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Performance Analysis of Mode Division Multiplexing Passive Optical Network Using Compressed Spectrum Return to Zero (CSRZ)

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A B S T R A C T

Mode division multiplexing (MDM) is getting great attention of researchers due to potential of serving users with high speed in passive optical networks (PONs). With incorporation of MDM, existing PON networks can be upgraded and system capacity can be improved. In this research article, Laguerre-Gaussian (LG) modes based MDM-PON system at 50 Gbps/wavelength is demonstrated over distance of 2.8 km using compressed spectrum return to zero (CSRZ) advanced modulation. Performance of proposed system is evaluated at different link lengths of multimode fiber (MMF) in terms of Q factor, and BER.

Keywords: MMF, LG, CSRZ, WDM, FTTH, BER, Q factor

1. Introduction

With the increase in internet applications such as online gaming, video conferencing, and high definition TV etc, peer pressure is observed on existing optical networks. Capacity of 10 Gbps fiber to the home (FTTH) networks is not sufficient to cater demands [1]. Passive optical networks are not at par in the view of supporting high data rates and therefore integration of wavelength division multiplexing (WDM) is required in FTTH networks. WDM PON systems has several advantages such as high-speed access, high bandwidth, large capacity, ease of management, channel independence, format transparency, and network security [2]. Future networks should have following attributes (i) enormous bandwidth (ii) legacy networks compatibility (iii) reasonable cost (iv) flexible networks, can be upgraded and managed. For the last mile connectivity, WDM PON is emerged as an important solution for optical networks. Mode division multiplexing is prominent these days because of high data rate carrying capacity and used in WDM-PON systems to boost the system capacity. MDM is basically an addition as new dimension to WDM-PON systems [3]. This introduces another multiplexing dimension to the standard wavelength dimension [4-6]. MDM is viable through a variety of approaches such as producing matching eigenfunction wavefronts [7-9], modal decomposition techniques [10-11], adaptive optical equalisation [12] [13], offset launches [14] [15] as well as spatial filters based on single mode fibres [16], phase masks [17] and gratings [18]. From an electromagnetic point of view, there are actually four different types of mode in a multimode fiber depending on the angle between the electric field vector and the axis of the fiber. For most communication fibers, however, where the refractive-index difference between the core and cladding is relatively small, the different types of mode can be grouped together into a single series of modes known as the Linearly Polarized (LP) modes [19].The LP modes are normally designated by two parameters; these are the radial mode number, m, and the azimuthal mode number, n. For a particular mode n' corresponds to the number of intensity peaks in the radial direction and 2m' corresponds to the number of intensity peaks over 360 degrees in the azimuthal direction. Mode number can be calculated as

$$M = n + 2m - 1$$

MDM-PON at 25 Gbps over 1 km link distance using non return to zero modulation format in [20]. However speed, distance enhancement is required in future PON systems using MDM.
In this work, Laguerre-Gaussian (LG) modes based MDM-PON system at 50 Gbps/wavelength is demonstrated over distance of 2.8 km using CSRZ advanced modulation. Performance of proposed system is evaluated at different link lengths of MMF in terms of Q factor, and BER.

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2. System Setup

MDM-PON system consisting of 5 LG modes per transmitter and carrying 10 Gbps per LG mode has been presented for 5 transmitters. Total capacity of proposed system is 50 Gbps per transmitter and results into 250 Gbps using 5 LG modes and different 5 wavelengths. Block diagram of proposed system is shown in Figure 1.

