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Audio Transmission Through Visible Light Communication System : Design Considerations and Performance Evaluations

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***Abstract*— As the radio spectrum is already crowded, there is a need for new medium for faster and more secure wireless communication. To address this problem, a new communication technology called Visible Light Communication (VLC) is introduced. VLC system to transmit an audio signal is presented in this paper. Performance of visible light communication system is tested and analyzed. Besides that, influence of additional amplifier at the receiver on the system is characterized. Results show that the performance of the system is increased by adding the amplifier circuit. Also, the distance between transmitter and receiver can influence the system performance. For longer distances, performance is poor and loss is more. As a conclusion, a visible light communication system for audio transmission is demonstrated and a maximum range of 50 cm is achieved for this system.**

Keywords—Radio Spectrum; Wireless Communcation; Visible Light Communication; Amplifier

I. INTRODUCTION

Communication has a vital role in the field of electronics and communication. It deals with transfer of data from one place to another. Transmission can be done by wired or wireless medium. Current trend of wireless communication demands higher throughput and ubiquitous coverage, which sets high demand for spectrum utilization of the radio frequency communication. This ever increasing demands will leads a growth in mobile data traffic at a compound annual growth rate (CAGR) of 61 percent from 2013 to 2018 [1]. Visible Light Communication (VLC) has been proposed as an alternative means of wireless transmission.

Visible light provides about 400 THz unlicensed, unregulated, safe and radio free media for wireless communications. The bandwidth of visible light is over 1000 times wider than all other radio frequencies and together which allows enormous capacity for communication purposes. Fig. 1 shows the location of visible light spectrum in electromagnetic spectrum. It can be seen that wavelengths between 380 nm to 780 nm is used for visible light communication system. With the development and utilization of Light Emitting Diode (LED) technology, interest of visible light communication has been increased. LED can provide high energy efficient and bandwidth efficient system for communication purposes.

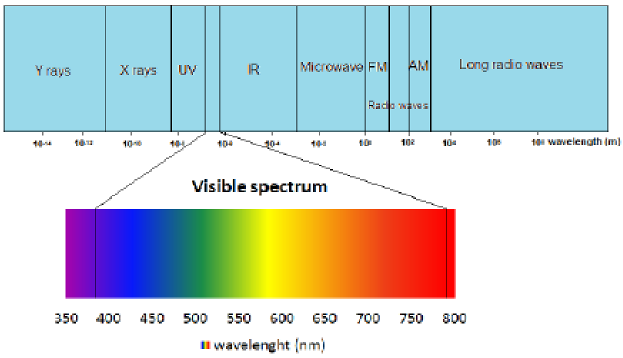

Fig. 1. Visible light as a part of electromagnetic spectrum

The basic idea of VLC system is to add information into the light source and at the receiver side, the light intensity changes detected using a photo detector. This is called intensity modulated communication and the modulation frequency used is much higher than that the human eye can detect and so, the flickering can be avoided. Since the light can not penetrate through the opaque objects, VLC is a directed communication medium. The combination of lighting and communication infrastructure will be cost efficient and consumes less energy.

Before the evolution of LED, sunlight or fire or other lamps were used for the transmission of information. For example, they were used in beacon fires and lighthouses. Development of LED has enhanced the bandwidth and intensity modulation in VLC system. First LED based VLC system was made in 2001 by RONJA project [2]. A long range optical bidirectional link was developed by this system and achieved a 1.4 km link at a data rate of 10Mbps using red light.

VLC has several advantages over traditional radio frequency and infrared communication. The main advantage of VLC is the 400 THz unlimited, unlicensed and safe band for communication. The whole RF band is 300GHz wide and which is strictly limited and regulated. Another advantage of VLC is low power consumption and low cost. VLC uses low cost illumination lamps for communication while RF communication requires its own base station and more energy. The main difference is, RF can propagate through obstacles. While the VLC and IR can provide high security data transmission over the required area. So, the coverage and mobility is limited in VLC and IR. RF suffers from electromagnetic interferences where as VLC and IR suffers only from ambient lighting. RF may have high potential health risk than VLC and IR. RF frequencies cause thermal effect to human. VLC has one health risk due to blue light sources and known as blue light hazard. This can be avoided by using normal light sources.

