JOURNAL PUNJAB ACADEMY OF SCIENCES (Peer Reviewed Open Access Journal)
JPAS, 23: 08-15 (January-December, 2023)
Available online at www.jpas.in
ISSN 2229-7014 (P)

HIGH SPEED 100 GBPS VISIBLE LIGHT COMMUNICATION LINK EMPLOYING SINGLE CHANNEL PDM-QPSK AND DSP

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ABSTRACT

With the tremendous increase in the high capacity demands in sixth generation (6G) wireless networks, Visible light communication (VLC) is turned up as efficient and appealing candidate. In this work, a single channel 100 Gbps VLC system is presented by incorporating polarization enabled multilevel modulation and digital signal processing (DSP). Effects of different VLC link lengths, and transmitter half angles are explored in terms of Q factor, log symbol error rate (SER), log bit error rate (BER) and error vector magnitude percentage (EVM%). Results revealed that proposed system can cover 14 m link distance using lower transmitter half angle and DSP for multifarious functions such as nonlinear and linear compensations, normalization, and phase error compensation.

Keywords: PDM, QPSK, VLC, OWC, LD

INTRODUCTION

Researchers have been obliged to move ahead of limited bandwidth radio frequencies (RF), toward wireless optical systems (WOC), which provide practically wider range of usable frequencies such as greater than 400 THz (P.Yang,2019). Due to the prominent use of light-emitting diodes (LEDs) in the variety of commercial applications, such as lighting systems, multimedia display, houses, cars, offices and smart phones, the VLC system offers predominant advantages among the numerous OWC systems currently in use. Greater data rates, the absence of electromagnetic interference (EMI), energy-efficient operation, and increased security are the few of the features of the VLC systems (G.K Hussain,2022) (S.H Park,2022). Despite these advantages, standard c-plane LEDs are not appropriate for data rates greater than gigabit because of their large internal polarisation fields (S.Ariyanti,2021)(R.Bian,2019). A speed of 3 Gbps can be achieved with recently projected micro LEDs, however, their dimming light functions are not suitable for using it as a illumination source (Y.Zhou,2020) (M.S.Islim,2017). In contrast, enhanced output power and wide bandwidth in laser diodes (LDs) are better suited to provide the optimal solution in a quick and extensive VLC system. (C.Fei,2018).

A. Timeline Development of VLC Systems

In literature, a 10 Mbps VLC link was demonstrated employing 650 nm laser diode (LD) over 300 m distance in (H.Guo-yong,2007). Advanced modulation formats, like OFDM or QAM, have been shown to improve high data rates when employed with VLC systems, but they also increase system cost and complexity. Economical operation and less complex architecture are the two major traits of On-off keying (OOK). Therefore, a 266 Kbps data throughput and 2 m link length was achieved by researchers in 2016 utilising OOK (Zhijian,2017). Further, data rate was improved to 600 Mbps by incorporating gallium nitride LD in VLC using OOK linecoding over 60 m in 2017. The use of VLC with indoor white lightning is enabled by a new type of red, green, and blue (RGB) LDs. In (A.Neuman,2011),

researchers claimed that LDs combined elements of red, green, blue, and yellow light to produce an unusually dazzling white light. Researchers have used a variety of multiplexing techniques, including polarisation division multiplexing, MIMO, and wavelength division multiplexing (WDM), to increase data throughput (PDM).

Tsonev et al. presented a 100 Gbps system in 2015(Dobroslav,2015) using a WDM-VLC system based on RGB LD and 36 parallel data streams. A 3.35 Gbps data transmission was conducted in (Nan Chi,2016) over 1 m using Manchester coding in multichannel RGB LD system. Another study from 2017 (M.Zhang,2017) suggested a WDM-based VLC system with a data throughput of 4.05 Gbps over a 1 m span. Messa et al. has practically established WDM-VLC signal detection with a single photodiode and MIMO signal processing in 2020 (Alessandro,2020). According to these investigations, using RGB-LD-based WDM-VLC can greatly improve system performance. Another multiplexing technology, such as the PDM technique, is suggested to further increase the proposed system's capacity. Kwoon et al. experimentally exhibited data rate increase up to 2.04 Gbps in (Do-Hoon,2015) by utilising the PDM technique in the VLC. A 1.4 Gbps data rate VLC system based on OFDM-PDM was demonstrated by Hsu et al. in (Chin-wei,2018). Using dual polarised green and blue LED-based light streams, authors recently demonstrated in (C.Chen,2020) the transfer of 1.2 Gbps and 1.12 Gbps over a 3 m and 4 m wireless link respectively. Recently in 2023, a 8m VLC link was covered by using constant envelop OFDM and reported 43% reduction in EVM (H.Camporez,2023). On the other hand, several researchers (A.Affan,2020) (A.Kharbouche,2019) use hybrid multiplexing strategies to boost the bandwidth and capacity of optical communication networks.

