
15. F. S. Vetelino, C. Young, L. Andrews, and J. Recolons, "Aperture averaging effects on the probability density of irradiance fluctuations in moderate-to-strong turbulence," *Applied Optical*, vol. 46, pp. 2099–2108, 2007.
16. J. C. Ricklin and F. M. Davidson, "Atmospheric optical communication with a Gaussian Schell beam," *Journal Optical Soc. Am. A,* vol. 20, pp. 856–866, 2003.

17. O. Korotkova, L. C. Andrews, R. L. Phillips, “Model for a partially coherent Gaussian beam in atmospheric turbulence with application in laser communication,” *Optical Engineering*, vol. 43, pp. 330–341, 2004.