The framework of this paper is as follows: Part II describes
the literature review based on the visible light communication system. Then the transmitter and receiver part of VLC is introduced in part III. Part IV presents the performance analysis of VLC. Finally, summary of the full paper is made.

II. LITERATURE REVIEW

The first significant step for the evolution of visible light communication system is by Alexander Graham Bell in 1880 by the development of photo-phone to transmit voice data over a distance of 200 m using sunlight [3]. Vibrating mirrors are used to transfer the voice through beam of sunlight. After the inventory of fluorescent lamps, they were used to send data at low data rates. The development of LED enhances the use of visible light communication system and they are used for high data rate transmission [4]. In 1999, pang *et al.* introduced fast switching LEDs and use of modulation in visible light for communication purpose [5]. In the early 2000's in Japan, white LEDs were utilized for illumination and communication [5]. In 2001, Twibright labs open-source project Reasonable Optical Near Joint Access (RONJA) presented a long range bi-directional optical communication link to transfer the data over light at 10Mbps over a distance of 1.4km [2]. In 2003, in Japan, Visible Light Communication Consortium (VLCC) was established to promote and standardize the VLC technology [6]. VLCC have proposed three Japan Electronics and Information Technology Industries Association (JEITA) standards : CP-1221 visible light communication system, CP-1222 visible light ID system and CP-1223 visible light beacon system. The first two were proposed in 2007 and third one proposed in 2013. In 2011, IEEE published, IEEE 802.11.7 standard for visible light communication system. It defines the physical layer and MAC layer of VLC.

By integrating different communication technologies, European Union funded hOME Gigabit Access project (OMEGA) for developing global standard for home networking [7]. They aimed at delivering gigabit data rates for home users and achieved a data rate of 100Mbps with the unidirectional VLC link. In 2011, professor Harald Haas demonstrated a high quality real-time video transmission over VLC link at Technology Entertainment Global conference [8].

Kahn and Barry introduced a system for indoor wireless optical applications [9]. In this system, Intensity Modulation with Direct Detection (IM/DD) is employed and a directed Line of sight link has been considered. In a IM/DD system, the data is modulated on optical intensity of transmitted light using an optical modulator. By using rate-adaptive discrete multitone (DMT) modulation and phosphorescent white LED, a 1 Gbps transmission was demonstrated in IEEE photonics journal in 2012 [10]. In 2014, a 3 Gbps transmission over a single color gallium nitride micro LED was demonstrated in Ultra Parallel Visible Light Communication (UP-VLC) project [11]. The distance between the transmitter and receiver is only few centimeters but the result shows the potential of VLC for wireless communication.A software based VLC testbed for real time transmission of video over 3meter link distance were demonstrated in 2011 [12]. A 1Mbps speed achieved using USRP devices and GNU Radio software. Authors also succeeded in testing OFDM with BPSK and QPSK modulators in data rates upto 2 Mbps.

III. VISIBLE LIGHT COMMUNICATION SYSTEM

Typical VLC link structure contains a signal generator, LED as transmitter and a photodetector for reception. Due to the illumination purposes, VLC link uses LOS configuration. LEDs emit incoherent light so, Intensity Modulation (IM) is done. In intensity modulation, the signal is modulated into instantaneous optical power of the LED. If the pathloss and dispersion over short distances lowered then a higher bandwidth will be achieved. To control the intensity of the light, forward current through the LED is controlled. At the receiver side, a photodiode is used to convert the incident optical signal power into a proportional current. Since the intensity modulation changes the instantaneous power of the LED, Direct Detection is the only way to down convert the signal.