In this study, a 12-meter-long single-channel 540 THz PDM-QPSK system is used to show an indoor VLC system. VLC parameters, including THA (degree), and VLC lengths are investigated.

The remaining four sections of the paper, such as Section II, cover the suggested system setup. Q factor, log SER, EVM%, and BER analysis of the proposed system presented in Section III Final thoughts and the future range of the proposed works are covered in Section IV.

SYSTEM SETUP

Optisystem is taken into consideration for the proposed work's implementation, and Fig. 1 (a) system diagram shows the single channel VLC system.

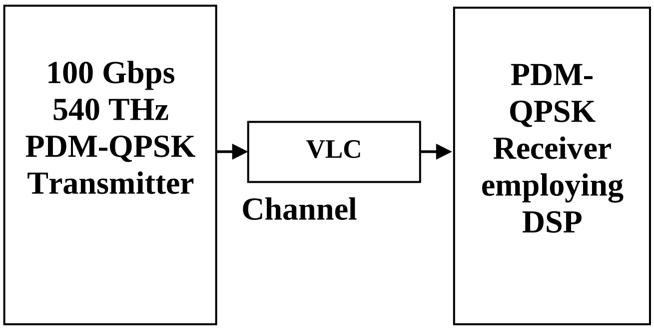


Fig. 1 (a): Single channel VLC system employing PDM-QPSK-DSP.

Each channel is taken into consideration and modulated at a 100 Gbps data rate using PDM-QPSK. Fig. 1 (b) shows the internal architecture of PDM-QPSK, which comprises of a serial to parallel converter, a QPSK modulator X, and a pseudo random bit sequence generator (PRBG) that produces a 100 Gbps serial bit stream. Two portions of the laser signal are separated and sent to the QPSK X and Y modulators. By utilising a polarisation combiner, both polarizations, X and Y, are mixed. As illustrated in the internal architecture of the receiver (Fig. 1(c), balanced detection using photodetectors (PIN), polarisation synchronisation, and phase synchronisation via LO are done in the receiver. Electrical signals are turned into noise like shot and quantum, and noise is rectified by running the signal via low pass filters (Bessel Filter).

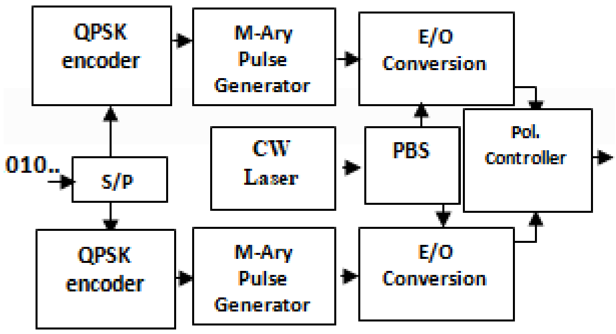


Fig. 1 (b): Block diagram of PDM-QPSK transmitter.

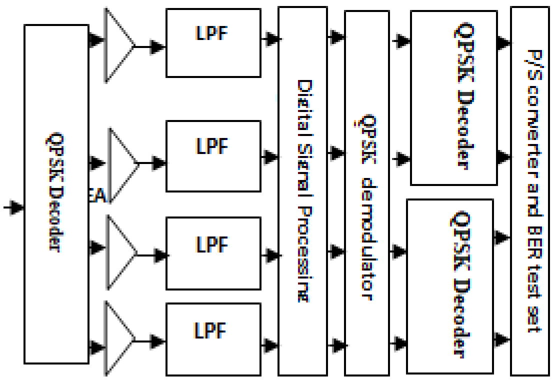


Fig. 1 (c): PDM-QPSK Receiver.

Table I Values and parameters of proposed 100 Gbps single channel VLC system

Parameter	Values
Data rate over VLC	100 Gbps
Input power	30 dBm
Frequency	540 THz
Modulation	PDM-QPSK
VLC Length	2-14 m
Amplifier	EDFA
Polarization states	2

DSP then performs additional frequency offset estimation, carrier phase estimation, nonlinear compensation, pulse width broadening, equalisation, and normalising before threshold detection, QPSK decoders, and BER test set. To correct for phase and frequency mismatch between the transmitter and LO, a modified Viterbi-and-Viterbi phase estimation technique is utilised (operating jointly on both polarizations). TABLE I displays the simulation settings for the proposed work.

