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Data Transmission using Visible Light Communication: Experimental Approach

Avinash Shinde
Master of Technology, Student
Department of Electronics and Telecommunication
K. J. Somaiya College of Engineering
Mumbai, India
avinash.shinde@somaiya.edu

Kunal Mahajan
Master of Technology, Student
Department of Electronics and Telecommunication
K. J. Somaiya College of Engineering
Mumbai, India
kunal.mahajan@somaiya.edu

Swati Mahajan
Associate Professor
Department of Electronics and Telecommunication
K. J. Somaiya College of Engineering
Mumbai, India
swatimahajan@somaiya.edu

Abstract -Visible Light Communication (VLC) is internationally recognized as an innovative and capable technology to accomplishshort-range, high speed as well as large capacity wireless data transmission. In this paper, an optical Indoor wireless communication system using visible light as media is proposed. In this proposed model an audio signal is used for transmission.At transmitter end the input signal are used to drive the LED with on-off keying (OOK) modulation. White colored LED is preferred for this purpose as it has better intensity than other LEDs. The LEDs produce a subtly changing light in accordance with input signal. This light is detected by a photo detector (PD) at receiver. The PD produces a voltage at its output which corresponds to light variations at its input. The transmitted and received waveforms of audio signal are observed on Digital Storage Oscilloscope (DSO).

Index Terms - *VLC; LEDs; OOK.*

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I. INTRODUCTION

Demand for Bandwidth in mobile communication has increased with significant increase in number of users. In today's digital age, high speed connection has become essential. To support various services such as HDTV, computer network applications (up to 100Mbps), VoIP, video conferencing etc. wireless communication system should be able to offer higher capacity. But the existing technologies are unable to keep up with the increasing demand, as the RF spectrum is limited and reserved for other applications. The overcrowded RF spectrum is regulated, scarce and costly. Also, to get license to use RF spectrum is long process and requires lots of permission. Because of all this issues, there is a need for alternative technology or betterment of existing technology. Thus, a new technology is developed that uses visible light spectrum instead of RF spectrum and is known as "Visible Light Communication" (VLC). The visible light spectrum is cheap, easily available and it offers 10000 times larger spectrum than RF spectrum [1].

Visible light Communication (VLC) is a progressive communication technology which utilizesvisible solid-state light sources (LEDs). A LED is a semiconductor device that has the advantages of fast switching, power efficiency and emits visible light that is safe for the human because it is not harmful to vision. Already a lot of LED-based lights are installed which can be used for communications. Therefore, LED lights can perform dual operations i.e. illumination and transmission data. VLC is a data communications technique whichuses visiblelight between 400 THz (780 nm) and 800 THz (375 nm) as media.

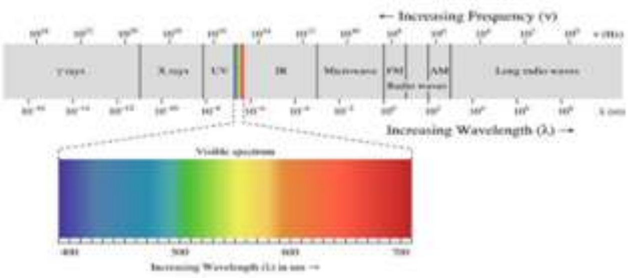
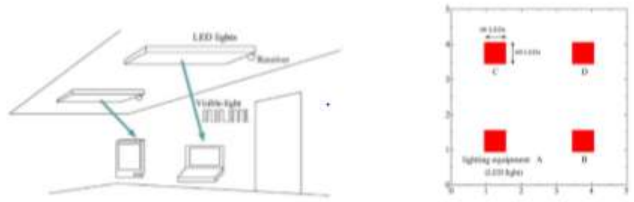


Fig.1 Frequency Band for Visible Light Communication

Although, RF communications is the most popular wireless technology today but it has its disadvantages as well. The use
of RF communication is prohibited at some areas like Hospitals, Airplanes, Oil refineries etc., VLC can be used for wireless communications in such areas. IR (Infra-red) communications is also used in many applications including mobile phone and laptops. Even if IR communications offers the same advantages in terms of available bandwidth but then again it is not good for human beings and lags behind VLC in certain areas. A unique quality of VLC Systems is that by using visual light to transmit data, the data cannot be accessed by any device not in the same room as the system. Unlike Wi-Fi systems, VLC systems are contained within the room they exist in because visual light is not capable of traveling through walls the same way radio frequencies are.