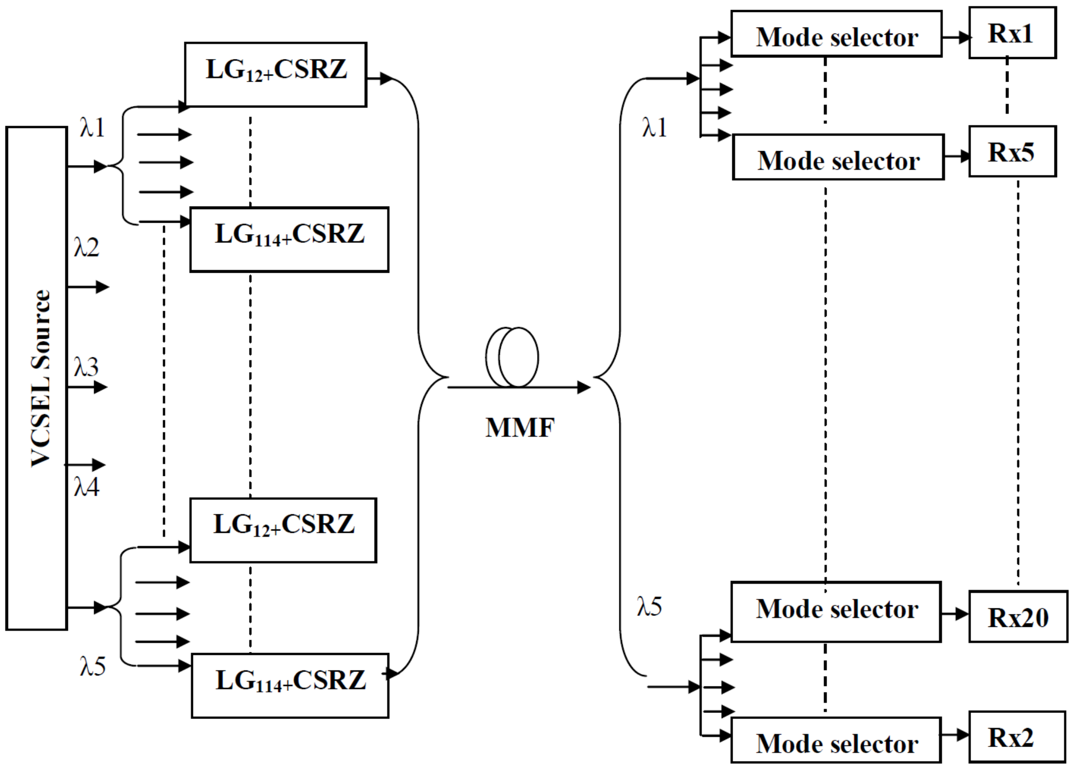


Figure 1 Representation of proposed MDM-WDM passive optical network

VCSEL lasers are used and five wavelengths are generated such as 1546.92 nm, 1548.52 nm, 1552.12 nm, 1551.72 nm, and 1553.33 nm. Each wavelength is divided into five parts and each path is then assigned with LG modes such as LG_{12}, LG_{15}, LG_{18}, LG_{111} and LG_{114}. Table 1 shows the simulation parameters of proposed work. CSRZ modulated channels combined through multiplexer and fed to MMF of length 2.6 km.
Optical spectrum analyzer (OSA), spatial visualizer and BER are analyzers placed in the system to check signal. Signals are de-multiplexed using 1 x 4 demux and each wavelength then divided into five ports. Mode selector is placed t each port to pass only intended signal followed by receiver which incorporate photo detector, low pass filter, 3-R regenerator and BER analyzer.

Table 1 Parameters of proposed work

Parameters	Values
Data Rate	50 Gbps/wavelength
Capacity	250 Gbps
Users	25
Channel spacing	1.6 GHz
MMF Length	2.8 km
Modulation	CSRZ
LG modes	LG_{12}, LG_{15}, LG_{18}, LG_{111} and LG_{114}
Photo detector	PIN

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 9.5 pt. Here follows further instructions for authors.

3. Results and Discussion

Performance investigation of proposed work is carried out in simulation software optisystem. Proposed system is investigated at different distances, modulation formats in terms of Q factor, BER. Carrier spectrum of VCESEL laser source for different wavelengths is depicted in Figure 2 which represents the carrier power and carrier wavelength.

