เทคนิคการหรี่หลอดไดโอดเปล่งแสงที่สนับสนุนการสื่อสารทางแสง

นายไพรัช ลีลาวัชรกุล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมไฟฟ้า ภาควิชาวิศวกรรมไฟฟ้า
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2558

LED DIMMING TECHNIQUE THAT SUPPORTS VISUAL LIGHT COMMUNICATION

Mr. Pairush Leelawatcharakul

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Engineering Program in Electrical Engineering

Department of Electrical Engineering

Faculty of Engineering

Chulalongkorn University

Academic Year 2015

Thesis Title	LED DIMMING TECHNIQUE THAT SUPPORTS VISUAL LIGHT COMMUNICATION
By	Mr. Pairush Leelawatcharakul
Field of Study	Electrical Engineering
Thesis Advisor	Associate Professor Ekachai Leelarasmee, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Engineering

(Professor Bundhit Eua-arporn, Ph.D.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Suree Pumrin, Ph.D.)

....Thesis Advisor

(Associate Professor Ekachai Leelarasmee, Ph.D.)

....External Examiner

(Waleed Mohammed, Ph.D.)

ไพรัช ลีลาวัชรกุล : เทคนิคการหรี่หลอดไดโอดเปล่งแสงที่สนับสนุนการสื่อสารทางแสง (LED DIMMING TECHNIQUE THAT SUPPORTS VISUAL LIGHT COMMUNICATION) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. เอกชัย ลีลารัศมี, 59 หน้า.

งานวิจัยชิ้นนี้กล่าวถึงเทคนิคการออกแบบในการสร้างเครื่องควบคุมความสว่างของหลอดไฟชนิด LED(Light Emitting Diode) เพื่อให้มีความสามารถในการแทรกสัญญาณการสื่อสารเข้าไปในแสงสว่างเพื่อให้เกิดประโยชน์ในการใช้งานหลอดไฟชนิด LED ที่มากกว่าการให้แสงสว่างแต่เพียงอย่างเดียว ระบบการสื่อสารผ่านแสงนี้ถูกเรียกว่า Visible Light Communication (VLC) หรือการสื่อสารทางแสง หรือ แสงสื่อสาร โดยส่งสัญญาณออกไปสู่เครื่องรับทางแสงสว่างในรูปของความถี่และรับสัญญาณตอบกลับทางแสง Infrared หรือแสงใต้แดง ซึ่งการสื่อสารก็จะสามารถนำเอาไปใช้งานได้ในวัตถุประสงค์ที่หลากหลาย สำหรับงานวิจัยชิ้นนี้ได้ทดลองใช้ประโยชน์จากการสื่อสารผ่านแสงเพื่อวัตถุประสงค์ 3 ประการ คือ 1.แสดงข้อความบนจอ LCD เช่นแสดงป้ายราคาชนิดอิเลคทรอนิคส์ 2.เป็นระบบตอบรับความคิดเห็น (Voting System) และ 3. เป็นระบบรับส่งข้อมูลอุณหภูมิ และยังสามารถควบคุมความสว่างแต่ละดวงไฟได้อย่างอิสระตามการใช้งานได้อีกด้วย

ภาควิชา	วิศวกรรมไฟฟ้า	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมไฟฟ้า	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2558		

5470560321 : MAJOR ELECTRICAL ENGINEERING
KEYWORDS: LED DIMMER / ELECTRONICS PRICE TAG / VISUAL LIGHT COMMUNICATION / VISIBLE LIGHT COMMUNICATION / TIME DURATION CODING / INFRARED / ELECTRONIC VOTING SYSTEM / TEMPERATURE MONITORING

PAIRUSH LEELAWATCHARAKUL: LED DIMMING TECHNIQUE THAT SUPPORTS VISUAL LIGHT COMMUNICATION. ADVISOR: ASSOC. PROF. EKACHAI LEELARASMEE, Ph.D., 59 pp.

This research describes a design technique to control brightness of LED(Light Emitting Diode) light bulb that can be able to mix communication signal into visible light. This method is called Visual or Visible Light Communication (VLC) by put frequency in visible light and receives response back from receiver by Infrared. This method can be used for many various applications. In this research will test 3 applications, 1st Display message on LCD display via VLC for Electronics price tag, 2nd Application for Electronics Voting System and 3rd Application for temperature monitoring. Other feature is identically control brightness each LED light bulb for utility usage.

Department:	Electrical Engineering	Student's Signature	....
Field of Study:	Electrical Engineering	Advisor's Signature	....
Academic Year:	2015		

ACKNOWLEDGEMENTS

I would like to have my sincere thanks to my advisor, Prof. Ekachai Leelarasmee , for his kindly helps and suggestion. Even though I'm not a good student he still keep his effort to suggest me on track. And also others professor, Asst. Prof. Suree Pumrin, Asst. Prof. Wanchalerm Pora, Arjarn Boonchuay Supmonchai, for plenty of knowledge from them while I was studying.

CONTENTS

Page

THAI ABSTRACT iv

ENGLISH ABSTRACT v

ACKNOWLEDGEMENTS vi

CONTENTS vii

CONTENTS of FIGURE x

CONTENTS of TABLE xiii

CHAPTER 1 INTRODUCTION 14

1.1 Background information and the significance of the problem 14

1.2 Research objectives 17

1.3 Scope of this thesis 18

1.4 Brief methodology 18

1.5 Benefits 18

CHAPTER 2 What is Visible Light Communication (VLC)? 19

2.1 Analog signal VLC 21

2.2 Digital signal VLC 22

2.2.1 Li – Fi (Light Fidelity) 24

2.3 VLC Coding Technique 24

CHAPTER 3 CONCEPTUAL DESIGNED 26

3.1 LED Brightness control and transmit signal 26

3.2 Transmit Data Coding 27

3.3 IR Data Receiver 28

3.4 Receiver Data Coding 29

Page

CHAPTER 4 CIRCUIT DESIGN....30
4.1 Transmitter Circuit....30
4.1.1 Transmitter software....32
4.1.2 IR Receiver software....35
4.2 Receiver Circuit....37
4.2.1 VLC Sensor....38
4.2.1.1 LDR (Light Dependent Resistor) [2]....38
4.2.1.2 Photodiode....40
4.2.1.3 Phototransistor....41
4.2.1.4 Selected Photo Detector for VLC in this thesis....43
4.2.2 Receiver software....44
4.3 Hardware Specification....45
CHAPTER 5 TESTING....46
5.1 Testing on no data transmission....46
5.2 Transmit data 0x31 testing....47
5.3 Transmit error and effective length testing....48
5.4 Send infrared signal response back testing....51
5.5 IR Transmit error....52
5.6 Test Application....54
CHAPTER 6 SUMMARY and SUGGESTIONS....56
6.1 Summary....56
6.2 Suggestions....56
REFERENCES....57