In spite of this advantages over RF technology. VLC faces many technical issueslike many emerging technologies. The greatest shortcoming of visible light communication is that it entails line of sight communication, even though NLOS communication can take place but with low SNR. Also, the receiver of the system could get unintentionally blocked. This would cause the signal to be interrupted, potentially by things like a person walking through a room. Thus, VLC is not meant for replacing existing wireless communication technologies; its sole purpose is to complement the existing wireless technologies.

With the time, old bulbs are getting replaced by LED lights. In 2003, a team at the Nakagawa Laboratory located at



Keio University in Japan used LEDs to transmit data via visible light [2]. Indoor visible light communication system is shown in Figure 2 where LED lightings are used in place of fluorescentlamps. So that LED lights can perform dual operations of illumination and communication. On Off Keying RZ (OOK – RZ) modulation scheme is used due to its simplicity [1].

Fig.2 VLC model room, Distribution of LEDs inside model room [1]

The usage of Traffic lights and headlight of car can be extended for communication as they are already equipped with LED. Vehicle-to vehicle or Roadto vehicle communication using the LEDs in the traffic signal lights is possible. The vehicle can communicate with each other and also with traffic signals, providing the owners information and other facts while travelling. This can be practical approach for autonomous vehicles. In this model, a camera on front of the car is used as the information receiver from traffic signal lights [3]. The advantage of using the camera is that multiple data can be transmitted by the LEDs and received by High-speed cameras.

Since the RF communication suffers high degree of attenuation underwater, so there is need of VLC techniques. In order to maintain a communication between the surface controller and the Remotely Operated Vehicles (ROV) a link is required, here VLC can come handy. It can provide a live feed of video to the surface station [4][5]. A VLC system for wireless underwater communication was proposed in [6] for robotic inspection of nuclear power plants, as the reactor exists in an underground environment. The sensed data around the reactor are sent to ground station using VLC link. Same approach is used to inspect the underwater climate changes, prediction of natural crashes, and discovery of natural resources, marine biology, sea and ocean environment by observing the changes in attenuation [7].

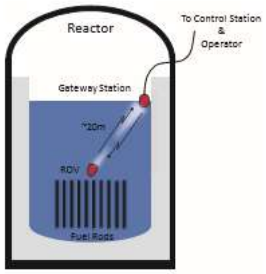


Fig.3 Nuclear reactor inspection with a wireless ROV [5]

A prototype of real-time audio and video broadcast system using inexpensive commercially available light emitting diode (LED) lamps a maximum transmission distance of 3m is achieved. By adding focusing lens between the transmitter and the receiver prototype can be further improved [8][9].Philips recently did a ground-breaking collaboration with Carrefour to implement the world's first application of VLC indoor positioning technology in a supermarket in Lille, France [10].

TABLE I
COMPARISON OF VLC WITH OTHER COMMUNICATION TECHNOLOGIES [2][11]

CHARACTERISTICS	BLUETOOTH	WI-FI	VLC
Frequency	2.4 GHz	2.4 GHz – 5 GHz	No frequency for light
Range	10 meters	100 meters	Based on LED light falling
Data transfer rate	800 Kbps	11 Mbps	>1 Gbps
Power Consumption	Low	Medium	Low
Cost	Low	Medium	Low
Security	Less secure	Medium secure	High secure
Standard	IEEE 802.15	IEEE 802.11b	IEEE 802.15
Operating Band	ISM Band at 2.5 MHz	RF Band	Visible Light band
Maximum Members	7 members can connect at a time	Number of devices depends on bandwidth availability	Number of recovers present within range of light
Topology	Master-slave	Various topologies	Point to Multipoint

II. VLC SYSTEM MODEL

VLC is free space optical communication and line of sight (LOS) is the common link between two points in optical wireless communication system. A Visible light beam modulated by a message signal is directed by transmitter towards receiver in an un-obstructed straight path to the receiver. The light source at transmitter is a simple, off-the shelf LED. The modulated light beam flickers in intensity equivalent to the variation in input signal. The Detectors at receiver end are needed to be aligned with the most intense portion of the emitted light beams. After propagating through the optical wireless channel, varying light beam is detected by a photodiode which convert it into equivalent photo electric current proportional to the variation of incident light. Intensity modulation and direct detection are adopted by the prototype for data transmission. Figure 4 shows the basic block diagram of VLC transmitter and receiver.