RESULTS AND DISCUSSIONS

Fig. 2 illustrates the optical carrier spectrum of PDM-QPSK modulation at 540 THz frequency. Insertion losses are higher in PDM-QPSK due to multiple intensity modulators with 3 dB attenuation and therefore output power after PDM-QPSK transmitter is -14 dB.

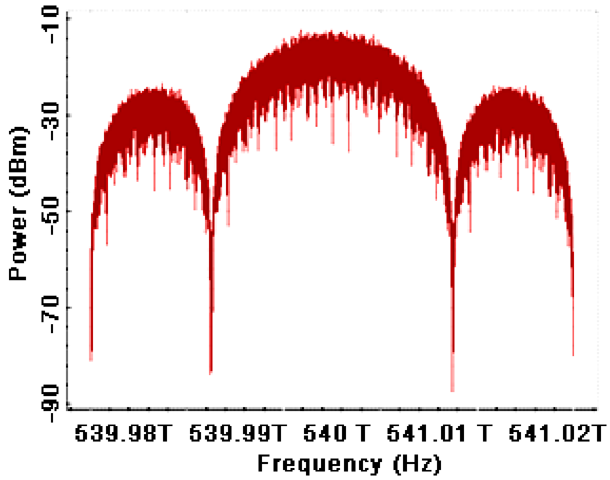


Fig. 2: Output carrier spectrum of PDM-QPSK.

Fig. 3 represents the performance of proposed VLC system at different link lengths employing PDM-QPSK and DSP. Distance is increased from 2 m to 14 m and line of sight based VLC channel is used in the presence of background noises. Performance is accessed in terms of VLC and as distance increased, output EVM% also increased.

In QPSK modulation, there are 4 different symbols and each symbol contains 2 bits. For the better performance, these symbols should be placed at their respective positions but any misalignment cause increase in the EVM%. Therefore, EVM% should be as small as possible for better performance.

The proposed VLC system offered better performance i.e. lower EVM% at small distances but increase with the increase in distance. At 2 m VLC link distance, EVM% of 2 has been reported and at 16 m, EVM% was increased to 22.

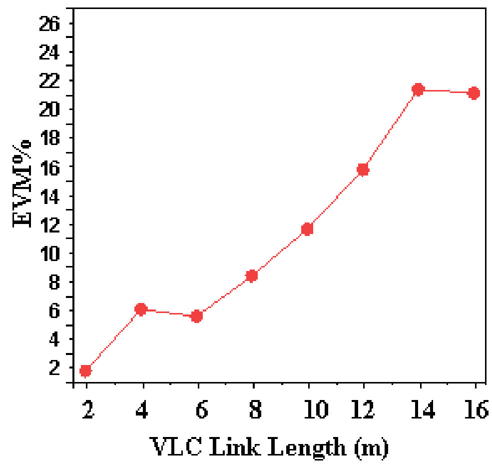


Fig. 3: Performance of proposed VLC system at different VLC distances in terms of EVM%.

Fig. 4 represents the log SER versus VLC link length performance of proposed system and it is observed that log SER increases with VLC distances and maximum log SER is reported at 16 m. Multiple performance factors depend on the log SER performance such as log BER, EVM, and Q factor. Results revealed that log SER of -150 and -27 are observed on 2 m and 16 m VLC distance respectively.

Received average power in the VLC depends on VLC link length and internal parameters of the channel such as transmitter half angle and receiver half angle. Received power is prime factor required for evaluation of the performance of the system and it derives Q factor and log BER of the VLC systems. Fig. 5 represents the effects of transmitter half angle on Q factor of the system at angles 400 to 800. It is evident that wider transmitter half angles increase the field of view and therefore, receiver accumulate lesser received power. Therefore, higher are the transmitter half angles, lower is the received power and lower is the Q factor.

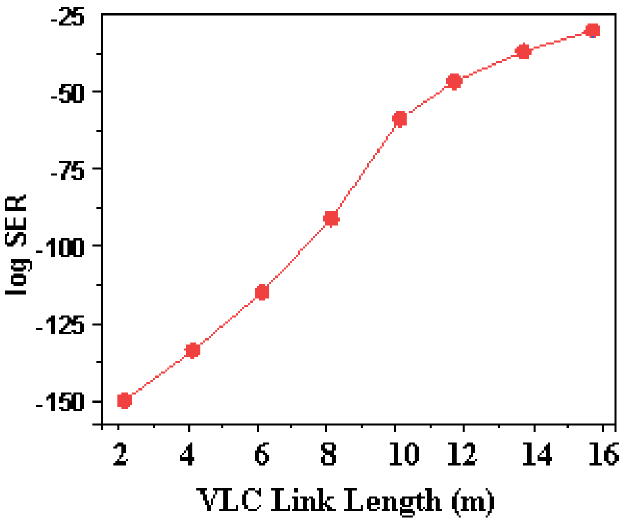


Fig. 4: Variation of log SER with respect to the VLC link length.