Page

VITA....59

CONTENTS of FIGURE

Figure 1 The internal structure of an LED 14

Figure 2 Light Emitting Diode (LED) compared with other devices such as light bulb or fluorescent lamp. A LED has significant efficiency as well as life expectancy. 15

Figure 3 Compare data specifications between incandescent lamp, halogen lamp, Fluorescent lamp and LED lamp 16

Figure 4 Block diagram of the dimmable and VLC supporting LED 17

Figure 5 Brightness control technique, Left: Vary voltage, Right: High frequency switch on/off duty cycle 19

Figure 6 Visible Light Communication 20

Figure 7 Diagram to show roughly VLC Element..21

Figure 8 Analog Signal VLC diagram 21

Figure 9 Modulate frequency in analog signal..22

Figure 10 Under water communication that use analog VLC 22

Figure 11 Digital Signal VLC diagram 22

Figure 12 Shown famous modulation technique Amplitude Shift Keying (ASK), On Off Keying (OOK), Frequency Shift Keying (FSK)[7] 23

Figure 13 Light Fidelity (Li-Fi) [2] one kind of digital VLC that use SOLAR Cell to be sensor and power transfer. 23

Figure 14 Pulse Position Coding or Pulse Position Modulation (PPM)[9] 24

Figure 15 Frequency coding or Frequency shift keying (FSK)[7] 25

Figure 16 Inverse Pulse Position Coding[3] 25

Figure 17 Duty cycle control diagram 26

Figure 18 Duty Cycle 26

Figure 19 Data in duty cycle 50% 27
Figure 20 Transmit Data Coding...27
Figure 21 IR Response back signal diagram 28
Figure 22 Infrared Module Decoding 28
Figure 23 VLC Transmitter & LED Driver with IR Decoder diagram 30
Figure 24 Transmitter schematic 31
Figure 25 Left: Prototype circuit board, Right: Completed circuit board 31
Figure 26 Connection diagram for PC and transmitter 32
Figure 27 VLC Transmit Data Coding and Flow chart...33
Figure 28 Duty cycle control flow chart 34
Figure 29 LED Driver and IR Decoder diagram 35
Figure 30 LED Driver and IR Time Duration Decoder schematic 35
Figure 31 LED driver and circuit inside 36
Figure 32 Time Duration Coding 36
Figure 33 Time Duration Coding 37
Figure 34 Receiver Device circuit diagram 37
Figure 35 Receiver schematic...38
Figure 36 Completed Receiver circuit board 38
Figure 37 LDR Light Dependent Resister [2]..39
Figure 38 LDR Sensitivity 39
Figure 39 Visible spectrum...40
Figure 40 Brightness to Resistance transfer of LDR 1M Ohm......................................40
Figure 41 Fundamental Circuit of Photodiode (Without Bias) [11].............................41
Figure 42 Fundamental Circuit of Photodiode (With Bias) [11]...................................41

Figure 43 Photodiode Sensitivity 41

Figure 44 Fundamental Phototransistor Circuit 42

Figure 45 Phototransistor Sensitivity 42

Figure 46 Silicon NPN Phototransistor with $V\lambda$ Characteristics from OSRAM 43

Figure 47 SFH3410 sensitivity (most sensitive at yellow color) and transfer en characteristics 43

Figure 48 Transmitter signal and Receiver signal at Duty 5% (Up) and Duty 30% (Down). 46

Figure 49 Transmitter signal and Receiver signal at Duty 60% (Up) and Duty 70% (Down) both duty cycle occur noise high duty is high noise 47

Figure 50 Transmitter signal and Receiver signal at Duty 5% while send data 0x31 47

Figure 51 Transmitter signal and Receiver signal at Duty 30% while send data 0x31 48

Figure 52 Maximum duty cycle for transmit length..50

Figure 53 signal IR while send data 0x3A, 0x44, 0x41, 0x0D (ASCII “:DA<ENT>”) ...51

Figure 54 Detail signal from IR LED (Yellow) and output IR receiver module (Blue) 51

Figure 55 Testing IR transmit data error and approximate curve 53

Figure 55 Program for Test VLC 54

Figure 56 Application for testing Electronic Prices Tag 55

Figure 57 Application for testing Temperature monitoring..55

Figure 58 Application for testing Voting System 55

CONTENTS of TABLE

Table 1 Time measurement from rising edge to rising edge to coding data 36

Table 2 Hardware specification of VLC transmitter and receiver 45

Table 3 Test effective duty cycle for transmit length by sending "U" 450 bytes. 49

Table 4 Maximum duty cycle for transmit length. 49

Table 5 Testing IR transmit data error by sending data "U" 450 bytes. 52

CHAPTER 1

INTRODUCTION

1.1 Background information and the significance of the problem

Energy costs especially on electricity increases every year. One of the major power consumption is lighting. To reduce such cost there is a need for incandescent bulbs and fluorescent tubes to be replaced by LED (Light Emitting Diode) lamps. An LED is a semiconductor device that makes light emission upon passing electric current through it as shown in Figure 1

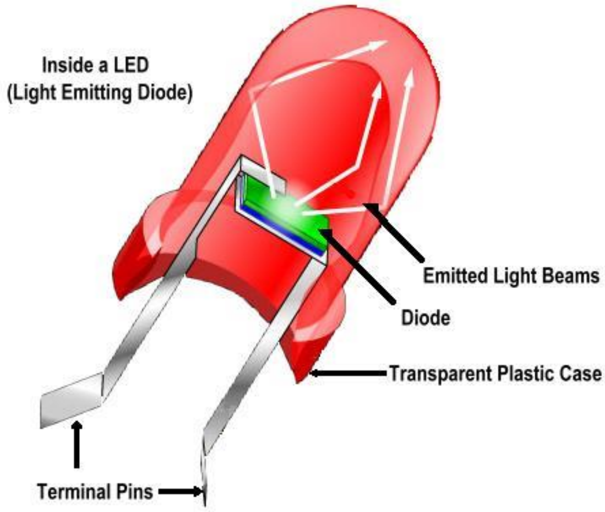

Figure 1 The internal structure of an LED

The LED is continuously improved in quality and brightness efficiency until it is competitive with fluorescent lamp. However the cost of LED is still high as shown in figure 2 and figure 3. The cost of LED can be decrease significantly via mass production.

