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Implementation and Analysis of LP Modes Over OWC Link using Different Pulse Shapes

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***Abstract*—Optical wireless communication link utilizes the intermixed features of two most powerful communication technologies Wireless and Optics to transmit data between two points using lasers. This technology is useful where fiber optic cable is impractical. In this paper, a system performance has been investigated for different linearly polarized modes such as LP_{00}, LP_{01} and LP_{02} with return-to-zero (RZ), non-return-to-zero (NRZ) and compressed-spectrum-return-to-zero (CSRZ) modulation formats at varied data rates in terms of Q-factor and eye diagram. Simulation investigation results show that out of all above mentioned scenarios the NRZ modulation scheme performs best. Then the system performance of optimal modulation format-NRZ has been analysed with varied aperture diameters and input powers for three linearly polarized modes LP_{00}, LP_{01} and LP_{02}. This proposed linearly polarized system analysis illustrates that all linearly polarized modes transverse with same Q-factor and BER over OWC channel.**

Keywords*—Optical Wireless Communication (OWC), Linearly Polarized modes (LP modes), Spatial Continuous Wave Laser (SCWL), Spatial Mode Selector (SMS).

I. INTRODUCTION

Over the last two decades, wireless communications has gained enormous popularity, offering attractive options for many personal and organizational communication needs due to its inherit characteristics such as flexibility, cost effectiveness, and mobility [1]. Two transmission techniques for wireless communications have been bring into service so far; *Radio Frequency (RF) and Optical Communications* [2]. But due to its numerous advantages over traditional RF wireless communications, such as large bandwidth, ultra-high data rate, license free, higher immunity to interference, narrower beam width, light weight, low power, low loss and hence low cost, there is a rapidly growing interest in Optical Communications [3, 4, 5]. The OWC have distinct application areas that include satellite networks, aircraft, deep space under water and terrestrial communications [6]. The key technology for realizing such applications by OWC system is the use of lasers as signal carriers. Earlier if we want to transmit distinct signals then we require different wavelength lasers (i.e. no. of lasers are required), due to which cost of system increases to very large extent. In addition, system complexity increases. One solution to this problem will be use of tuneable lasers. Definitely, system complexity reduces to large extent but cost of tuneable laser is very high. So this method is not considered effective and efficient. Another solution to the reported problem will be the use of LP modes concept. As with the use of this concept, we transmit distinct signals with same laser (i.e. only one laser is required). Hence, cost and complexity both reduces at the same time. So, with one laser we can transmit various distinct signals, just by altering the mode of transmitted signal. In this paper we have presented the concept of signal transmission by generating different LP modes through OWC link.

Linear Polarized Modes: Light propagates in the form of Linearly Polarized modes called LP modes [7]. They are used so as to enhance the capacity of OWC link. Basically, they are the light intensity profiles (patterns) that propagate through any transmission medium (here OWC) maintaining their respective transversal field shapes. Each mode corresponds to a light beam travelling with different angles [8]. They can be obtained by changing the refractive index of core, changing the core size, changing the wavelength or setting the specific Eigen value [9].

The LP modes are normally designated by two parameters: the azimuthal mode number, n and the radial mode number, m. For a particular mode, ‘$2n$’ corresponds to the number of intensity peaks in the azimuthal direction and ‘m’ corresponds to the intensity over 360 degrees in the radial direction. Fig. 1 shows the intensity distributions of some LP_{nm} modes.

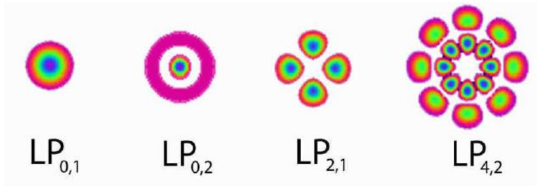

Fig.1 LP mode intensity distributions [10].

All modes with the mode group number G must fulfil the following equation. [10],

$$G=n+2m+1$$

The mode having same group number will have the same phase constant and group delay. Table 1 gives some of LP modes groups.