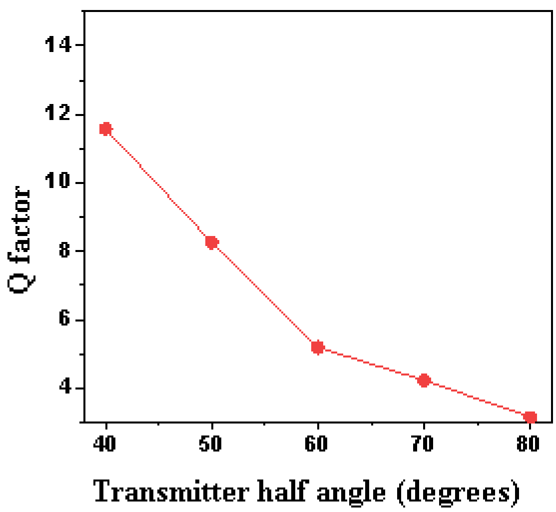


Fig. 5: Q factor versus different transmitter half angle values.

Fig. 6 depicts the log BER of proposed VLC system for the maximum distance covered and it is perceived that log BER of -4.25 is observed at 14 m link distance. If we further increase the distance, log BER not covered under the acceptable limit i.e. -3. Therefore, total link length covered is 14 m with proposed system setup.

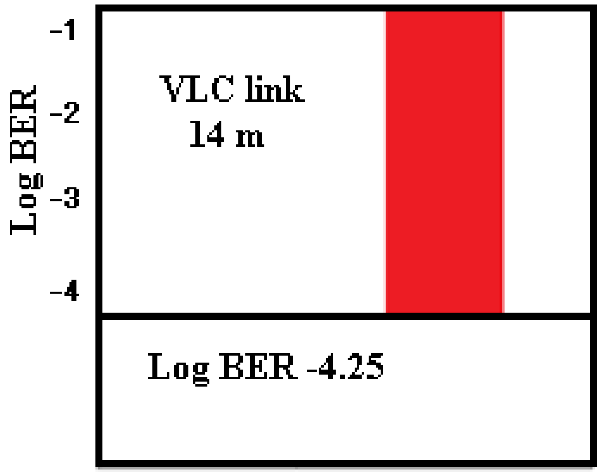
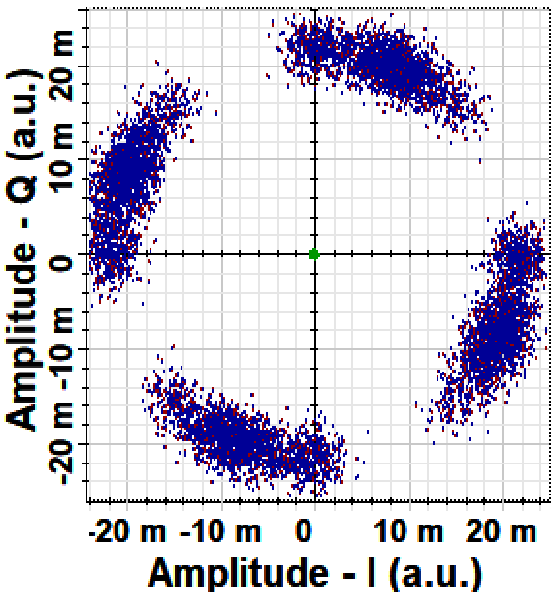
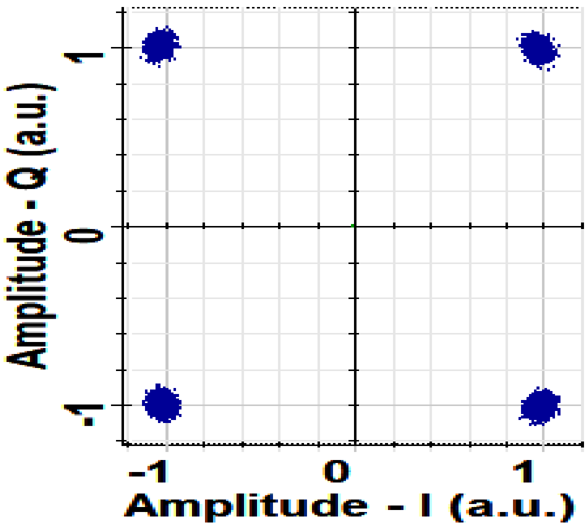


Fig. 6: Log BER at 14 m VLC link.