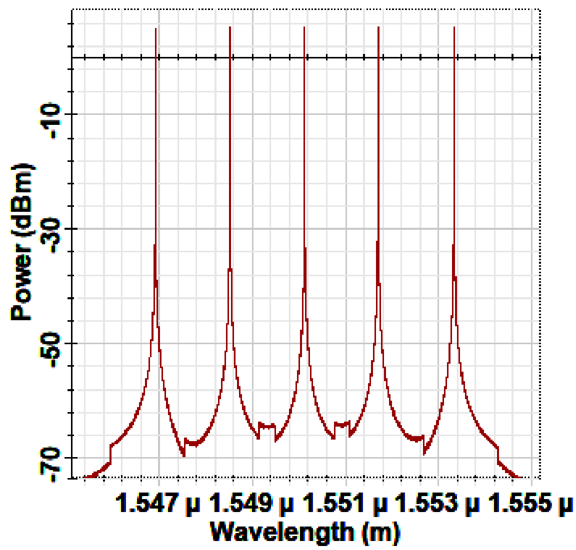
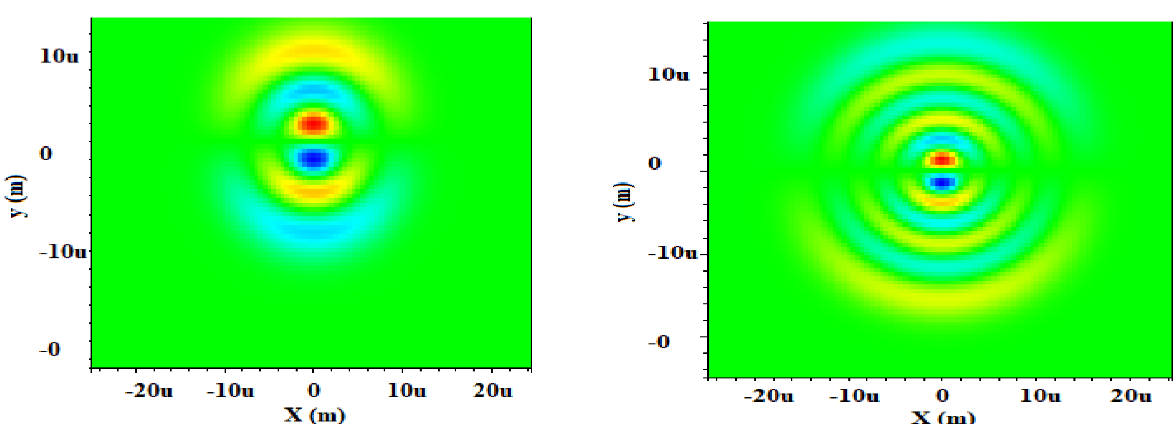


Figure 2 OSA showing carriers of VCSEL laser for 5 wavelengths

LG modes are used in the WDM-PON system to increase the capacity of the existing optical networks and in this work LG12, LG15, LG18, LG111 and LG114 modes are employed for 5 wavelengths. Spatial analyzer represents the LG mode profiles as depicted in Figure 3. As the radial number increase, circular rings around the azimuthal peaks increases. All the LG modes travel through MMF and for the analysis, distance of MMF is varied as shown in Figure 4. Comparison of non return to zero (NRZ) modulation format has been done with CSRZ in terms of Q factor and BER. Distance is varied from 200 m to 2800 m and it is observed that with the increase in MMF length, Q factor of the both modulations decreases due to attenuation, dispersion, mode coupling and scattering. Performance of CSRZ is far better than NRZ because of compressed spectrum, and high dispersion tolerance. CSRZ work for 2800 m within acceptable BER range 10-10, while NRZ work for only 1000 m.



