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Experimental Evaluation of Intelligent Transport System with VLC Vehicle-to-Vehicle Communication

Faisal Ahmed Dahri[1] · **Hyder Bux Mangrio**[1] · **Attiya Baqai**[1] · **Fahim Aziz Umrani**[1]

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Abstract Visible light communication (VLC) is suitable and natural candidate for vehicular communication. This paper presents the vehicle to vehicle communication system based on VLC technology utilizing light emitting diodes (LEDs) as a transmitter and photodiode as a receiver. The LEDs are present everywhere in outdoor and vehicles utilizing those for communication. Vehicular ad hoc networks are facilitated by empowering enormous applications to require both proficient and reliable data delivery. Low-latency, simple and cost-effective system is designed with less complexity and high consistency by employing off-the-shelf LEDs and photodiodes which mitigates the implementation of complex protocols of typical wireless communication systems. The signal is transmitted from one vehicle that will be received by another vehicle to make sensible steps and to maintain strategic distance to avoid accidents. In this paper, the performance analysis of VLC based vehicle to vehicle communication (V2V) is presented. The results show that 3.5 Mbps and 500 kbps of data rates have been achieved over the distance of 0.5 and 15 m respectively. Amplitude shift keying, frequency shift keying (FSK) and phase shift keying schemes are tested with non-return-zero coding scheme. Bit error rate, received optical power and received signal voltages are measured and analyzed in this paper for V2V communication. The FSK modulation is an efficient technique for long distance as it has lower losses compared to other techniques. Warning messages are displayed on liquid crystal display. The prototype is evaluated experimentally over the

✉ Faisal Ahmed Dahri
faisalahmeddahris@gmail.com

Hyder Bux Mangrio
hyder.bux@faculty.muet.edu.pk

Attiya Baqai
attiya.baqai@faculty.muet.edu.pk

Fahim Aziz Umrani
faheemaziz.umrani@faculty.muet.edu.pk

[1] Institute of Information and Communication Technologies, Mehran University of Engineering and Technology, Jamshoro 76062, Pakistan

distance of 15 m using an array of LEDs to reduce the chances of accidents. Bit error rate of 10^{-11} for FSK modulation has been achieved with the signal to noise ratio value of 13 dB in this work. The results confirmed the performance of the proposed system and presented that VLC is a feasible technology for vehicular communication.

Keywords V2V · LED · LCD · Photodiode · VLC

1 Introduction

The World Health Organization (WHO) released a global status report on road security, according to the report road accidents are speeding up death causes in youngsters aged 15–29 and the eighth accelerating worldwide death reason [1]. There is a need for a taking a vital step to prevent and reduce the road crashes, in addition, to make roads safer. Present trends, propose that road injuries will become the fifth growing reason for the loss of life through 2030 [2, 3].The major problem is traffic congestion with increasing number of vehicles on roads. In current developments visible light communication has received increasingly more interest due to its exclusive benefits which include unlicensed spectrum, high-security level and risk-free for human health [4]. Visible light communication works by deploying light emitting diode (LED) having dual intentions of data transmission and illumination [5]. In recent times, researchers proposed detection of the road surface, protect against backside accidents; VLC based positioning technology and infrastructure for vehicle communication [6–8]. By enabling an emerging VLC technology, the received signals from their near vehicles it improves the safety and reduces the accidents. Present day vehicles have just empowered most required part of VLC communication. Specifically, LED-based VLC transmitters can be controlled electronically [10]. Attentively, LASER light is likewise being envisioned in vehicle lights in the near future. VLC receiver contains photodiodes (PD) [11, 12] or CMOS cameras [13] are accessible in present-day vehicles. The inter-vehicle communication has transformed into a dynamic research theme for vehicular security. A vehicle driving in clear climate conditions with sufficient perceivability does not commonly make any risk, but rather in view of poor atmosphere, it gets the chance to be risky. To manage such circumstances, assurance and precautionary measures should be settled in vehicles for short-range communication utilizing VLC technology [9]. RF systems, in any case, include an unpredictable structure with scarce requirements. In this manner, this technique isn't yet famous and utilized for vehicular communication in the market. The utilization of visible light, infrared or ultrasonic systems have been broadly adopted as a result of their simplicity and effectiveness. In this paper, we have carried out a performance analysis of VLC based V2V Communication system. The deployed system warns the driver based on the received signal intensity and the voltage thresholds through 2 * 16 LCD display. We have incorporated different modulation schemes to mitigate ambient noises, employing modulation schemes such as; ASK, FSK and PSK for increasing data rates and distance ranges. The link configuration parameters have been elaborated and developed the bit error rate (BER), received optical power under different communication ranges and eye diagrams of modulation schemes to estimate the data reception and corruption. The rest of the paper is organized as follows: Sect. 2 explores the previous work that has been done on vehicular communication. Section 3 deals with the V2V system configuration and experimental implementation. Section 4 addresses and discusses the performance analysis in terms of BER, received optical power, eye diagrams and finally, Sect. 5 concludes the paper.