A. VLC Transmitter

LED is used as the transmitter in visible light communication system. The LED lamp contains a driver circuit to control its brightness. To modulate the data, driver circuit is modified. In a simple on off keying, the data bit '0' is transmitted at low intensity level and '1' is transmitted at relatively high intensity level. The performance of VLC system is depending on the design of LED illumination. LED is a solid state semiconductor device which converts electrical energy directly into light energy. The semiconductor chip inside in the LED contains a semiconducting material doped with impurities to create a p-n junction. On applying a voltage, an electron meets a hole and falls into a lower energy level, and releases energy in the form of photons, which is seen as emitted visible light. This process is called electroluminescence. High switching capability of LED along with its energy efficiency and longer lifetime makes them more suitable for VLC system.

The influence of the type of the LED on system performance is marginal. For a successful transmission of audio signal, LED is selected in such a way that it should have high brightness and high switching frequency. To select proper LED for this system, a comparison is made on commercially available LEDs. Fig. 2 shows the response of LEDs with different frequencies. Results show that white LED has a better performance compared to other LEDs.

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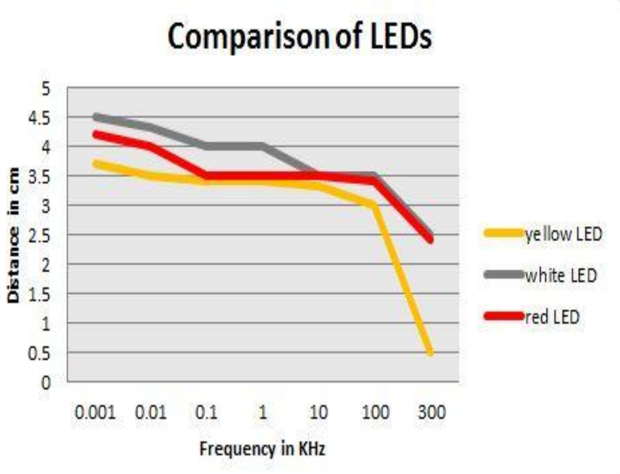

Fig. 2. Comparison of commercially available 3 LEDs

In order to choose the most optimal LED, other important factors are brightness, frequency speed, price and color. A comparison is also made between these factors of different LEDs. Result is shown in Table I.

TABLE I Comparison of leds

Color	Brightness	Frequency Speed	Price
Yellow (YSL-R531Y3D-D2)	150-200 mcd	>1 MHz	$ 0.12
Red (NC1003AHR1-25Q)	18000-3400 mcd	>1 MHz	$ 0.35
White (334-15/T1c1-4WYA)	14250-8500 mcd	>1 MHz	$ 0.66

A high level of brightness is preferable so that data can be transmitted reliably under ambient light condition across a larger distance. In order to transmit the data quickly enough, the LEDs should have to turn on and off quickly. Based on these criteria, table I shows that white LED is the best.

B. VLC Receiver

To receive the transmitted signal, two types of receivers can be mainly used: An imaging sensor and a nonimaging sensor. An imaging sensor or a camera sensor can be used to receive the transmitted signal since such camera sensors are available on today's smartphones to capture images and videos. An imaging sensor consists of many photo-detectors arranged on an integrated circuit in matrix form. In order to enable high resolution photography, the number of photo-detectors should be very high. This is the limitation of an imaging sensor. Imaging sensors can provide only limited throughput due to its low sampling rate.

The nonimaging sensors also referred as photodiode or photodetector is a semiconductor device that converts the received light into current. While consider the VLC receiver, important factors to be taken into account are response time, price and range of wavelength. Comparison between different nonimaging sensors are shown in Table II.

TABLE II Comparison of vlc Receivers

Model Number	Response Time (ns)	Price	Wavelength Range (nm)
SFH 203	5	$ 0.42	400-1100
OP993	5	$ 0.74	600-1100
TEFT4300	7.5	$ 0.48	350-1120
SFH 213	5	$ 0.54	400-1100

Based on Table II we can conclude that, TEFT4300 phototransistor is capable of detecting the flashing of LED fast enough. So, TEFT4300 phototransistor is selected for this VLC system.