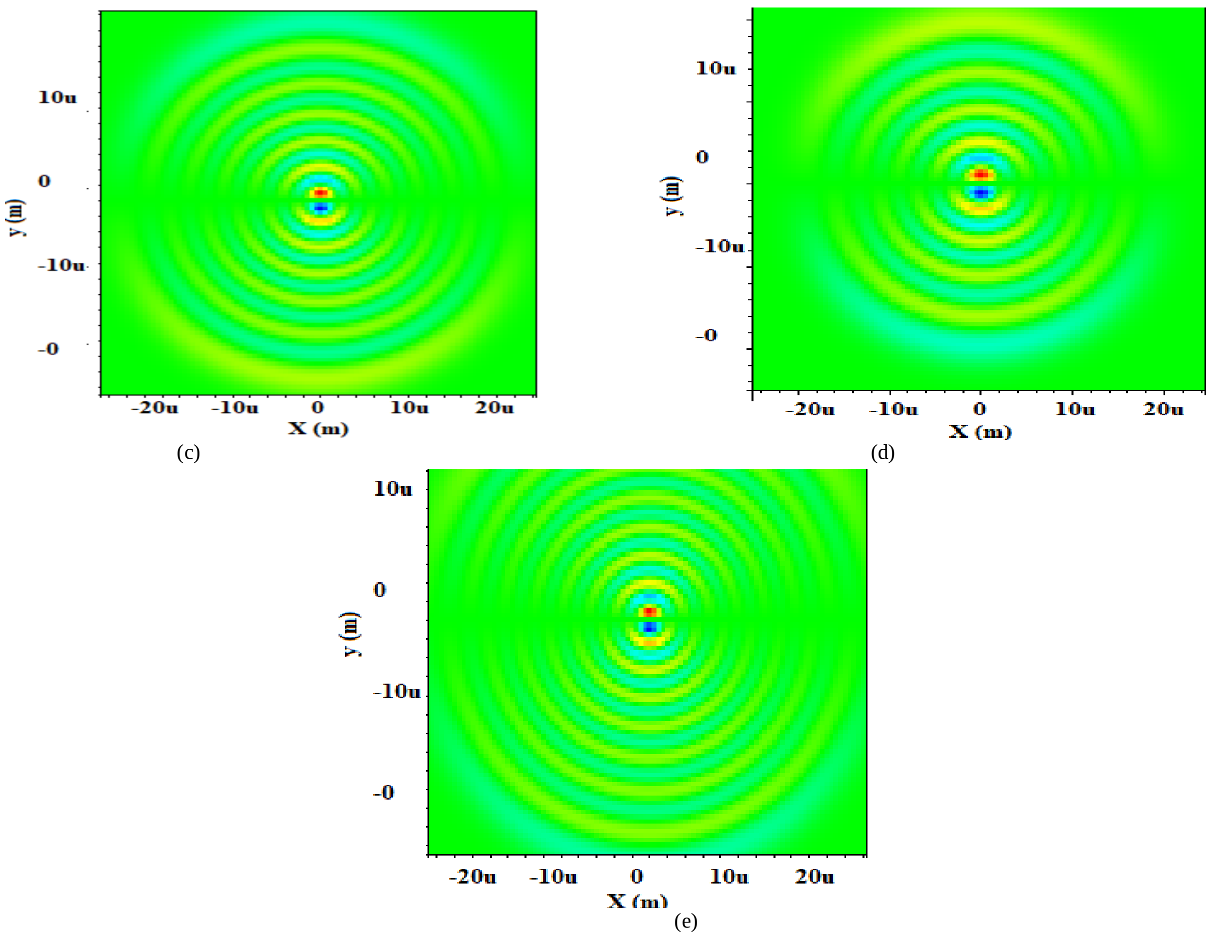


Figure 3 Mode profiles of LG_{12}, LG_{15}, LG_{18}, LG_{111} and LG_{114}

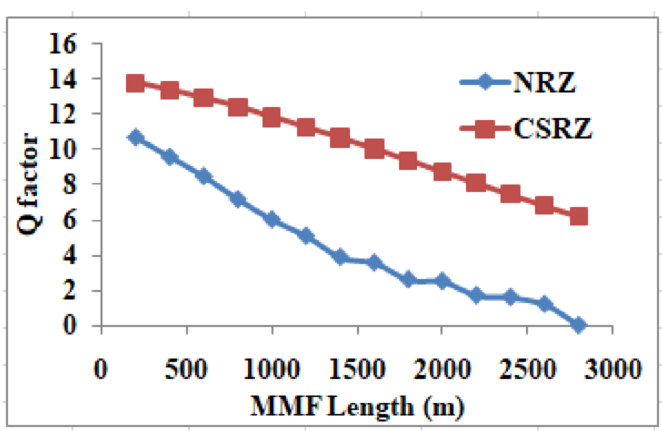


Figure 4 Performance comparisons of NRZ and CSRZ in proposed MDM PON system

Figure 5 represents the performance of NRZ and CSRZ in proposed system at different distance of MMF in terms of BER. BER is basically increase of Q factor i.e. more the BER, lesser