Development and Experimental Evaluation of a Visible Light Communication System with Ambient Light Cancellation

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Abstract— Light emitting diodes (LEDs) hold several attractive characteristics such as low power consumption, fast switching times, high durability and size reduction to find applications in modern digital communications. This paper presents the design, implementation and suppression of interference due to ambient light sources of a visible light communication system (VLC). The transmitter of the designed VLC system uses White LEDs to modulate visible light with digital data using On-Off keying (OOK) modulation. Low cost transistors were used in the transmitter to switch the LEDs. In the receiver the modulated visible light is captured using high speed photodiodes. Moreover, general-purpose operational amplifiers were used in the receiver to implement the amplifier and comparators in order to perform signal detection. At present, the implemented VLC system is capable of operating at 100 kHz. Moreover, the speed can be further increased by using high speed transistors and operational amplifiers. In order to test the implemented VLC system and collect data, a real time measurement campaign was also carried out. Initial results demonstrated that the ambient light variations in the environment have a significant impact on the performance of the VLC system. In order to mitigate these deleterious impairments, a hardware setup was developed to cancel out the constant component of the ambient light effect. Further, the effects of CFL sources and variations of sun light condition cannot be treated as constant and a signal processing technique was utilized for cancellation. Distance between the transmitter and receiver also affects the system performance. Various arrangements of the transmitter and receiver were tested to increase the maximum transmitter-receiver distance. The approach makes VLC systems more immune to the ambient light variations and in particular enables successful integration into state-of-the art high speed indoor communications.

Keywords— Visible Light Communications, Ambient Light Cancellation, Communication System Performance

I. INTRODUCTION

Light Emitting Diodes (LED) are solid state devices which are used for many applications in Electrical Engineering as well as in many other fields. With the introduction of power LEDs which are intended for illumination purposes, boundaries of the LEDs are extended to interior and exterior illumination.

In addition to the energy efficiency and high reliability, LEDs inherent high frequency capability from the solid state electronics (Gujjari, 2012). Once the LEDs are fed with digital data, the light emitted through the LEDs follow the digital data sequence. We exploit this characteristic to realize Visible Light Communication (VLC). Transmitter of the VLC system uses LEDs to transmit data in the form of light. As a result any LED illumination can be used as a transmitter. For example LED display unit, Power LED lighting systems, traffic light systems, etc. (Bhalerao, 2013). Receiver of the VLC system employ a photodiode to capture the subtle variations in the visible light and then reconstructs the original signal. Even cameras embedded in the mobile devices can be used for data reception. But the data rate should in the range of tens of kbps.

VLC systems can achieve very high data rates compared to the existing technologies. Azhar (2013) proposes a method to achieve 1 Gbps speed using VLC. As Curtis (2015) states, researchers believe that the VLC systems have the capacity to achieve 100 Gbps. As the number of wireless devices increases the radio frequency spectrum gets crowded. VLC enables us to effectively utilize the visible light spectrum (380 nm to 780nm) to compensate the radio frequency scarcity. VLC systems can be adopted to existing infrastructure and use the same power for communications as well. As a result the capital cost and the operational cost of the communication drastically reduces (Kumar, 2013).

Performance of the VLC systems depend on various effects of the environment. Variations of the ambient light intensity is the most dominant of all the effects. Ambient light intensity of a place can change due to various reasons like changes in the sunlight, turning on

lights, opening windows, etc. Changes in light intensity changes the reference level of the digital signal at the receiver. As a result the receiver fails to correctly identify the bits. In addition, fluorescent lamps also cause severe interferences on the VLC systems. Fluorescent lamps flicker while turning on. These flickers causes spikes in the VLC receiver.

In this work, a VLC system is implemented using power LEDs and high speed photodiodes. Next the performance of the system is evaluated under various ambient light conditions. Experimental results shows that the ambient light variations and fluorescent lamps have severe effects on the performance of the VLC system. Finally an algorithm is proposed to mitigate the interferences on the VLC system. Results show that the algorithm effectively cancels the effects of the ambient light variations and other light sources.

This paper first describes the development of the VLC system and the experimental results of the system under the section 2. Next the ambient light effect cancellation method is introduced under section 3 and the experimental results of the improved system are presented.

II. DESIGN AND IMPLEMENTATION OF THE VLC SYSTEM

In this section we describe the design and implementation of the VLC system.