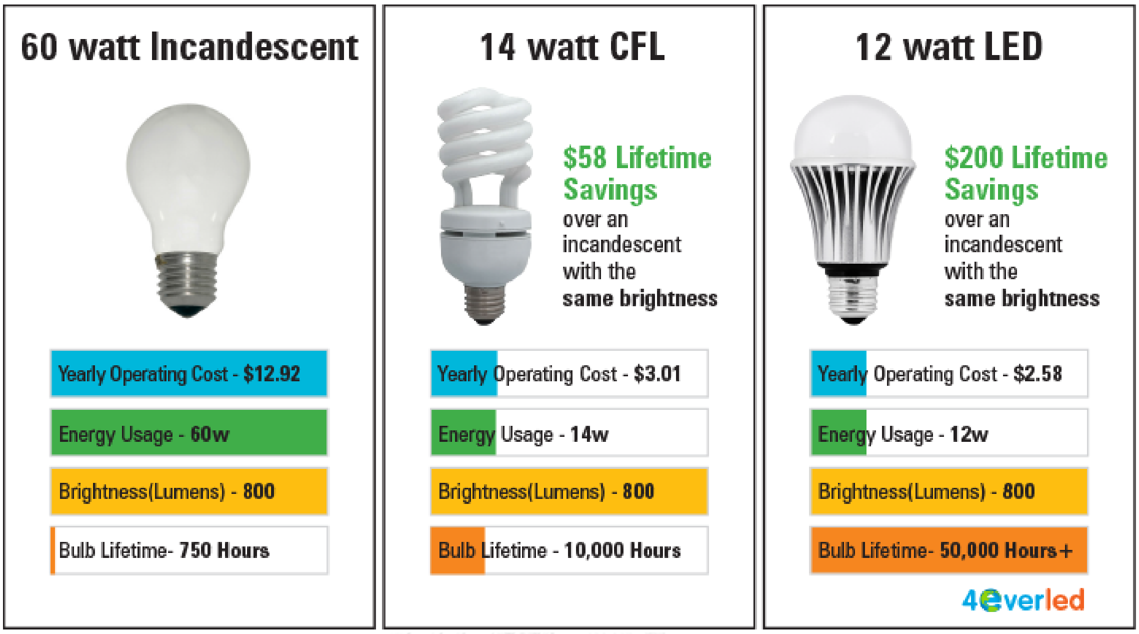

Figure 2 Light Emitting Diode (LED) compared with other devices such as light bulb or fluorescent lamp. A LED has significant efficiency as well as life expectancy.

From www.forbes.com

	INCADESCENT 60watt	HALOGEN 42watt	CFL 13watt	LED 11watt
Approximate Cost Per Year To Operate	Almost $5	$3.50	$1	$1
Light Output for a 60 Watt Equivalent	750 Lumens	750 Lumens	900 Lumens	830 Lumens
Hours Rated for Use	1000 Hours	1000 Hours	10,000 Hours	25,000 Hours
Average Price Per Bulb	50¢	$2.50	$4.95 - $8.95	$9.95 - $19.50
Ease of Dimmability	Easy	Easy	Special Bulb and Dimmer Needed	Special Bulb and Dimmer Needed
Instant On?	Yes	Yes	Some Warm Up to Full On	1/2 Sec. Delay to Full On
Disposability	Standard Trash	Standard Trash	Recycle at Many Locations	Recycle as Electronics
Use in Cold Climates?	Yes	Yes	Lower Light Output, Slow Start	Yes
Typical Color Appearance / Rendering	100 CRI	100 CRI	70-85 CRI	70-85 CRI
Color Options	2700 Kelvin	3000 Kelvin	Various Available	Various Available
Performance in Enclosed Fixtures	Yes	Yes	Only if Rated	Only if Rated
Light Dispertion	Omni-Directional	Omni-Directional	Omni-Directional / Dark Spots at Base	Some Omni-Directional / Can Have Dark Spots

Figure 3 Compare data specifications between incandescent lamp, halogen lamp, Fluorescent lamp and LED lamp

From www.creative-lighting-blog.com

Because of its energy efficiency, there is an increasing use of LEDs in building offices and houses for lighting. For further reduce of energy usage, it is advantageous to employ dimming in place where the brightness is in effect to various emotions such as in a museum, an art exhibition, a jewelry gallery or where sunlight can be utilized such as around window areas.

Recently, there is a new LED application area where visible light is used as a transmission channel in open space. This technique is called visual or visible light communication (VLC) [1]. The first successful implementation of the VLC is called Li-Fi [2]. The highest communication speed of 224 Gbps. has been demonstrated using a high speed LED. However a Li-Fi module (i.e., transmitter and receiver) is just a way of transmission and is basically a line of sight communication. Its cost is still high due to the fact that high speed communication needs high technology module where this technology is not in common commercial stage.

1.2 Research objectives

This thesis proposes a low cost lighting system that implements a dimmable LED lamp along with a capability of simultaneous data transmitting of a VLC at a moderate speed. It uses pulse width modulation for dimming light and frequency shift keying for data. These two functions are performed at a high speed making it invisible for bare human eyes. To make the VLC system two-way communication, a return path using conventional infrared LEDs is proposed. Its concept is shown in Figure 4.