is the Q factor. Therefore, CSRZ shows lesser BER as compared to NRZ modulation format. This is because of advantages of CSRZ over NRZ modulation format.

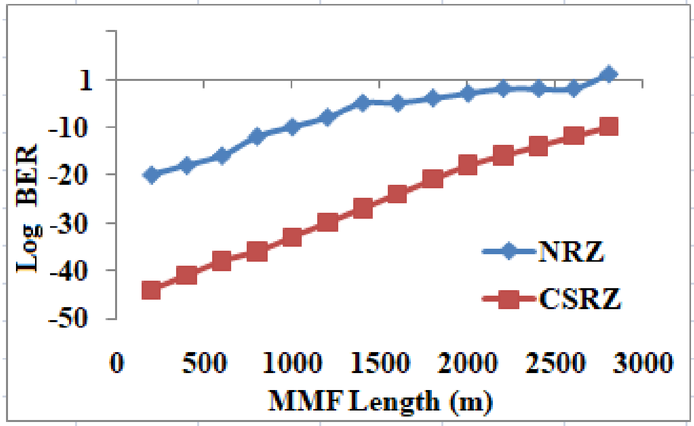


Figure 5 Effect of MMF lengths in terms of log BER in case of NRZ, CSRZ

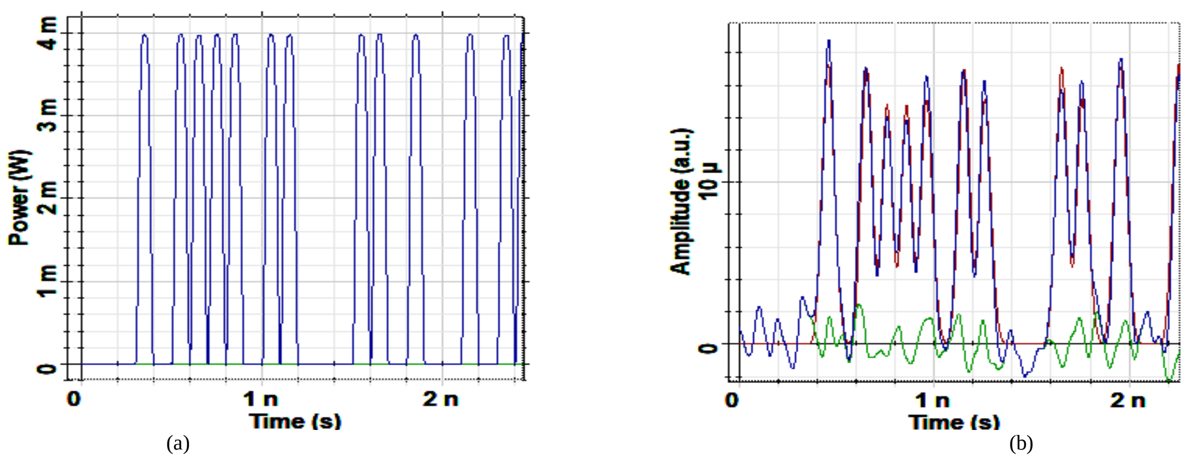


Figure 6 Optical time domain analyzer output for LG12 CSRZ (a) at transmitter (b) after 2800 m