2 Related Work

In recent times, researchers are looking to make high speed, high security, and health friendly communication networks via high-speed pulse light rather than radio and microwaves. There is a growing interest in the field of intelligent transport system (ITS) in order to avoid and reduce the road accidents, environmental anxiety and traffic flow [14]. Inter-vehicular communication is the basic strategy to ensure the security from road disaster. Paper [15] presented the current status of the vehicle by transmitting event-based messages; the data rate achieved was 0.6 kbps over a distance of 20 cm. It could not achieve appropriate distance for vehicular communication. The researchers in [16] have demonstrated numerical and simulated system results for vehicular communication and used sonar pulse for analyzing the speed of the vehicle. The authors failed to present experimental results to reduce the losses. Khairi et al. [17] implemented the visible range of spectrum in the vehicle for high data rate transmission also used the Line of Sight, (LoS) property of light to reduce the packet loss. The presented work provides only simulation based results and compares features of radio frequency and visible light communication. Loureno et al. [18] suggested that employing camera as an alternative to photodiode achieved long range because of a large number of pixels. The number plate and tail lights are used for differentiating distance ranges during the day and night respectively. Direct sequence spread spectrum (DSSS) modulation scheme is deployed in outdoor ITS VLC system and it mitigates the ambient noises and interferences. It could not achieve the higher data rates in presence of ambient light and moreover presented simulation based results only. IEEE published radio frequency standard 802.11p in 2010 which supports ITS application and operated range 5.835–5.925 GHz [19]. Sasaki et al. [20] have reported that the data rate was achieved 10 kbps over distance of 20 m using VLC in vehicles. You et al. [21] have provided details on the analytical study of VLC channel model supported the measurement of light distribution of available scooter light for vehicular communication. The received data rates were low which are not suitable for current vehicle systems. Kim et al. [22] investigated the system performance under foggy environment. Fresnel lens is used to focus the light sufficiently at the receiver and perceive the most intensity over Non-Line-of-Sight (NLoS) with the help of three candidate photodiodes. It increases the complexity for vehicular communication and less attractive to deploy a substantial number of receivers in vehicles. The LED-based V2V technique is a potential possibility for future vehicular communication to meet the adversarial effects of fog. LEDs and photodiodes are used to evaluate the performance of vehicular communication based on the error rate and throughput. The current RF technology faces unwanted loss of packets, poor packet delivery rate and longer delays as more number of vehicles are there in rush hours on the roads. The performance analysis of modulation scheme in both optical and RF spectrum based on V2V communication links are largely ignored. Therefore, we have established an alternative to the radio vehicular ad-hoc network which uses VLC technology; experiments show a realistic and effective LED-based V2V system. In this paper, we have analyzed the performance of the system, experiments were conducted to explore, bit error rate (BER), optical received power, SNR, warning messages and modulation effects at minimal losses for the vehicle to vehicle communication system. Table 1 shows the comparative results in terms of data rates with the recent work done in V2V communication.

The literature review shows that the current VLC based V2V communication system achieve very low data rates typically up to 100 kbps as shown in Table 1. In this work, we have proposed and designed V2V communication link operating at a range of 15 m and

Table 1 Comparative summary of V2V VLC based communication

References	Year	Distance (m)	Data rate (kb/s)
[23]	2012	15	15
[24]	2013	23	15
[25]	2016	30	10
[26]	2017	30	110
This work		15	500

achieved a data rate of 500 kbps. The authors have explained that more than 100 kbps data rates are sufficient for critical data transmission in vehicular communication more data rates are required for multimedia applications [26]. This work provides details on warning messages; those are recoverable at the distance of up to 15 m in comparison to [27] where author displays the warning messages over a limited distance of less than 5 m. In comparison, this research work has provided better and effective results over the 15 m distance range.