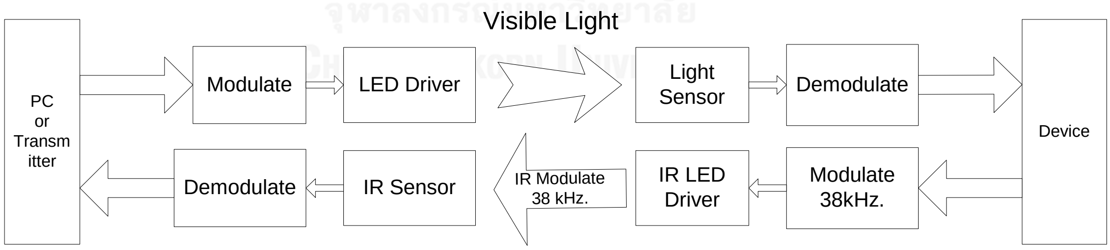

Figure 4 Block diagram of the dimmable and VLC supporting LED

Possible applications of the proposed works are

1) Traffic Information
2) Museum Application
3) Indoor Pager
4) Voting System

1.3 Scope of this thesis

1. To develop a circuit that can drive and control intensity of white color Ultra Brightness LED that can transmit low speed (5kbits/s – 10kbits/s) data communication to other devices and can receive IR data signal response back from devices.
2. To make a target device, namely, An Electronics Price tag for convenience store that can update product prices in real time.

Extended scope expectation

1. Temperature measurement and send temperature value via IR back to PC.
2. Voting system.

1.4 Brief methodology

1. Study characteristic of LED.
2. Study characteristic of photo detector.
3. Study visible light communication theory.
4. Design transmitter prototype and test result.
5. Design Receiver prototype and test result.
6. Design program visual basic for testing.
7. Design improved hardware and test.
8. Write thesis.

1.5 Benefits

1. To understand VLC in deeper details.
2. To get a real and hand-on experience on VLC usage.
3. To serve as a prototype that can extend VLC uses to various systems such as electronics label price, temperature monitoring, voting system.

CHAPTER 2

What is Visible Light Communication (VLC)?

Existing techniques for dimming LED is to control LED average current. Normal LED has its own forward voltage depending on materials used for LED coloring. For LED light emission, there is need for power supply of at least V_f (forward voltage). The brightness intensity of LED is controlled by current pasting through the LED. In this thesis the normal white light is used. The V_f of white LED is approximately 3.0 to 3.2 volt, where the internal resistance is approximately 7 ohms. There are 2 techniques to control the current. First method is to apply varying input voltage to LED with external resistance to change current up to maximum of approximately 30mA, depending on specification. However LED can be damaged if current input is over the maximum. Second method is to fix input voltage at high continuous current (not over the maximum limit of current) and to chop the input by putting frequency to control LED to be on and off (called duty cycle). This technique will be used throughout this thesis.

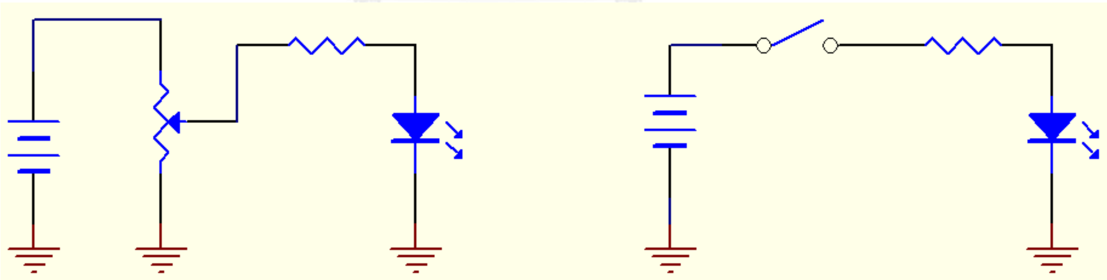

Figure 5 Brightness control technique, Left: Vary voltage, Right: High frequency switch on/off duty cycle

Visible light communication [1, 3-5] is a communication that is put into light source, fluorescent, LED etc. An application of VLC is shown in Figure 6. The figure shows example VLC used. The LED light that mixed with data can communicate with devices under lighting such as personal computer, PDA, laptop, printer or switch on/off control etc. This communication can not only be visible to human eyes but also can be sensed by electronics photo detector that converts very fast signal changes of brightness to analog signal output or digital data. Figure 7 is shown the operating principle of the system. The data is sent by PC via communication line such as RS485 or power line to transmitter. Then data is modulated as signals and drives LED bulb. After light with data is shined to photo sensor of device, the signal output will filter put noises and is amplified then demodulated to be data again before sending back to device. The device will take action to data command and response confirm signal via IR. The IR receiver module of transmitter demodulate IR signal to data and send to PC. There are 2 existing techniques for VLC, namely, analog signal VLC[6] and digital signal VLC[4].

