LED to LED Communication using WDM

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ABSTRACT
Interestingly Visible Light Communication is gaining much interest by researchers due to its some unique advantages over Radio Frequency. In this paper we will look at the possibilities of LED to LED communication using different color LED as a sensor (called Wavelength Division Multiplexing).This technology has quit unique applications. One can discover the way to use it appropriately.

Keywords
Visible Light Communication (VLC), LED-LED Communication, WDM, LED as Photodiode/Sensor

1. INTRODUCTION

Visible Light Communication is not new entrance, since ancient times it has been done. Today researchers [1] [2] are more interested in advantages and potential of this technology. Due to many reasons like Radio Frequencies is being more and more busier, to make RF network congestion free we have to move somewhere else. Here VLC comes in a picture. Despite having some disadvantages it still has some unique and very useful advantages [3] [4]. Some of are like it is license free, and no health concerns as everybody use light at home, office, etc. we want to use them as our data communication hot-spot like Wi-Fi router does.

For under water communication [5] VLC is useful where Radio Frequencies won't work.VLC uses solid state devices especially LED from which we can expect less power consumption, highly reliable, high brightness at the same time it can blink so faster that human eyes cannot perceive flickering of it, which opens door to world of new technology.

In simple terms if you want to do communication through visible LEDs you can simply switch it On & Off for certain period of time. E.g. To sending "1" LED should be On, and for "0" It should be Off. Likewise on receiver side when it will detect light it will guess it as "1", in absence of light receiver will take it as "0", and so on. In simple terms if there is light "1" if there is absence of light "0".Popularly known as On-Off-Keying(OOK).Modulation schemes take most important role in Visible light communication, like PWM, OFDM[1],OOK, etc are some of most popular modulation schemes among researchers for VLC this days.

Visible Light Communication has lots of way/techniques [6]; we are much interested in LED-LED Communication because it is unique and has some interesting application waiting for someone to find out.

2. LED AS A SENSOR

LED can be used as a Sensor too. It generates small photocurrent when light fall on it. It can be used with many techniques 3 are described in Figure. 1. In which (1) is connecting LED with transistor which is quite popular technique as level converter. (2)connecting with Op-Amp which is useful to achieve high amplification (3)here one shall connect LED's Anode and Cathode with Microcontroller to do bi-directional communication[7][8] which requires microcontroller to change polarity after defined time to use it as LED and Sensor/Photodiode. Here LED will act like capacitor, when light fall on it capacitor discharge faster. We can figure out intensity of light by this way by calculating time of discharging.

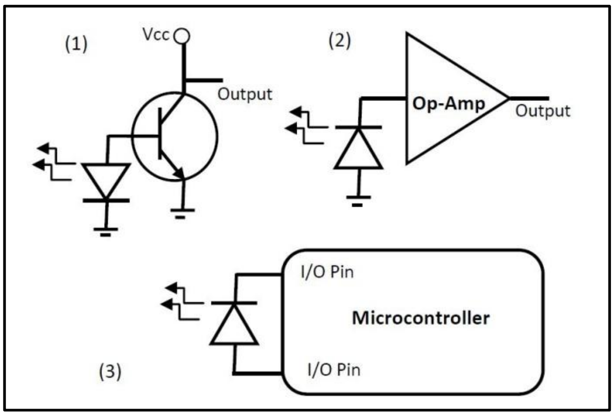

Figure.1 Different techniques which can be done to use LED as sensor (1) with transistor(2) with Op-Amp(3) with microcontroller for bi-directional communication.

But in experiment 1st technique of Figure.1 is used. Operational Amplifier also can be used. But for simple application it is better. Reason for choosing NPN transistor over Op-Amp is to understand properties of LED as sensor and in second setup in Figure 3. Raw waveforms of LED were captured on receiver side (use of amplifier/filter are general terms which depend on applications and requirements). Right now we are only doing one way LED to LED communication due to some limitation.

3. WDM WITH LED

LED can sense light with lower wavelengths than it emits so one can say LED's sensitivity region is slightly wider then its spectral emission profile. Still visible LEDs are better than IR sensor generally available in the market as far as VLC is concern as here visible light has to be detected. After checking some LEDs decision was taken to go with 5 clear lens 5mm LEDs. Which are very low cost and widely available. As shown in table all LEDs are described with its behavior with other LED as Emitter and as Detector (Sensor).