3 Proposed System Design

The novel design has been proposed in this work, which uses the available lights in vehicles instead of including new circuits and makes the system complex. Figure 1 illustrates the block diagram of the transmitter and receiver. The signal is generated from function generator or laptop, fed into the Arduino then shifted to a driver circuit that will transmit it through LED. IRFBC30 metal-oxide semiconductor field-effect transistor (MOSFET) is used in a drive circuit for switching purpose to increase data rates to get optimum results for data transmission. Blue/White LEDs are used in vehicles, which are more efficient and cost-effective as a transmitting source is fitted in vehicle front bumper. The DC biasing voltage of 5 V is required to operate MOSFET and it has power dissipation levels appromaxitely 50 W with the rise time of 13 ns. Light signal propagated in free space reaches after a fraction of a second at the receiver. The photodiode is still the first choice for optical communication, in particular for VLC due to its attributes, such as speed, energy consumption, and sensitivity. The selection of photodiode is very important because it impacts the sensitivity, range reliability, response time, cost and other factors in communication. The photodiode detects the weak signal, this received signal is then amplified, the received signal is amplified by LM318 which is a low cost and quad

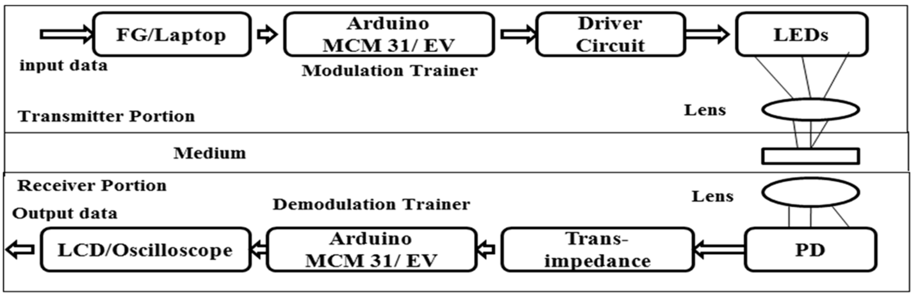


Fig. 1 Block diagram of transceiver

amplifier, this amplified signal is then fed to Arduino. The received signal is decoded into a digital sequence utilizing an analog to digital conversion that will warn the drivers. The bumpers are used for placing transceiver system. The Modulation/Demodulation trainer kit is used for testing purpose in this research which can be replaced by the modulator/demodulator circuits in actual systems.

Figure 2 represents the V2V VLC model, it was committed to concentrate upon the range and communication quality in the free space conditions for Line of Sight (LoS), where more number of iterations for data recording have been performed at the receiver side. We have recorded data for each iteration, where d is the distance between vehicles and h is the height of receiver from the ground to estimate the accurate position to achieve better results. The starting value of d is 1 m. Experiments are conducted by varying the distance and receiver height position to analyze the impact of these parameters on the reliability of V2V communication.

The simulation tools used in this work includes MatLab 2016, Multisim 14, Origin Pro 8 and Arduino. The MatLab and Origin Pro are used for plotting high-quality graphs. The circuits were analyzed by simulating them in Multisim 14 and LCD based messages were displayed by comparing them with particular threshold voltage level, Arduino programming is used to compare these thresholds and display warning message for drivers.

4 Experimental Results and Discussion

The V2V performance analysis of VLC based system is done by analyzing key parameters, namely received voltage, received optical power, data rates, BER, SNR and eye diagrams along with threshold values for displaying warning messages at predefined values. The modulation techniques which are utilized include ASK, FSK, and PSK. MCM31/EV kit is used to generate ASK, FSK, and PSK modulation schemes. Figure 3a presents signal received voltage as a function of distance with lens and without the lens. Received Voltage varies from 20 to 5 and 15 to 2.5 mV at distance of 0.5–5 m respectively. Figure 3b shows the received voltage against varying distance range for different modulation schemes. It is noted that FSK has better signal strength than other modulation schemes in terms of voltage and covers more distance in contrast with others. It is observed that as the distance is increased between vehicles, the voltage levels drop and the photodiode is unable to detect the signal, furthermore, the ambient light is also severely affecting the signal strength. To mitigate noise effects, we have used a lens and detected a good quality signal. The lens is used at the receiver side to perceive the maximum signal and increase the distance; the experiment is conducted in both manners with and without the lens.