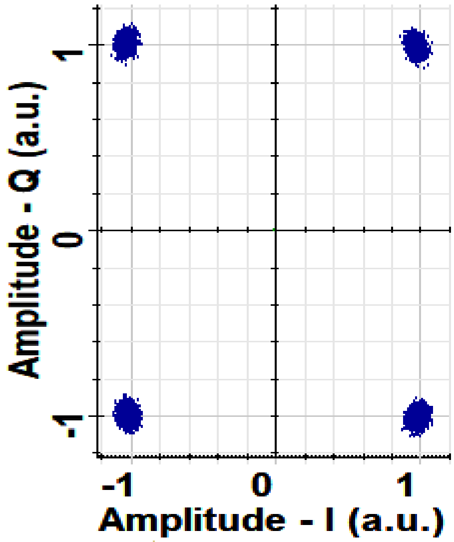
(a)



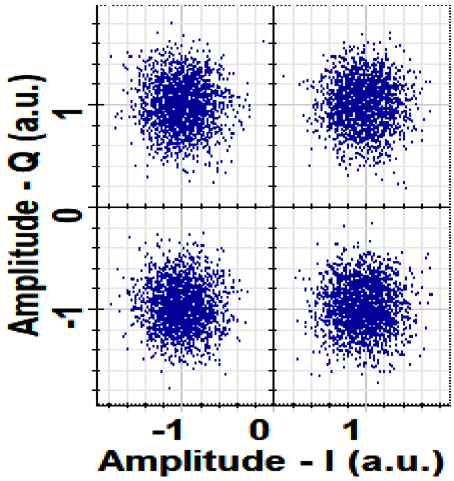
(b)

Fig. 7: Constellation diagrams of VLC system for PDM-QPSK receiver (a) without DSP and (b) with DSP.

Further, effects of the DSP in the receiver are explored in terms of placements of symbols in the received constellation. More is the distortion in the symbols, more is the EVM. Fig. 7 (a) represents the constellation for the VLC system without incorporating DSP in the receiver. Further, in Fig. 7 (b), constellation is analyzed for the VLC system with the incorporation of DSP. Results revealed that symbols are efficiently placed in case of the system with DSP due to compensation of nonlinear effects, phase error compensation, noise suppression, pulse width reduction and normalization. On contrary, system without DSP experience interference of symbols to adjacent quadrant and distorted symbols are obtained.



(a)



(b)

Fig. 8: Constellation diagrams for 100 Gbps VLC system at (a) 2 m and (b) 14 m link distance.

Fig. 8 (a) and (b) show the constellations of the proposed PDM-QPSK system at 2 m and 14 m, respectively. Due to thermal noises, background noises, and quantum noises, amplitude degradations, etc, displaced symbols are more noticeable at a distance of 14 m than at a distance of 2 m. At 2 m VLC link distance, EVM% of 2 has been reported and at 14 m, EVM% was increased to 22. Therefore, more symbols errors are observed in case of 14 m VLC link distance.

The presented system is compared with the existing VLC systems in terms of data rate, distance achieved, technique used and capacity as represented in TABLE II.

TABLE II Comparative analysis of existing VLC systems and proposed system

Parameter	L. Li [24]	S. Zhu [25]	Proposed work
Data rate	10 Gbps	5.71 Gbps	100 Gbps
Capacity	60 Gbps	15.78 Gbps	100 Gbps
Technique used	PDM and duobinary encoding	micro LEDs and WDM	PDM-QPSK, DSP
Distance covered	8 m	13 m	14 m

CONCLUSION

In this work, a single channel 100 Gbps VLC system employing PDM-QPSK and DSP in the receiver is demonstrated over 14 m link distance. Results revealed that EVM% of the proposed system increases with the distance such that at 2 m, EVM% of 2 has been reported and at 16 m, EVM% was increased to 22. Background losses, environmental factors, ambient sources etc are the prime factors for performance deterioration in VLC systems with the increase in distance. Similarly, log SER of -150 and -27 are observed on 2 m and 16 m VLC distance respectively. Further, it is concluded after detailed investigation of VLC system at different transmitter half angles that 400 angle offered best Q factor as compared to all other higher angles. Proposed system with the incorporation of DSP in the receiver successfully covered 14 m at log BER -4.25 due to compensation of nonlinear effects, phase error compensation, noise suppression, pulse width reduction and normalization. On contrary, system without DSP experience interference of symbols to adjacent quadrant and distorted symbols are obtained. In near future, QPSK can be replaced with higher QAM modulations for performance improvement.

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