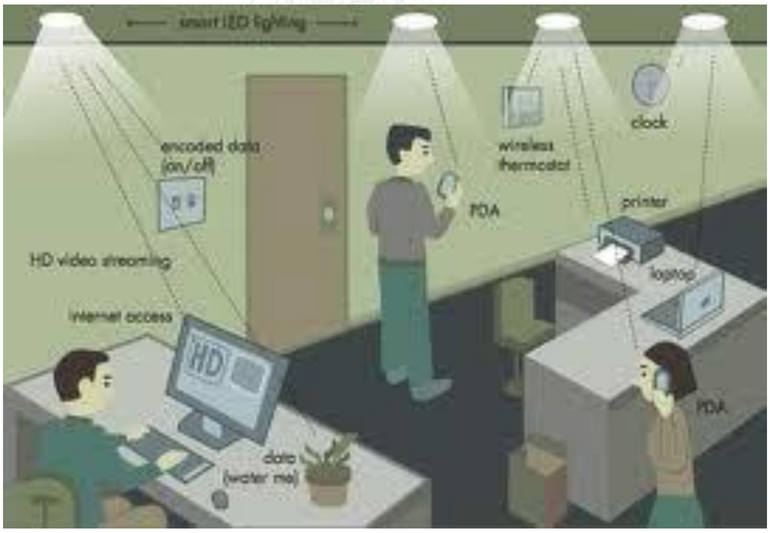

Figure 6 Visible Light Communication

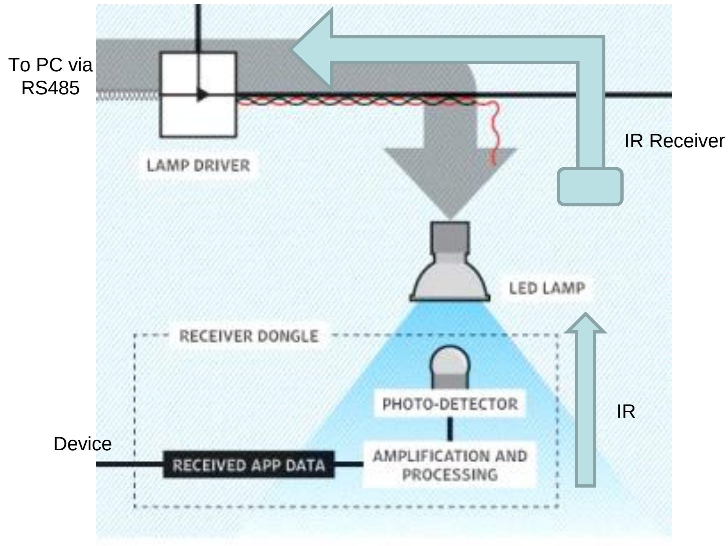

Figure 7 Diagram to show roughly VLC Element

2.1 Analog signal VLC

Analog VLC system uses light to transfer information in analog form. One popular implementation is shown in Figure 9. Here the input signal modulates a carrier of high frequency using a voltage to frequency (VOF) block as shown in Figure 8. The modulated signal drives LED transmitter to send out modulated light at high frequency that is human eye invisible. When the light that modulated is shined to the receiver sensor, it will sense the modulated signal and change back to analog signal again by using frequency to voltage (F to V) converter and then send amplified signal to output. (For example transmit video or sound signal via VLC.)

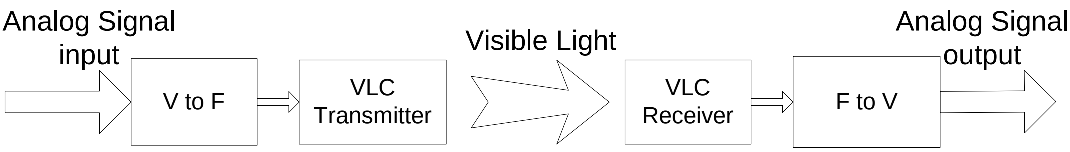

Figure 8 Analog Signal VLC diagram

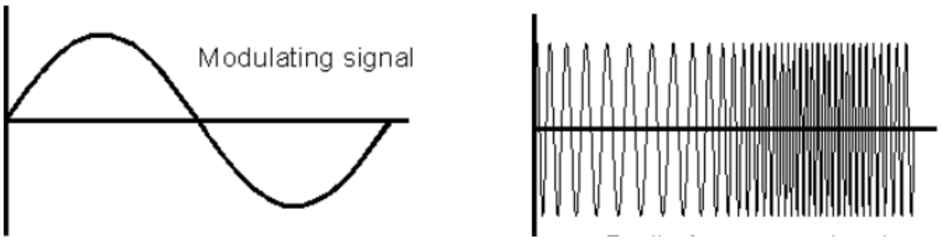

Figure 9 Modulate frequency in analog signal

Figure 10 Under water communication that use analog VLC

2.2 Digital signal VLC

By modulating frequency as well as analog but the various length of frequency is not much as analog because of the information sending in digital is binary data “0” and “1”. So it can use only 2 difference frequency. And then the receiver converts this 2 difference frequencies back to data again. For this thesis it is designed for sending digital information to show on display. So this method will be selected. Following figure 12 has shown some of famous binary modulation techniques

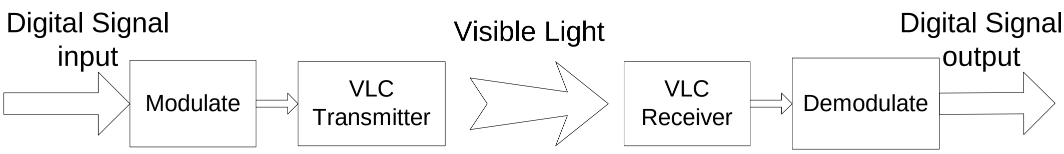

Figure 11 Digital Signal VLC diagram

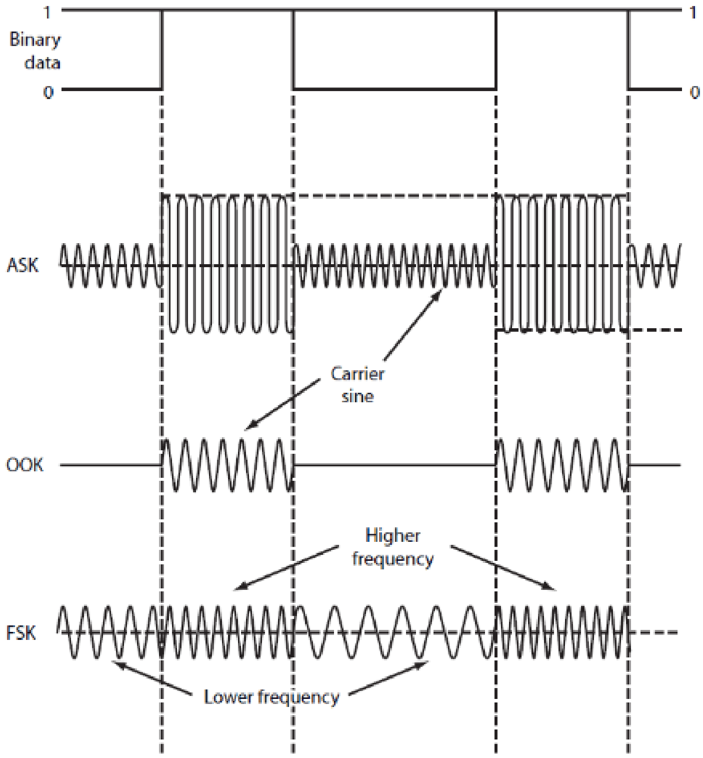

Figure 12 Shown famous modulation technique Amplitude Shift Keying (ASK), On Off Keying (OOK), Frequency Shift Keying (FSK)[7]