As shown in table all LEDs behavior as sensor is different due to wavelength emitted by them. Red LED is sensing every color as color emitted by it has higher wavelength. Which is near to infrared spectrum. Blue LED was able to sense only Blue and white color and so on. It is clear that Visible LED can sense color which has shorter/nearby wavelength compare to color emitted by it.

Table.1 LED as Emitter and Detector

LED	Detector					
		W	**R**	**G**	**O**	**B**
Emitter	**White**	11	430	405	420	30
	Red	0	750	0	30	0
	Green	0	450	105	1380	0
	Orange	0	140	0	50	0
	Blue	54	30	1250	165	270

Note:

1) All values are in millivolts(mV)
2) Values are average/approximate
3) Distance between Tx-LED and Rx-LED was 3 inch.
4) Performed at room light condition.

These experiments performed at distance of 3 inches because after it LEDs were not able to give response or it was very low. Because LED is not coherent light source like Laser is, so distance between Two LED (Tx and Rx) shall be very less. Of course we can use optics/magnifying lens to extend this range by concentrating light on LED. In fact these LEDs have very low light gathering angle at 10-20 degrees. So we have to strictly follow line of sight between Tx and Rx in this case. And we also want to mention that at 1 inch and 2 inches LED gave good and quit interesting results (Figure. 4).

Figure.2 Different color LEDs used in experiments.

Now how to use these results is another matter of research. Refer to Table.1 we can use Green LED (Tx) to Yellow LED (Rx), and Red LED (Tx) to Blue LED (Rx) at the same time. It should be noted that at very short distance they might interfere a little. But if we want to use in bi-directional we have to choose LEDs accordingly. And in case of interference of other color, filter can be used. By using this technique color filter won't be needed because LED material especially particular light sensing capability of it will do by itself. Figure 2. Shows LEDs used in experiments.

4. RESULTS

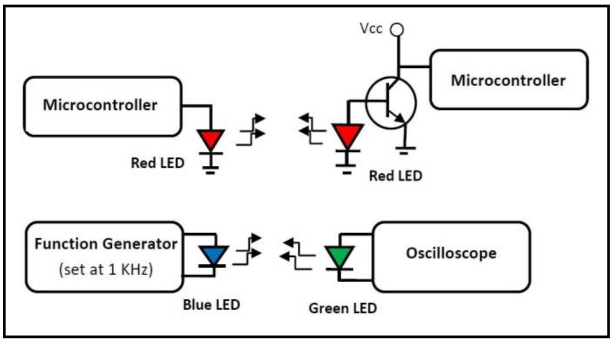

Figure.3 Experimental setup (LED symbol used on Receiver side too as we used LED as Sensor)

Figure 3 is our experimental setup; we can describe it in two parts. In first part we have selected Red LED as Transmitter (Tx) and same for Receiver (Rx) both connected to Microcontroller .Which is connected with 4 switches use to control 4 LED on receiver side. All switches assigned different bit streams to control different LED and specially to "tell" receiver to change the state of particular LED (if LED is off it will be on, in case of on it will off). We have used Atmel AT89S52 as it is low cost microcontroller easily available along with NPN transistor on receiver side. Transistor amplifier used to amplify signal to sufficient level so that Microcontroller can detect/understand it. In second part function generator and Oscilloscope used to send clock signal at 1 kHz. It can be taken as noise for the Red LEDs. In the Figure.3 we used LED symbol instead of Photodiode symbol at the receiver side because here LEDs are used as sensors.

There was only 1 inch distance between Tx-Rx Microcontroller because of limitations of Transistor/ Amplifier. Bit/Clock send by controller was set to 100ms for on/off (specifically 1 and 0) which was sufficient for our application (one can do that with high speed too).both LEDs where placed side by side with same distance and there was no interference noticed between them. At this distance when blue LED was placed near to Rx Red LED resulted in disturbance of control of LED/device on receiver side. In simple terms communication was little bit disturbed. As shown in Table.1 Red LED also sense Blue light at 3 inches so at 1 inch it must be so much higher. But at distance more than 1 inch there were no interference between them as shown in Figure. 4. It is waveform captured by Green LED and sent by Blue LED. Signals sent by Red LED were not noticeable as expected. So we can say we have successfully implemented parallel transmission without interference. During this experiment different wavelength (color) used for different communication lines, which is nothing but simple form of Wavelength Division Multiplexing (WDM).