A. Overview of the System

VLC system has a transmitter which takes digital data and transmit that data in the form of visible light. Receiver uses photodiodes to capture the signal transmitted through visible light. Figure 1 shows the block diagram of the implemented VLC system.
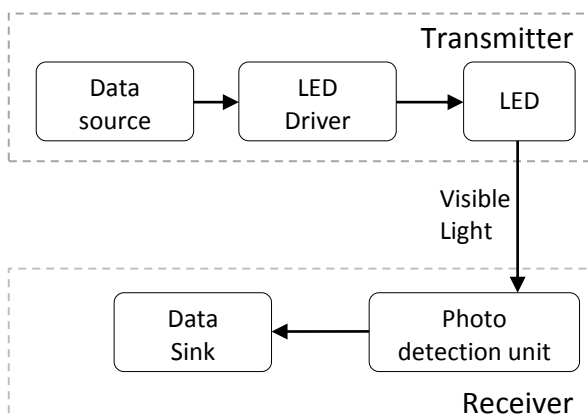

Figure 1: System Block Diagram.

LED driver of the transmitter takes the digital data stream from the data source and drives the LEDs. Once the data

is transmitted, the receiver captures the variations of the light and reconstructs the signal.

B. Transmitter

Transmitter of the implemented VLC system uses On-Off Keying (OOK) modulation scheme because of its simplicity. Serial ports of the computers, serial communications of microcontrollers use OOK for modulation.

Purpose of the transmitter is to convert the digital data stream into variations of light intensity. Data source (for example computer, microcontroller, etc.) can be directly connected to the LEDs if we use only few low-power LEDs. But for practical situations it is required to have number of LEDs which cause a high current in the data source. Therefore the data signal is first fed to the LED driver and the LED driver drives the LEDs.

Implemented transmitter uses power LEDs to transmit data. However switching high current at high speed is challenging. Therefore we have used 1 W power LEDs which require only around 350 mA.

As shown in Figure 2 transistors in the LED driver are used as switches. Digital data signal is applied to the base of the transistor through the base resistor. When the data stream sends bit '1', the transistor turns on the LED. In the same manner, transistor turns off the LED when bit '0' is transmitted. Base resistor is chosen such that the transistor remains in the active region when bit '1' is transmitted. Otherwise the transistor will go to the saturation region and reduces the switching speed.
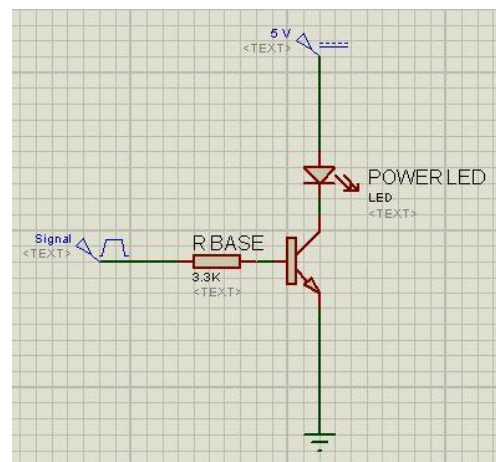

Figure 2: Transistor Switch.

Transistors for the LED driver are chosen by considering the speed and the maximum collector current. Table 1 presents the important parameters of the transistors.

Total power of the transmitter is increased by using several 1 W LEDs. Current implementation can drive sixteen 1 W LEDs simultaneously. Figure 3 shows the schematic diagram of the LED driver.
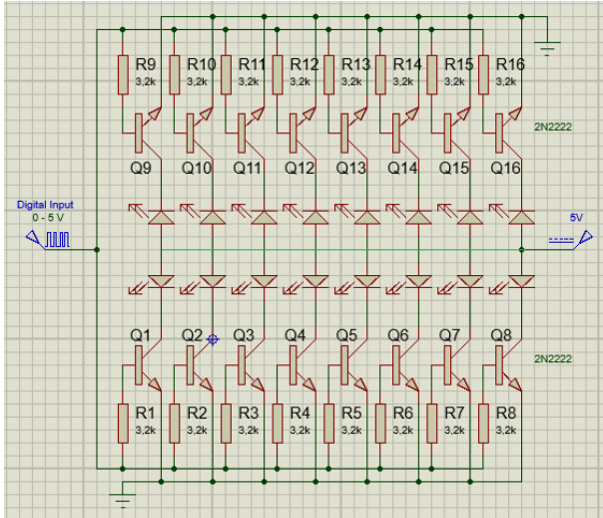

Figure 3: Schematic Diagram of the LED driver.

LEDs also play a key role in the transmitter. Therefore the performance of the transmitter depends on the type of LEDs used in the transmitter. We mainly considered the power rating and the viewing angle of the LEDs. Power rating decides the current it requires and the viewing angle sets the maximum angle up to which the transmitter is effective. Table 2 contains the specifications of the LEDs used in the implemented transmitter.