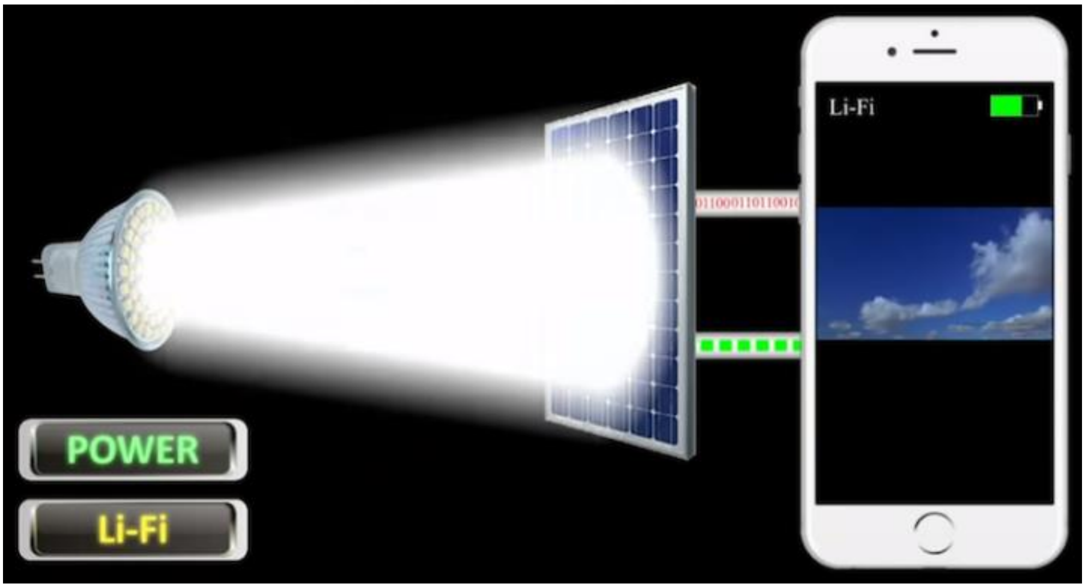

Figure 13 Light Fidelity (Li-Fi) [2] one kind of digital VLC that use SOLAR Cell to be sensor and power transfer.

2.2.1 Li – Fi (Light Fidelity)

Li-Fi (Light Fidelity) [4, 8] is the high speed two ways communication VLC (Visible Light Communication) that can transfer huge streaming data like internet, audio/video multimedia data. The speed can be increased by sending parallel data stream instead of serial streaming. The technique is to separate data into stream via prime color of Red, Green and Blue and to mix them together to white color. The receiver needs to use color filter to separate colors and demodulate signal separately then integrates data from each color together again. Thus Li-Fi can be increased on extremely high speed transfer data.

2.3 VLC Coding Technique

There are many techniques to decode digital signal VLC such as pulse position coding[9], inverse pulse position coding[3], frequency coding etc. However this thesis is designed to dimmable brightness while sending data at the same time. So the coding method needs to select the technique that can coding data while keeping certain brightness without any effects to transmit data.

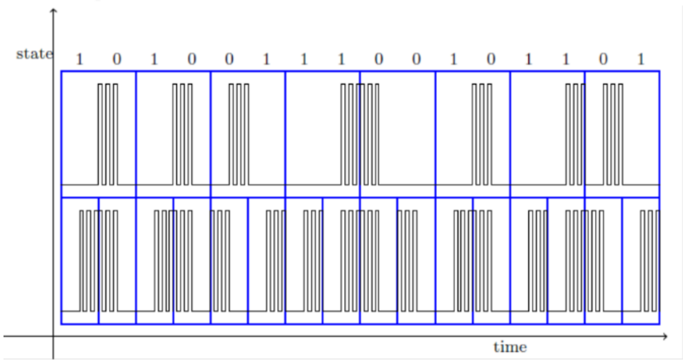

Figure 14 Pulse Position Coding or Pulse Position Modulation (PPM)[9]

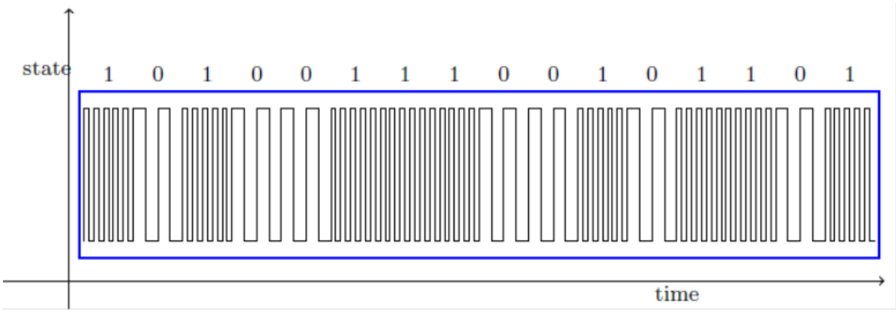

Figure 15 Frequency coding or Frequency shift keying (FSK)[7]

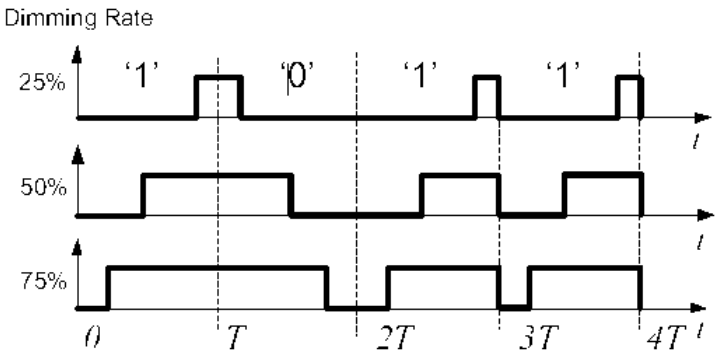

Figure 16 Inverse Pulse Position Coding[3]

CHAPTER 3
CONCEPTUAL DESIGNED

3.1 LED Brightness control and transmit signal

To control brightness of LED with fast response time characteristic of LED, we can use duty cycle technique by controlling on/off ratio in percentage. For example, to control duty cycle 10% it means switch on LED 1 time and switch off LED 9 times or on 1/10 of every cycle. And because of on and off it generates frequency of signal change. We can use this frequency to transmit data through the frequency by using frequency 10 kHz to transmit signal data “1” and 5 kHz to transmit signal data “0” which is Frequency Shift Keying (FSK) [7] technique as the following figure 18 and figure 19