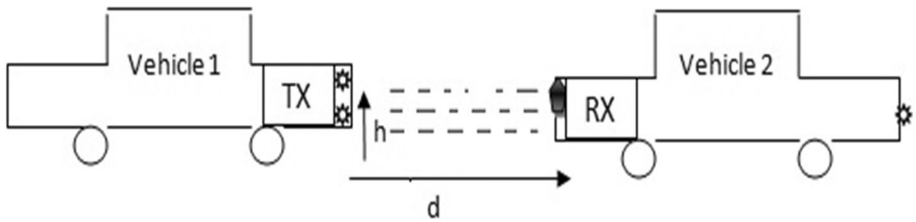


Fig. 2 VLC scenario for V2V setup

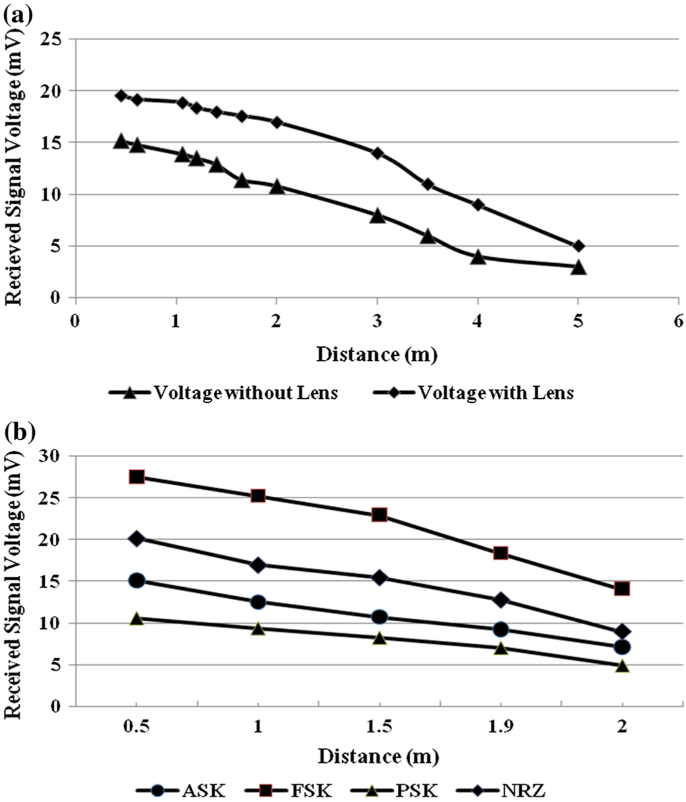


Fig. 3 **a** Received voltage variations at the receiver with and without lens at night, **b** performance analysis in terms of received signal strength in illumination of light using different modulation schemes

The bit error rate performance of the V2V VLC system against the different distances between two vehicles for a scale of h is shown in Fig. 4. It has been observed that BER is dependent on the value of h; it will increase the efficiency of

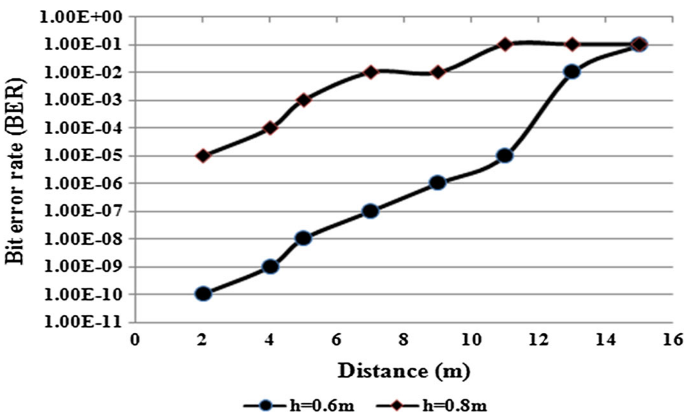


Fig. 4 BER performance analysis of V2V VLC based system for different distance ranges with two distinctive values of h (height of photodiode from the ground)

the system. BER of 10^{-2} is achieved with the height of receiver 0.6 and 0.8 m at distance of 15 m.