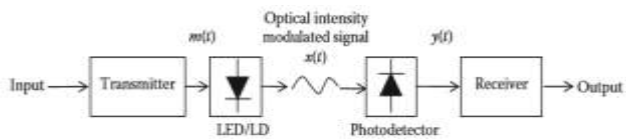


Fig. 4 Block diagram of an optical intensity, direct detection communications channel [2]

Intensity modulation with direct detection (IM/DD) is theone of the way for employing optical wireless systems mainly due to its reduced cost and complexity. The drive current from an optical source is directly modulated by the signal m(t), which in turn fluctuates the intensity of the optical source x(t). The receiver employs a photodetector that generates a photocurrent y(t). This photocurrent is directly proportional to the instantaneous optical power incident on it, that is, proportional to the square of received electric field. An IM/DD-based optical wireless system has an equivalent baseband model that hides the high- frequency nature of the optical carrier. The model is shown in Figure 5 where R is the photodetector responsivity, h(t) is the baseband channel impulse response and n(t) is the signal-independent shot noise, modelled throughout the book as the additive white Gaussian noise (AWGN) with a double-sided power spectral density (PSD) of N0/2.

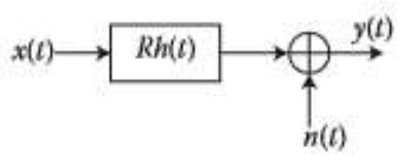


Fig.5 Equivalent baseband model of an optical wireless system using IM/DD [2]

The equivalent baseband model of an IM/DD optical wireless link can be summarized by the following equations,

$$y(t) = Rx(t) \otimes \mathrm{h(t)} + n(t)\, y(t) = \int_{-\infty}^{\infty} Rx(t)\mathrm{h(t-\tau)} + n(t). \quad (1)$$

where the symbol ⊗ denotes the convolution.

The optical wireless channel transfer function is defined by

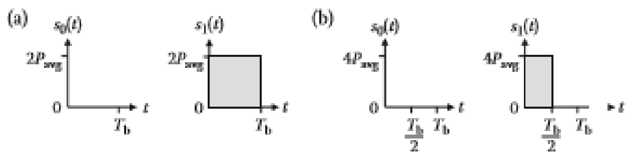
$$H_{OW}(f) = H_{los} + H_{diff}(f) \quad (2)$$

where H_{los} is the contribution due to the LOS, which is basically independent on the modulation frequency, and it depends on the distance between transmitter and receiver and on their orientation with respect to the LOS, whereas H_{diff} is almost homogeneous and isotropic in most rooms. In a directed link the power ratio between the LOS and the diffuse links can be increased by reducing the transmitter beam width and/or the receiver FOV. This can be quantified by the Rician factor,[2]

$$k_{rf} = \left(\frac{H_{los}}{H_{diff}}\right)^2 \quad (3)$$

OOK is the most reported modulation techniques for IM/DD in optical communication. This is apparently due to its simplicity. A bit one is simply represented by an optical pulse that occupies the entire or part of the bit duration while a bit zero is represented by the absence of an optical pulse. Both the return-to-zero (RZ) and nonreturn-to-zero (NRZ) schemes can be applied. In the NRZ scheme, a pulse with duration equal to the bit duration is transmitted to represent "1" while in the RZ scheme the pulse occupies only the partial duration of bit. Figure 6 shows the single mapping of OOK-NRZ and OOK-RZ with a duty cycle γ = 0.5 for average transmitted power of P_{avg}. Hence, the envelop for OOK-NRZ is given by [2]

$$h(t) = \begin{cases} 2P_r, & for\ t \in [0, T_b) \\ 0, & elsewhere \end{cases} \quad (4)$$



where P_r is the average power and T_b is the bit duration.
The simplicity of OOK has led to its use in commercial optical wireless systems.

Fig.6 Transmitted waveforms for OOK: (a) NRZ and (b) RZ γ = 0.5

III. IMPLEMENTATION

The Visible light communication (VLC) technology is projected to become an alternative means of wireless connection due to its efficiency and high bandwidth. An audio source from laptop through 3.5mm audio jack is applied as input to VLC transmitter. The transmitter produces intensity varying light in accordance with applied audio. At the receiver end photodiode detects this intensity varied output and generates the audio signal.