TABLE 1. PRIMARY LP MODE GROUPS [8].

G	Modes
1	LP_{00}
2	LP_{10}
3	LP_{01}
4	LP_{11a} LP_{11b}
5	LP_{02} LP_{21a} LP_{01b}
6	LP_{12a} LP_{12b} LP_{31a} LP_{31b}
7	LP_{03} LP_{22a} LP_{22b} LP_{41a} LP_{41b}
8	LP_{13a} LP_{13b} LP_{32a} LP_{32b} LP_{51a} LP_{51b}
9	LP_{04} LP_{23a} LP_{23b} LP_{42a} LP_{42b} LP_{61a} LP_{61b}

This paper is an attempt to optimize the OWC link by incorporating LP_{nm} modes for different modulation formats.

II. MODEL DESCRIPTION

This paper models optical wireless communication system for three different modulation formats RZ, NRZ and CSRZ to obtain different LP mode profiles. This is obtained with the help of single SCWL at transmitter side or combination of Transverse Mode Generator and CW laser. The SCWL is "ready-to-use" component that encapsulate an optical source and a transverse mode generator. The transverse mode generator have the ability to include transverse mode profiles in the optical signals.

A. Principle of RZ for LP modes

Fig. 2(a) shows the schematic of the simulation setup for RZ modulation format. This signal is generated by passing the RZ signal to the MZM. The other input to the MZM is from SCWL which is responsible for generation of different LP modes.

A. Principle of NRZ for LP modes

Fig. 2(b) shows the schematic of the simulation setup for NRZ modulation format. This signal is generated by passing the NRZ signal to the MZM. The other input to the MZM is from SCWL which is responsible for generation of different LP modes.

B. Principle of CSRZ for LP modes

Fig. 2(c) shows the schematic of the simulation setup for CSRZ modulation format. This signal is generated by passing the NRZ signal to the MZM and then applied to the phase modulator driven by a sine wave generator at the frequency equal to half the data rate. Thus a phase shift of π, between any two adjacent bits is introduced. As a result of this, the central peak at the carrier frequency is suppressed so as to obtain CSRZ output [11]. Here also SCWL is used to obtain different LP mode profiles.

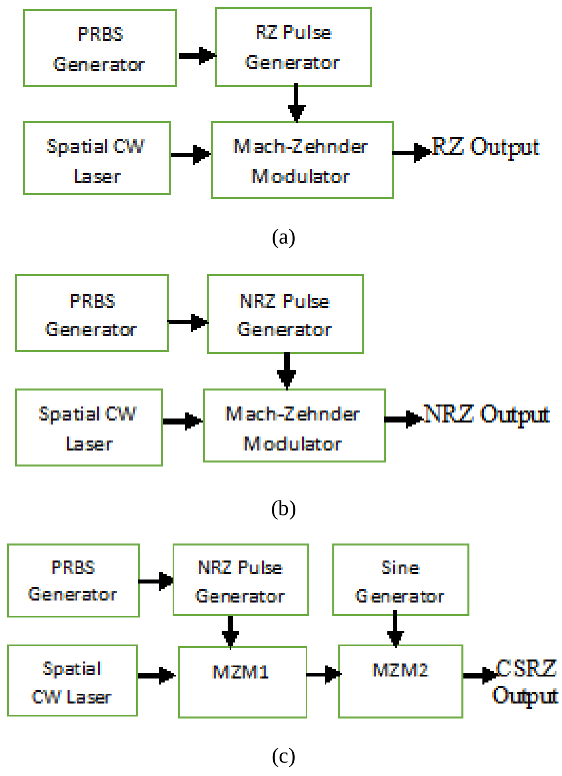

Fig. 2 Schematic of (a) RZ modulation format; (b) NRZ modulation format; (c) CSRZ modulation format.