IV. PERFORMANCE EVALUATIONS

The performance evaluation is divided into 2 parts. The VLC performance and characteristics of the signal waveform have been analyzed before the amplifier at receiver in the first part and in the second part, the performance is analyzed after employing an amplifier at receiver. Fig. 3 shows the characteristics of the signal without an amplifier.

It can be seen that a small distance is obtained without an amplifier. As distance increases, the power loss also increases. LED is a noncoherent light source. So, power of the emitted light decreases as the distance increases. This will increase the power loss. A maximum distance of 4cm is only achieved without an amplifier. This result shows that, audio can't hear clearly at the receiver. So, an amplifier circuit is added at the receiver to enhance the performance of the system. Performance of the system with an amplifier is shown in Fig. 4

When the amplifier is added at the receiver, the performance is increased to a larger value. Range of the system is increased to 50 cm and powerloss also increased from -24.55 dB to -25.20 dB.

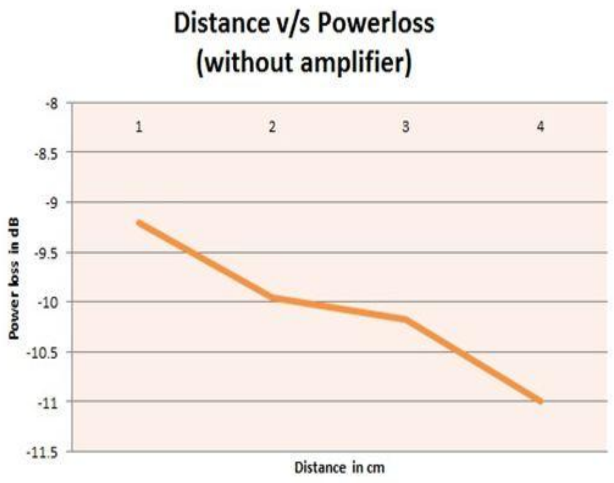

Fig. 3. Performance analysis without amplifier

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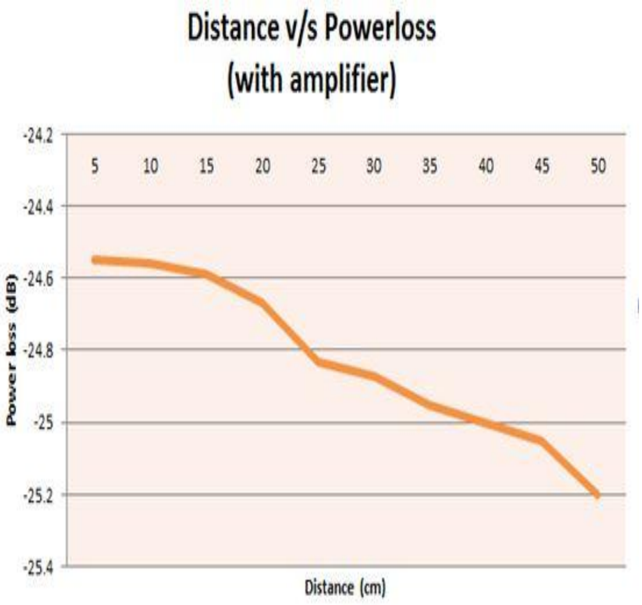

Fig. 4. Performance analysis with amplifier

V. CONCLUSION

To transmit an audio signal, a safe and cheap method is employed using visible light communication system. Two objectives have been successfully achieved. Firstly, the hardware for visible light communication system for audio transmission has been successfully designed and employed. The performance parameter of VLC such as voltage, current and power loss have been measured and analyzed before and after adding an amplifier to the receiver. The implementation of the amplifier helps to improve the signal quality and range of the audio signal. It can be seen that, the distance between the transmitter and the receiver can influence the performance of the system. For longer distance, the signal strength degraded and so loss increased. A maximum distance of 50 cm is achieved for this system with low noise.

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