C. Receiver
VLC systems use photosensitive devices like phototransistors, photodiodes or image sensors for signal reception. In the implemented system we have used a photodiode for reception. Photodiode is followed by amplifiers and a comparator to reconstruct the digital signal. This system as a whole is called the 'Photo detection unit' and the output of this system can be directly fed to the data sink. Figure 4 shows the block diagram of the photo detection unit.
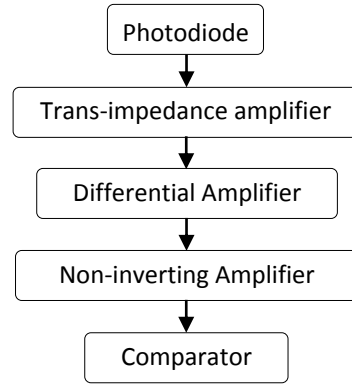

Figure 4: Block Diagram of the Photo Detection Unit.

First component in the photo detection unit is the photodiode. Photodiodes generate a current which is proportional to the light intensity. There are three major parameters of the photodiode which affect the performance of the receiver; response time, spectral sensitivity and half angle. Response time defines the maximum speed at which the photodiode can operate. Spectral sensitivity is the sensitivity of the photodiode for different wavelengths (colours). The photodiode we have used has a wide spectral sensitivity which means it is sensitive for all the colours of light. It is advantageous since we use white colour LEDs. Half angle is the angle at which the sensitivity of the photodiode drops to 50 % of the maximum sensitivity. Values of the parameters are included in the table 3. Figure 5 shows the spectral sensitivity of the photodiode.

Table 1: Parameters of the Transistors.

Parameter	Value
Model	2N2222A
Max. Collector Current	800 mA
Turn−On Time	35 ns
Turn−Off Time	300 ns

Table 2: Specifications of the LEDs.

Parameter	Value
Forward Current	350 mA
Forward Voltage	3.2 – 3.6 V
Viewing angle	120 °
Luminous Flux	90 - 100 lm
Light colour	6000 - 6500K

Table 3 - Specifications of the Photodiode.

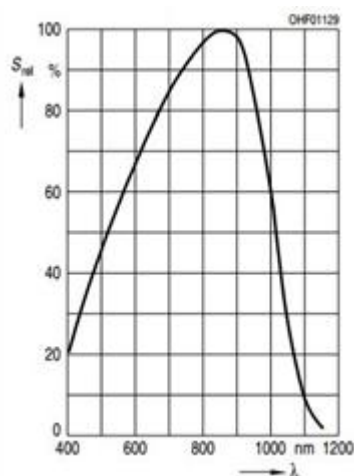| Parameter	Value
Model	OSRAM SFH 203
Response time	5 ns
Spectral range of sensitivity	400 − 1100 nm
Half angle	±75 °
Wavelength of max. sensitivity	850 nm
Dark current	1 nA

Figure 5: Spectral Sensitivity of the Photodiode.

Current signal generated by the photodiode is converted to a voltage signal by using a trans-impedance amplifier. This trans-impedance amplifier is implemented using an operational amplifier.

Next stage is the differential amplifier which cancels the unwanted DC offsets in the signal. These DC offsets are caused by the ambient light of the environment. This amplifier is a standard differential amplifier implemented using an operational amplifier. Received signal might have a constant DC offset and a time varying DC offset. Differential amplifier subtracts a pre-set value from the signal to cancel the constant DC offset. Pre-set value is obtained considering the previous experiments.

At the next stage, a non-inverting amplifier is used to amplify the signal to 1 V. It is also a standard non-inverting amplifier implemented using an operational amplifier. Finally the signal is sent through a hysteresis comparator to reconstruct the digital signal.

All the amplifiers are implemented using TL084 operational amplifier. TL084 is chosen considering its high slew rate (16 V/μs) and immunity to noise. Comparator is implemented using LM311 comparator.

E. Experimental Results without noise cancellation
Experiments were carried out to evaluate the VLC system. Bit Error Rate (BER) is used to quantify the performance of the VLC system. BER is the most commonly used metric to quantify the performance of the digital communication systems. It is calculated using the equation,

$$BER = \frac{No.\,of\,bit\,in\,error}{No.\,of\,total\,bits\,transmitted} \quad (1)$$

First the experiments were carried out to evaluate the BER with distance. Transmitter and receiver were placed in a vertical line and distance was increased in steps. This experiment was done under normal room light conditions. Figure 6 shows the BER variation with distance.

Figure 6: BER with transmitter-receiver distance.

Next the effects of the ambient light variations were observed by artificially increasing the light intensity of the room. Figure 7 show the effect of increasing light intensity.
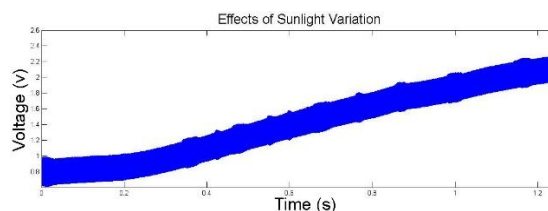

Figure 7: Effects of increasing Ambient light.