The bit error rate in FSK is optimum to extract the optical information, but the ASK and PSK have more losses so that from the signal, information cannot be extracted from the original data. BER for optical communication is 10^{-9} and BER comparison for the modulation schemes chosen is shown in Fig. 5. The BER curve defines that the FSK, ASK and PSK have SNR value of 13, 11 and 9 dB respectively. FSK has optimal SNR value for communicating properly, as the distance increases the BER will increase, therefore the data transmission and BER is limited.

SNR has been investigated as a function of distance, as the distance increases the SNR drops with different modulation schemes shown in Fig. 6a. The received optical power analysis at a different range of distances is shown in Fig. 6b. It exhibits that as the distance increases the received optical power is degraded. The data rates and distance range have been increased using an array of LEDs. Figure 7a articulates the data rates with distance variance between vehicles. The data rate is achieved 3.5 Mbps at distance of 0.5 m. Figure 7b demonstrates the eye diagrams of FSK, ASK and PSK, wide open eye describes the data transmission with minimal losses. It is observed that PSK eye diagram shows the higher losses in transmission and cannot be recovered in its original data. Whereas FSK has proved to be an efficient modulation scheme in our analysis.

The messages were displayed on the LCD such as Keep Driving, Be Careful and Brake based on the intensity of light. The condition of warning messages are set such as output analog to digital (ADC) voltage is in the range of **01–100**, **101–1111** and greater than **1111**,

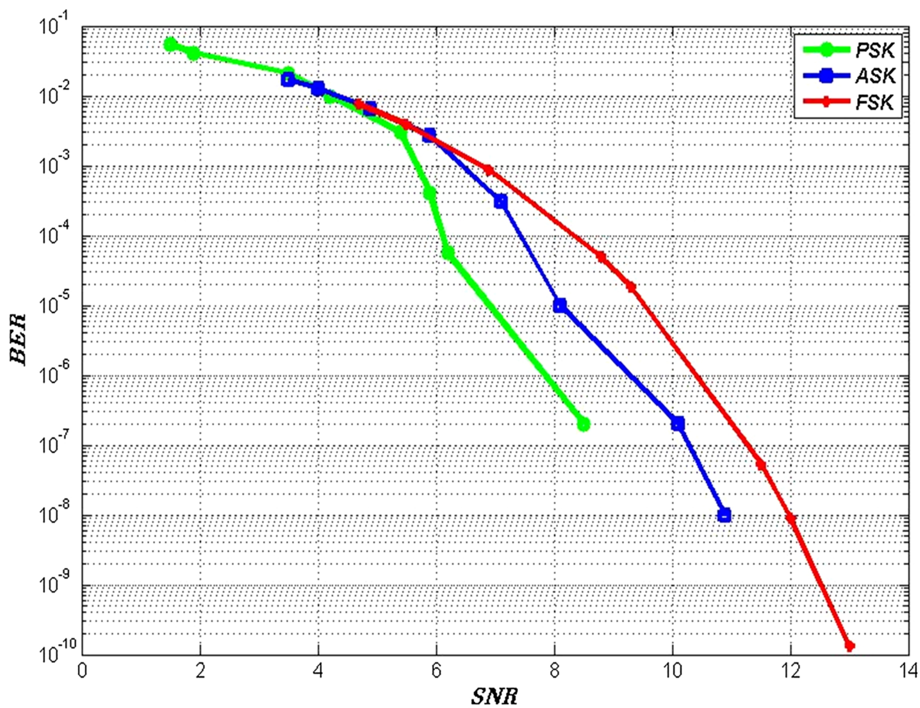


Fig. 5 Comparison of modulation schemes in presence of ambient light noise BER versus SNR