Optical time domain analyzer shows bits with respect bit time for CSRZ before and after 2800 MMF. It is perceived that noises level increase after 2800 m. Eye diagram is decision component in the communication systems and shows Q factor, BER, eye height, power penalties, jitter and receiver power etc. Eye diagram of proposed system at 200 m and 2800 m is shown in Figure 7 (a) and 7 (b) respectively.

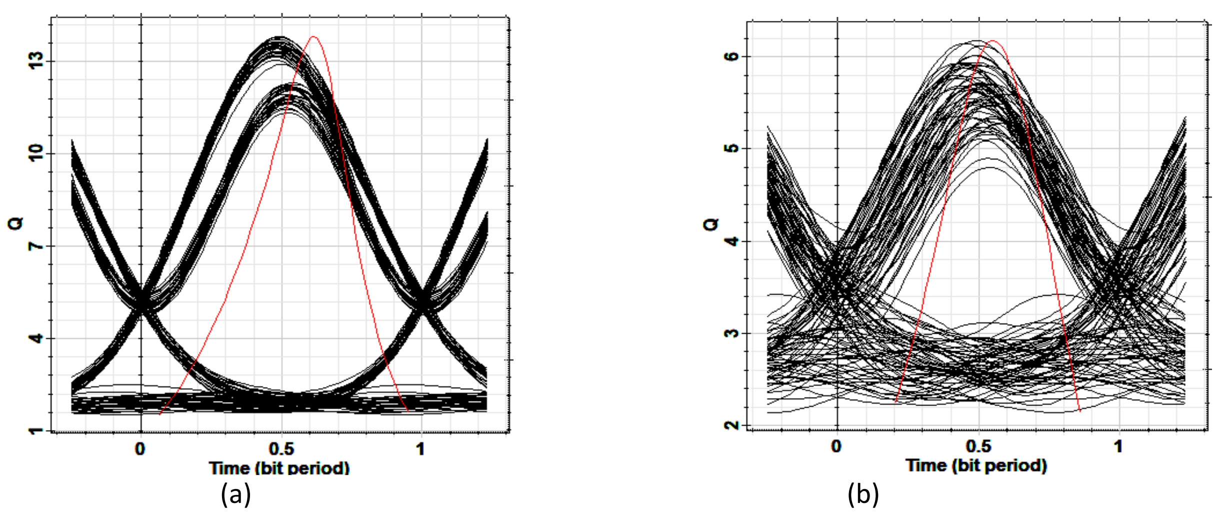


Figure 7 Eye diagram of CSRZ at (a) 200 m (b) 2800 m

It is perceived that eye is more open in case of 200 m because of lesser attenuation, dispersion, scattering and mode coupling. Minimum eye opening is observed in case of 2800 m distance.

4. Conclusion

The unpredictable augmentation of the needs of rapid communication and massive bandwidth hunger direct researchers to employ fiber optic in the access networks in place of copper cables. In order to use massive bandwidth of fiber optic cables, a promising and pioneering access technique is passive optical networks which benefit user with large bandwidth. In this research article, MDM-PON system is presented at 50 Gbps over 2.8 km MMF and served 25 users. Performance comparison of CSRZ and NRZ is performed and it is perceived that performance of CSRZ is far better than NRZ because of compressed spectrum, and high dispersion tolerance in CSRZ. CSRZ works for 2800 m within acceptable BER range 10-10, while NRZ work for only 1000 m. Proposed system is suitable for existing WDM PON system to enhance capacity due to future demands of bandwidth demand rise.

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