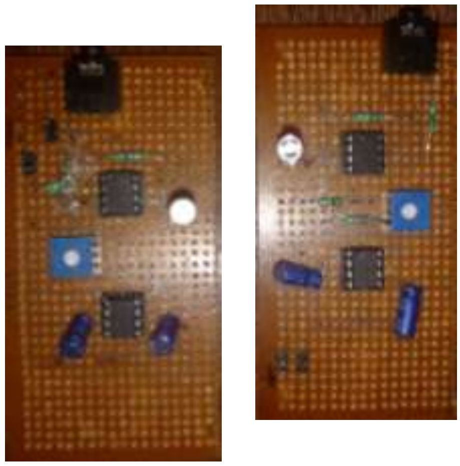
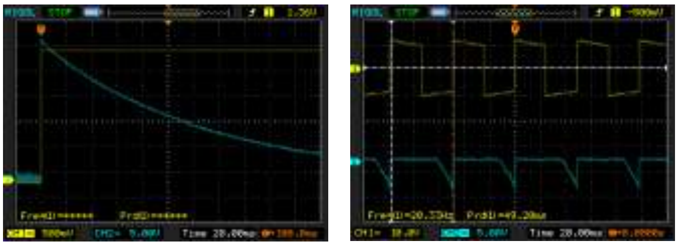


Fig. 7 VLC audio transmitters and receivers

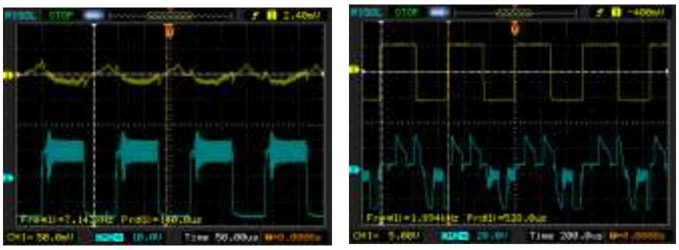
The LM7171 voltage feedback amplifier is used in transmitter and receiver. The LM7171 is a high-speed voltage feedback amplifier that has the slewing characteristic of a current feedback amplifier, yet it can be used in all traditional voltage feedback amplifier configurations. The LM7171 is stable for gains as low as +2 or −1. It provides a very high slew rate at 4100V/μs and a wide unity-gain bandwidth of 200 MHz while consuming only 6.5 mA of supply current. It is ideal for video and high speed signal processing applications such as HDSL and pulse amplifiers. With 100 mA output current, the LM7171 is used for video distribution as a LED/laser diode driver and is ideal for ADC/DAC systems.Using ICL7660 (a negative VCC generator IC) a reference voltage is generated for op-amp. For the audio circuit ICL7660 gives a whining sound.

IV. RESULTS

After implementation, for testing of system a signal generator with square wave is applied at the input of transmitter nd the same is detected using LDR and photodiode at receiver. The following results are obtained.

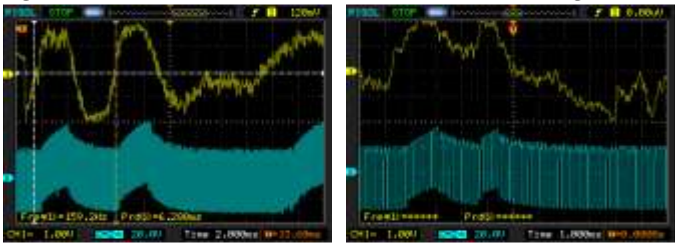


(a) (b)
Fig. 8 Transmitted Input and Receive Signal using LDR as detector; (a)LDR response on continuous light, (b) f = 20kHz



(a) (b)
Fig. 9 Transmitted and Received Signal using Photodiode as detector; (a) No response, (b) f = 1.894kHz

An audio signal is transmitted using VLC and after reception regenerated signal is played on speaker. Below figure 10 shows the transmitted and received audio signals



(a) (b)
Fig. 10 Transmitted and received Audio Signalfor different transmission distance (a) 2cm, (b) 10cm

V Conclusion

In this paper, data transmission using LED is implemented. Experimental results show that response of photodiode is better than LDR at higher frequencies. Transmission of audio signalis achieved. As the transmission distance increases, though the received audio is noticeable,the effect of noise increases.

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