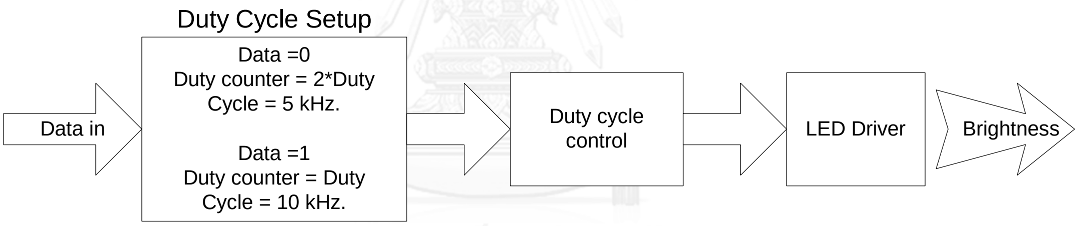

Figure 17 Duty cycle control diagram

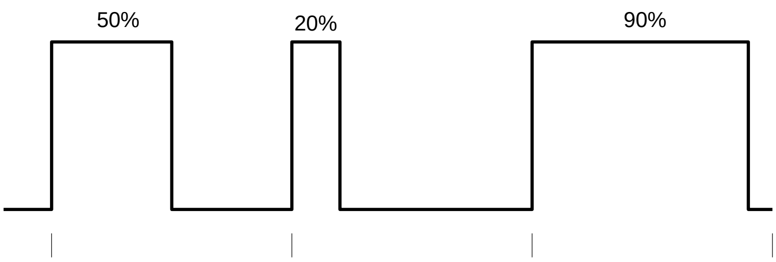

Figure 18 Duty Cycle

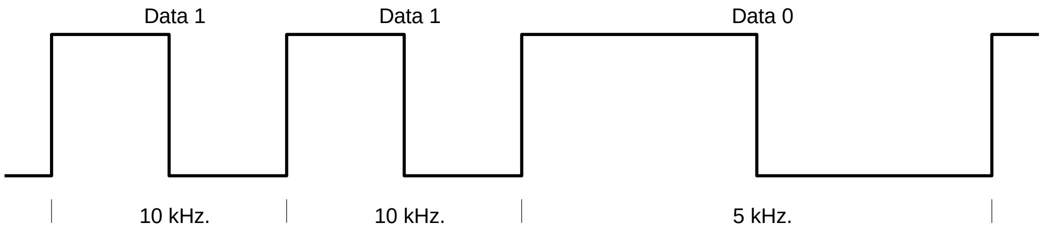

Figure 19 Data in duty cycle 50%

3.2 Transmit Data Coding

By determining the normal brightness or no transmit signal is always sending data signal “1” that means always sending frequency 10 kHz. When transmit data, it will start with sending start bit “0” following with 8 bits data from bit 0, 1, 2 until bit 7 and closing with stop bit “1”. It has same methodology as UART (Universal Asynchronous Receiver/Transmitter) [10] but different time interval, every UART data bit is fixed time interval called BAUD rate or every data bytes can calculated same transmit time but VLC transmit method in this thesis is not. The transmit data time is various to number of bit “1” and bit “0” maximum speed is occured when sending 0xFF is 10 kbps and minimum speed is when sending 0x00 is 5 kbps. Example is shown as following figure 20

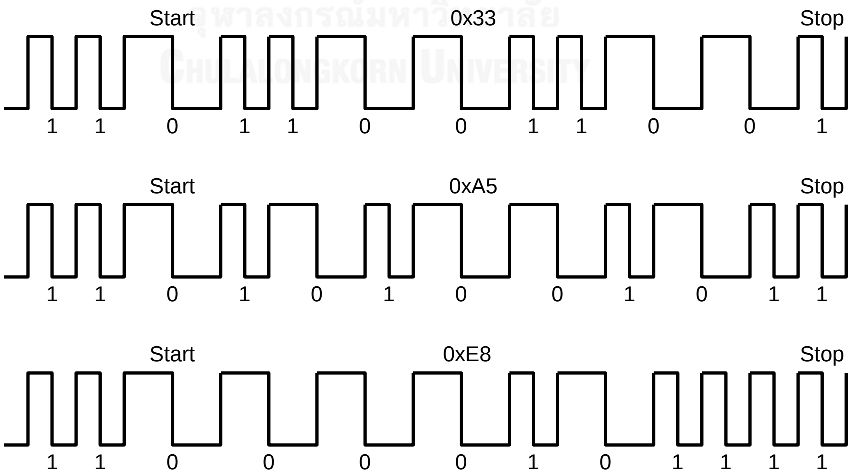

Figure 20 Transmit Data Coding

3.3 IR Data Receiver

To receive signal response back from devices by conventional infrared LED, the receiver of transmitter side is to receive data via infrared module that detects infrared frequency 38 kHz at least 15 pulse cycles to generate data signal “0” and no signal generate signal “1” as the following figure 21 and 22. By this frequency modification method, it will expand more effective length of receiving signal, because of Automatic Gain Control (AGC) of IR module can catch IR signal even though very small signal, but this decreases transmit data speed and the IR module is needed to add signal for training called preamble every time that transmit data. The technique that is used for detecting IR data is call Time duration coding that will be described later in IR Receiver software 4.1.2.