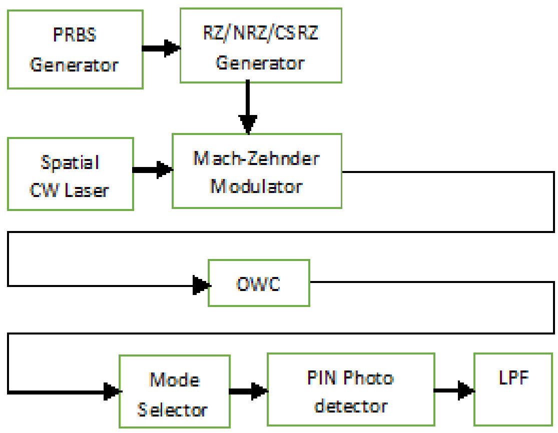

Fig. 3 Schematic of system model of LP modes.

The block schematic of modelled system for generating LP modes consists of three main communication parts which are transmitter, OWC propagation channel and receiver as shown in Fig. 3. The generated optical signal is modulated by the incoming data stream with the help of a commonly used optical modulator that is Mach–Zehnder modulator (MZM). The space between transmitter and receiver will be considered as propagation medium for transmitted light [12-13]. Then at receiver side the received light ray will be detected by the combination of mode selector and photodiode which will be followed by a low pass filter (LPF). The mode selector has the ability to pick out the respective transverse mode profiles from the optical signals. Single Spatial PIN detector can also be used in place of combination. Simulation parameters for modelled system are shown in Table 2.

TABLE 2. SIMULATION PARAMETERS OF SYSTEM

Simulation Parameters	Value
Input Power	0 dBm
Wavelength	1550 nm
Range	1000 km
Tx Aperture Diameter	20 cm
Rx Aperture Diameter	25 cm
Tx/Rx Pointing Angle	0.8 µrad
Responsivity	1 A/W
Dark Current	10 nA
Cut-off Frequency	0.8*Bit Rate

III. RESULTS AND DISCUSSION

The proposed setup is simulated for three different modulation formats RZ, NRZ and CSRZ using LP_{nm} modes with input power of 0 dBm and transmission distance of 1000 km at operating wavelength of 1550nm. Results illustrates successful transmission of LP modes through OWC link.

Fig. 4 represents comparison of RZ, NRZ and CSRZ modulation formats in terms of Q-factor at different data rates for three LP_{nm} modes LP_{00}, LP_{01}, LP_{02}. As the performance of OWC is highly affected by system data rate because Q-factor decreases with increase in the data rate [14]. So results are taken at varied data rates of 5-50 Gbps. It has been observed that for any LP_{nm} mode Q-factor for RZ, NRZ and CSRZ lies between 3.91211–12.2616 dB, 4.90982–15.2493 dB, and 4.59429–14.3872 dB respectively with acceptable BER. Hence, for any $LP_{n,m}$ mode NRZ modulation format performs best.

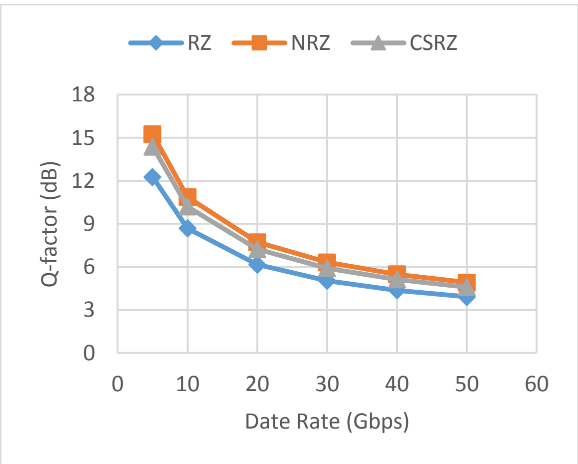

Fig. 4. Evaluation of Q-Factor w.r.t. data rate for various modulation formats for any LP_{nm} mode.

Fig. 5 and 6 depicts eye diagrams for 5 Gbps and 50 Gbps modelled OWC system using concept of LP modes for RZ, NRZ and CSRZ modulation formats. These eye diagrams are taken for LP_{02} mode but it has been observed from the analysis that all other modes gave similar results at similar simulation parameters. Furthermore, it is analysed that eye diagram for CSRZ is better than RZ but for NRZ it will give best results. Hence we use NRZ modulation format for rest of the analysis.