Figure.4 shows the waveform sent by function generator and received at Green LED. LEDs where not in exact line of sight so received waveforms were not as good as we can get in photodiode still distinguishable. Frequency supported by LED as sensor is very less so data rate can be achieved by this type of communication might be very very low in terms of Bytes or KBs depending on modulation scheme being used.

There are other option too like to use Green LED (Tx) to Orange LED (Rx) to transmit data and Blue LED (Tx) to Green LED (Rx) to receive data at the same time. Here Green

LED (Tx) will give very less interference to Green LED (Rx) as compare to Blue LED (Tx). Number of lines can be extended which highly depend upon characteristics of LEDs and selection of it by user. We are continuously doing research on improvement of this technology. And also working on better amplification and filtering of signal.

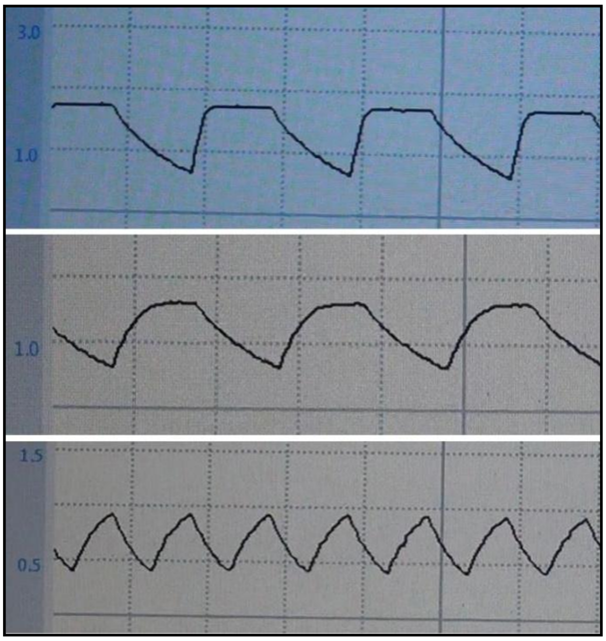

Figure.4 Waveforms at Rx2 Green LED (quality of waveform degraded when distance was increased)

5. APPLICATIONS & FUTURE WORK

5.1 Applications

There are countless applications where this can be used; some of them are described here.

Today our all appliances have indicator LEDs. In proposed system you can connect them to certain type of microcontroller to use as sensor/photodiode. This way if different appliances have different color LED they can be controlled individually by LED lamp or other source used for lighting at home. Today use of different color light for different mood is being popular (intelligent lighting) so it won't be unusual to see different colors of light used in houses, offices, they can be used to control appliances too.

All simple mobile phones have flash for use at night which can be used to install firmware updates or simple midi ringtones, etc. LEDs can be low cost option for sensing of light unlike LDRs or as color sensors (which are so costly).

Visible Light Communication (VLC) is suitable for broadcasting purpose. But with this technique data can be send as upstream to the some of the LEDs in LED lights used for broadcasting data. So problem for sending data can be solved this way.

5.2 Future work

At high distance there is very little difference between on-off voltage levels, so use of high end Microcontroller like AVRs and others recommended, or analog to digital converter also can be used to detect difference between voltage levels to extend range and achieve higher data rates.

Bi-directional communication with some minor changes in hardware and /software programming can be done. Different types of LED can be use in experiment to get better results. We suggest use of reflector at Tx side and magnifying optics at Rx side to improve range and results. More communication line to send data in parallel is also possible as more lines means higher data rate and less error.

6. CONCLUSION

After doing these experiments we can say that use of LED as sensor with WDM has potential to ignite interest among researchers. We can say that most of the LED can detect near or shorter wavelength compare to emitted by itself, We successfully communicated on two transmission line in parallel. But Very low data rate can be achieved with this technology. Hardly touching KBs. we are looking forward to extend range between Transmitter and Receiver and including more parallel lines in future.

7. REFERENCES

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