It is evident from Figure 7 that the receiver cannot identify the bit correctly when the ambient light conditions vary. Therefore in the next section we introduce the Ambient Light Cancellation methodology.

III. AMBIENT NOISE CANCELLATION
Ambient light effects have two components; constant component and time varying component. Constant component does not change with time and it is cancelled using the differential amplifier in the photo detection unit. In order to cancel the time varying component, received signal is sampled at the output of the non-inverting amplifier and obtained into the Matlab program.

A. Algorithm

Proposed algorithm first takes N samples of the signal and apply a median filter. Median filter reduces the spikes in the signal. Next the signal is passed through a moving average filter to suppress the high frequency noise components. After that another median filter is applied to further reduce the spikes of the signal. Finally minimum value of the N samples is subtracted from all the samples to cancel the DC offset. Figure 8 shows the steps of the algorithm.
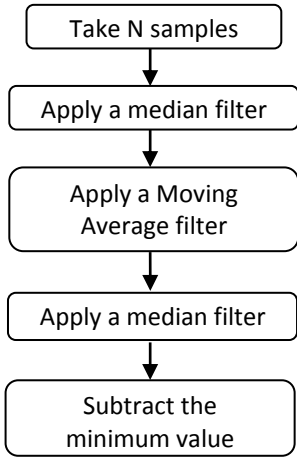

Figure 8: Steps of the Algorithm.

B. Experimental Results with Ambient Noise Cancellation

Proposed algorithm was emplyed to mitigate time varying ambient light effects on the receiver. Figure 9 shows the cancellation of effect of increasing ambient light.
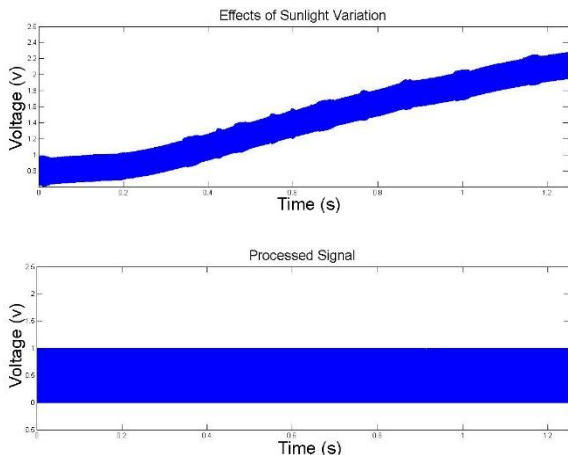

Figure 9: Cancellation of Increasing Ambient Light.

Next the effects of the fluorescent lamps were observed and mitigated. Figure 10 shows the spikes caused when a fluorescent lamps are turned on and the mitigation of those spikes.
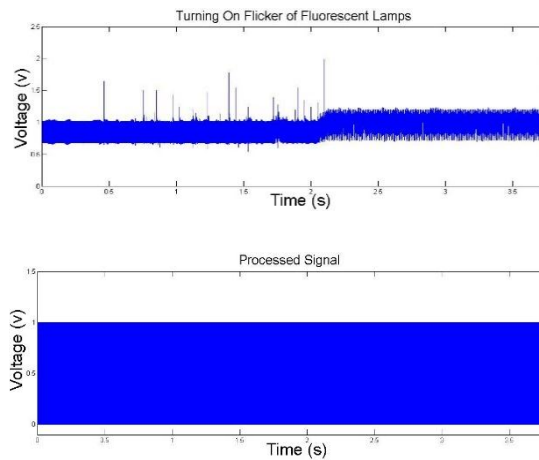

Figure 10: Mitigation of Spikes caused by Fluoresecent lamps.

Table 4 shows the improvement in the BER for each of the above cases.

Table 4 – Improvement in Bit Error Rate.

Case	Bit Error Rate	
	Before cancellation	After Cancellation
Ambient light variation	0.0251	0.0068
Fluorescent lamp turning on	0.8549	0.0181

IV. CONCLUSION

In this work we have implemented a Visible Light Communication system which can operate around 100 kHz up to 2 m. The system can be further improved using advanced electronics. We have used power LEDs to demonstrate that the VLC systems can be easily adopted to the existing LED illuminations.

Performance of the system was evaluated with distance and varying ambient light conditions. It was apparent that the ambient light variations largely affect the performance of the system. Ambient light cancellation method was introduced to overcome such problems. Experiments on the new system prove that the performance of the system has improved significantly.

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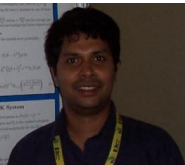
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