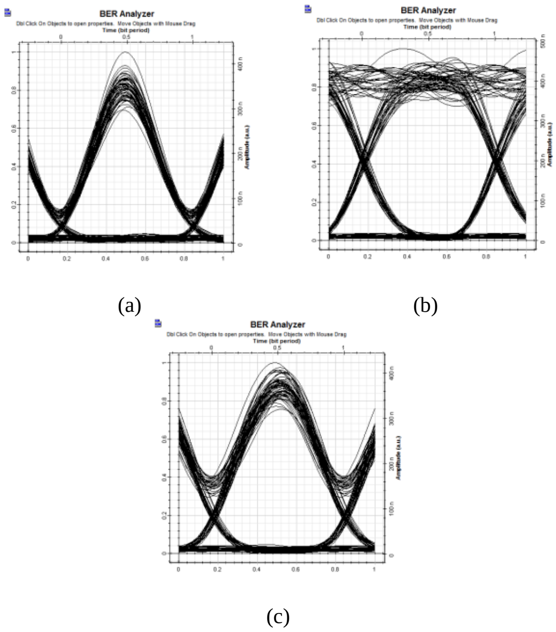

Fig. 5. Eye diagrams for LP modelled 5 Gbps OWC system using (a) RZ; (b) NRZ; (c) CSRZ

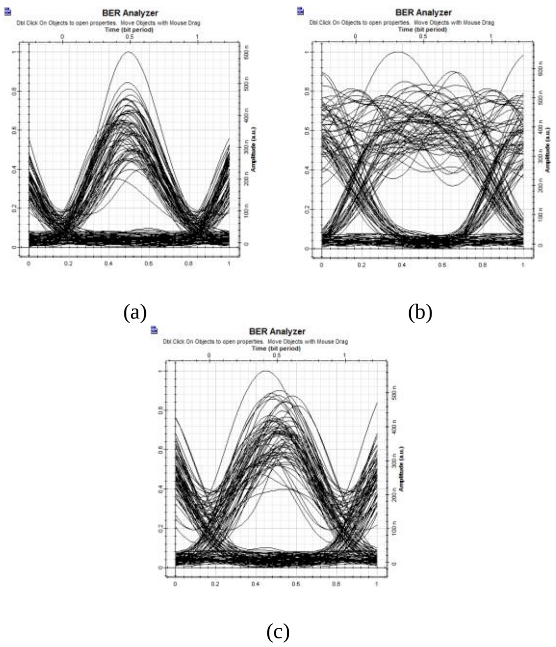

Fig. 6. Eye diagrams for LP modelled 50 Gbps OWC system using (a) RZ; (b) NRZ; (c) CSRZ

The 3-D spatial mode profiles for LP_{00}, LP_{01} and LP_{02} modes using 50 Gbps NRZ OWC system has been shown in Fig. 7. We obtain these profiles at transmitter as well as at receiver spaced 1000 km apart with the help of spatial visualizer component of OPTI-SYSTEM simulator. It has been observed that there will be no difference in spatial mode profiles in OWC link at such high data rate and transmission distance. Means we can transmit different modes without any changes in their respective profiles.