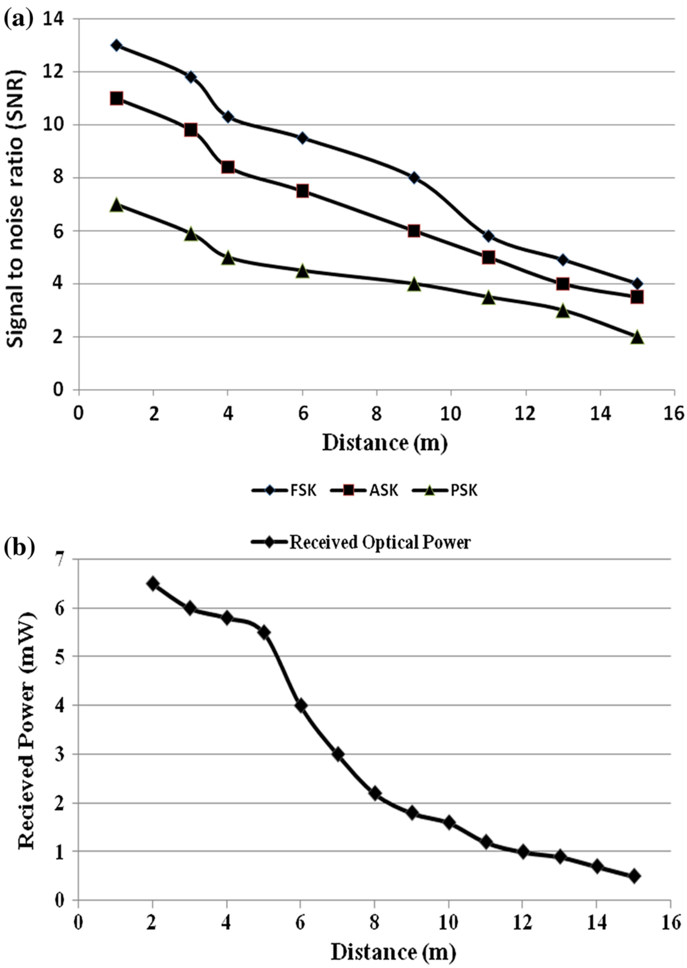


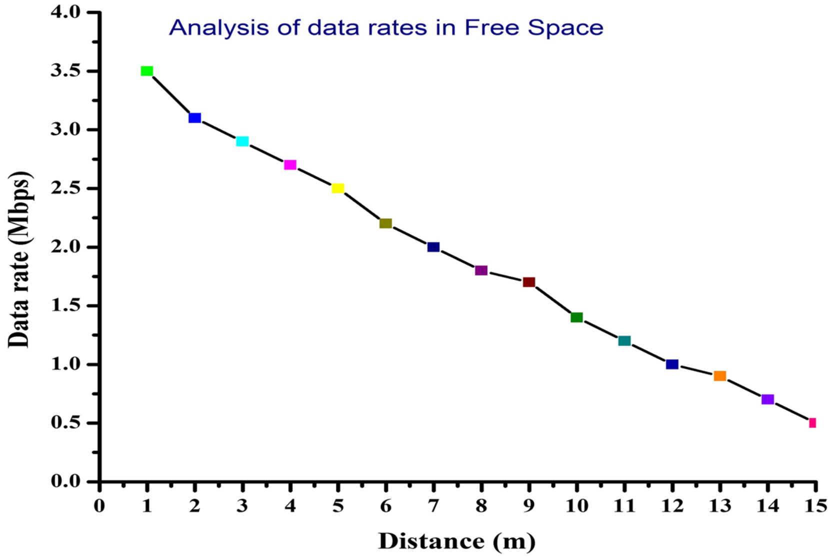
Fig. 6 **a** The signal to noise ratio (SNR) as a function of distance using different modulation schemes, **b** received optical power at a different range of distance values

The warning messages are shown on the LCD at particular predefined values received presented in Fig. 8.