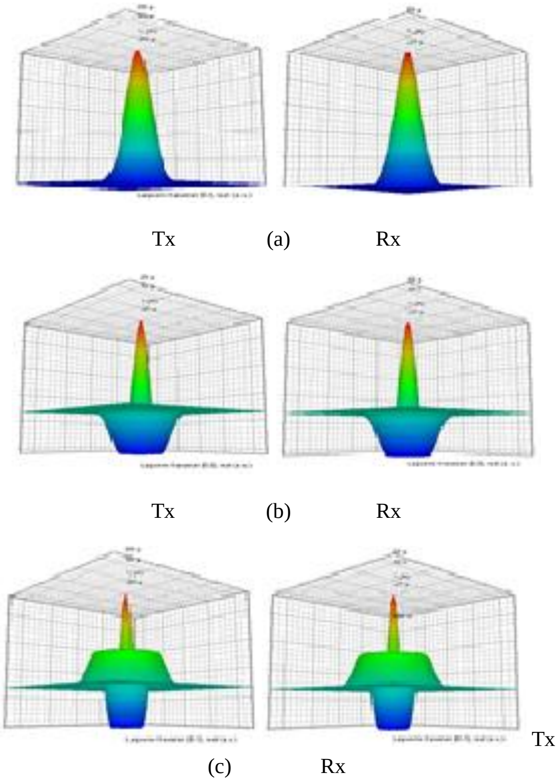

Fig. 7. 3-D Spatial mode profiles for 50 Gbps NRZ at Transmitter and receiver side. (a) LP_{00}; (b) LP_{01}; (c) LP_{02}

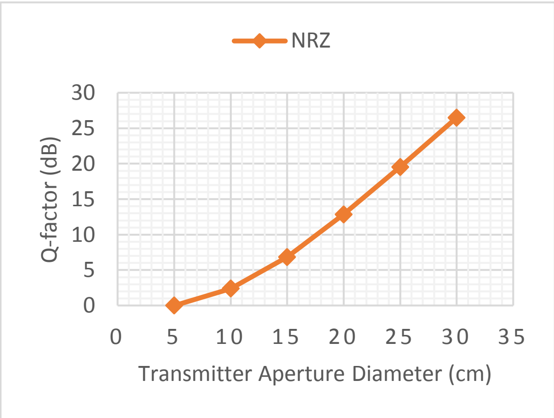

Fig. 8. Evaluation of Q-factor w.r.t different Tx/Rx aperture diameters for any LP_{nm} mode in case of NRZ modulation format.

Fig. 8 depicts the measurement of Q-factor at different Tx/Rx aperture diameters for three LP_{nm} modes LP_{00}, LP_{01} and LP_{02}. It is to be noted here that aperture diameter of receiver is to be kept 1 cm larger than transmitter so as to compensate the effect produced due to divergence of light beam. It has been observed that for any LP_{nm} mode Q-factor increases with increase in Tx/Rx aperture diameter.

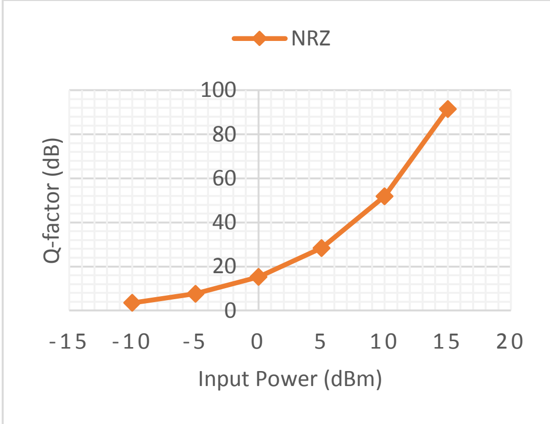

Fig. 9. Evaluation of Q-factor w.r.t different input powers for any LP_{nm} mode in case of NRZ modulation format.

Fig. 9 depicts the measurement of Q-factor at different input powers for three LP_{nm} modes LP_{00}, LP_{01}, LP_{02}. It has been observed that for any LP_{nm} mode Q-factor increases with increase in laser input power. Moreover, it is observed that system performs quiet well at low powers also.

IV. CONCLUSION

In this article we have presented the simulation investigation of OWC system for different modulation formats such as RZ, NRZ, and CSRZ using different LP_{nm} modes LP_{00}, LP_{01}, LP_{02} at varied data rates of 5-50 Gbps with low input power of 0 dBm and transmission distance of 1000 km at 1550 nm wavelength. Simulation investigation results shows that NRZ performs best with Q-factor of 15.2493 dB at data rate of 5 Gbps and 4.90982 dB at 50 Gbps for all LP modes. Hence, we conclude that all the LP modes transverse with same Q-factor and BER. Spatial visualizer results illustrates successful transmission performance of LP modes through OWC link.

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