5 Conclusion

This paper demonstrates the experimental implementation of VLC technology in the vehicle to vehicle communication for upcoming intelligent transport system (ITS). The prototype design is implemented in vehicles to avoid accidents; drivers alerted through warning messages, traffic information transmitted through transmitter depend on intensity of light and VLC based V2V system for communication by alert messages such as, keep driving, Be careful, and Brake to the following vehicle has been discussed which makes road safer and reduce the loss of lives on roads. Convenient awareness of warning

(a)



(b)

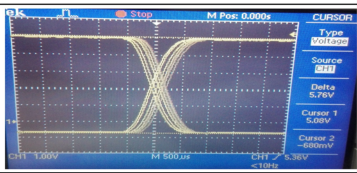
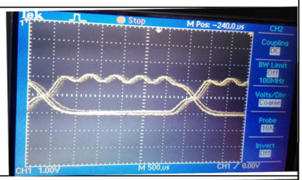
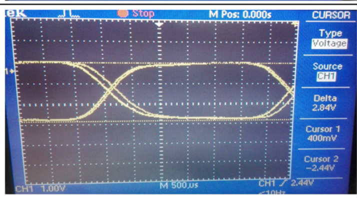
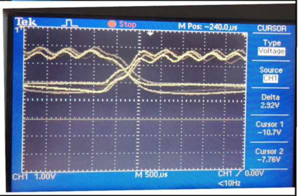
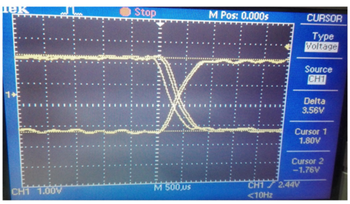
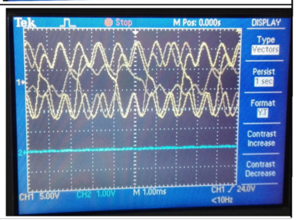
Free Space Optical Communication		
Name of Modulation	**Default**	**Blue LED**
Amplitude Shift Keying (ASK)		
Frequency Shift Keying (FSK)		
Phase Shift Keying (PSK)		

Fig. 7 **a** Analysis of data rates to increase distance along with the intensity of light using an array of LEDs, **b** comparisons of different modulation schemes eye diagrams in free space

Fig. 8 Warning messages display on LCD at threshold levels

messages to the leading vehicle is delivered. The system is applicable for data transmission and achieved 3.5 Mbps and 500 kbps at distance of 0.5 and 15 m respectively. Received voltage is 15 mV with the distance of almost 2 m using the lens. SNR would fluctuate because of changing light intensity. The acquired SNR preserves an SNR estimation of around 13 dB with BER of 10^{-11}. FSK modulation is an efficient technique in our analysis in terms of distance range and data transmission in vehicles for entertainment purpose and results confirms it's suitability for communication. In future, the link will be evaluated and analyzed in the foggy and rainy environment.

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Publisher's Note

Faisal Ahmed Dahri is a Master Student in Telecommunication Engineering and Management at Institute of Information and Communication Technologies (IICT) and he received his B.E. in Telecommunication Engineering from Faculty of Electrical, Electronics and Computer Engineering at Mehran UET, Pakistan. His research interests include Visible Light Communication, Free Space Optics, Wave propagation and Optical Wireless Communication.

Hyder Bux Mangrio is working as Lecturer in Department of Telecommunication at Institute of Information and Communication Technologies (IICT), Mehran UET, Pakistan. He received his B.E. in Telecommunication and PGD from Faculty of Electrical, Electronics and Computer Engineering at Mehran UET, Pakistan and his Master from Hamdard University, Karachi in 2017. His research interests include Optoelectronics and Optical Communication, Visible Light Communication, and underwater Optical Communication.

Dr. Attiya Baqai is an Assistant Professor in Department of Electronics Engineering Mehran University of Engineering and Technology Jamshoro, Sindh Pakistan. She received her B.E. degree in Electronic Engineering; Masters is inTelecommunication and Control Engineering and Ph.D. from Institute of Information and Communication Technologies Mehran UET Jamshoro. Her main research interests include Wireless Body Area Networks, Wireless Communications, Artificial Neural Networks, Fuzzy Logic Control and Embedded System Design.

Dr. Fahim Aziz Umrani is currently Associate Professor in the Department of Telecommunication at Institute of Information and Communication Technologies (IICT), Mehran UET, Pakistan. He received his B.E. in Electronics from Faculty of Electrical, Electronics and Computer Engineering at Mehran UET, Pakistan and his Ph.D. from Faculty of Advanced Technologies at the Glamorgan University in 2004 and 2009 respectively. His research interests include Optical CDMA, Spectral Amplitude Coding, Software Defined Radio, Multiple access techniques, and Body area networks.