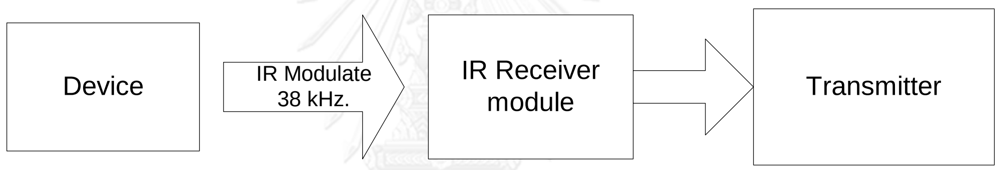

Figure 21 IR Response back signal diagram

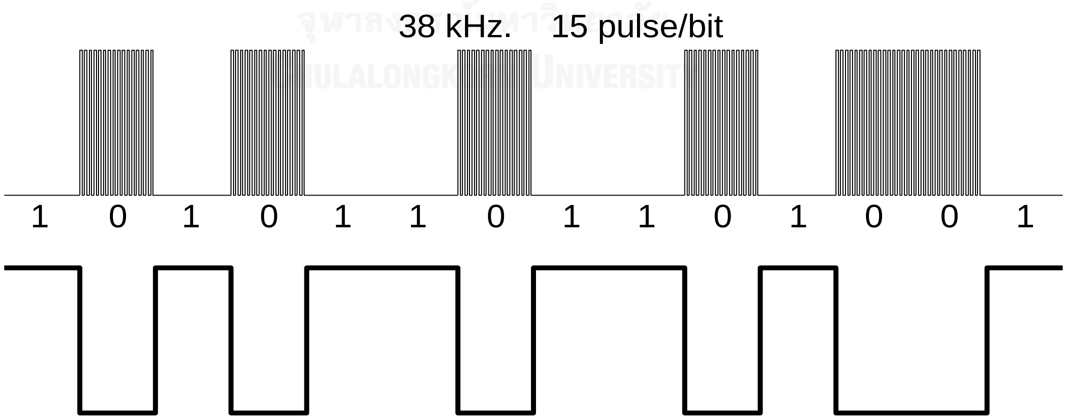

Figure 22 Infrared Module Decoding

3.4 Receiver Data Coding

From the reasons described previously, the infrared module needs preamble signal and demodulation method need time to operate. It causes to use technique that different to UART technique. We choose time duration coding method that used time interval decoding replace to direct data reading. By decoding a couple bit at a time for shortening decoding time as the figure 32 and the table 1 that will be described later in 4.1.2.

CHAPTER 4
CIRCUIT DESIGN

4.1 Transmitter Circuit

Transmitter circuit is designed to use Atmel MCU AT89LP4052 run at speed 24 MHz to control 4 sets of 2W. LED lamps each lamp has small circuit used PIC12F635 to receive infrared signal working for Time Duration Decoder. This main circuit work as a ballast connect to 12V. 1A. power supply and communication circuit RS485 that can communication with multi devices as multi drop type by a single couple wire. And connect with RS485 to RS232 decoder for connecting with PC communication port.

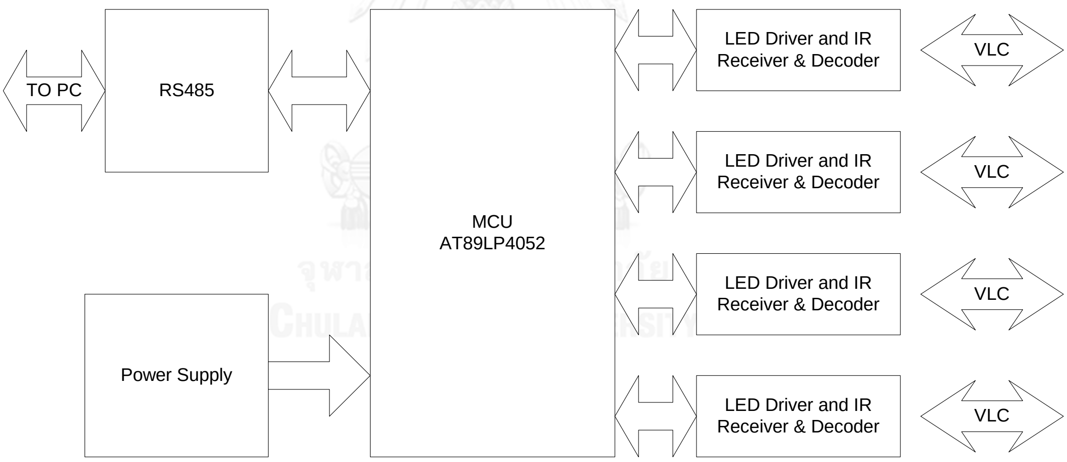

Figure 23 VLC Transmitter & LED Driver with IR Decoder diagram

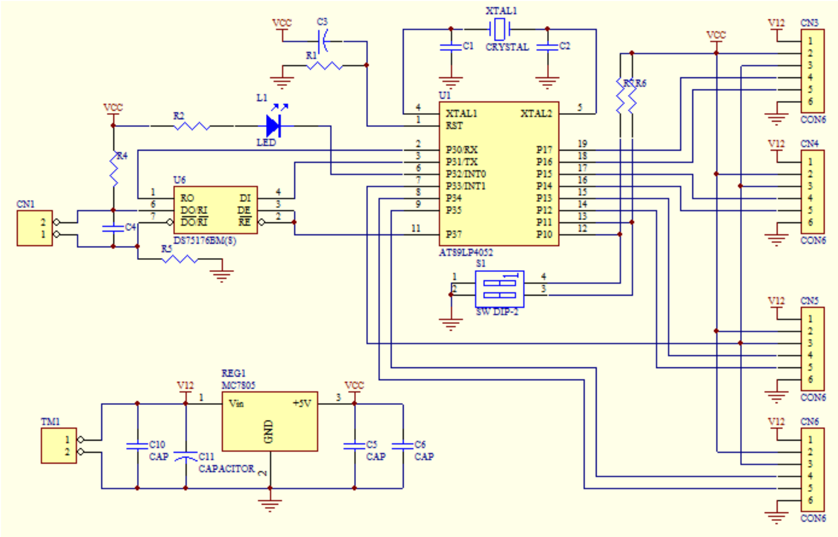

Figure 24 Transmitter schematic

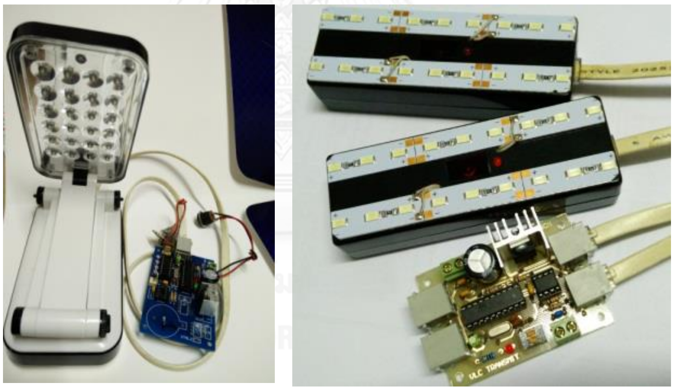

Figure 25 Left: Prototype circuit board, Right: Completed circuit board

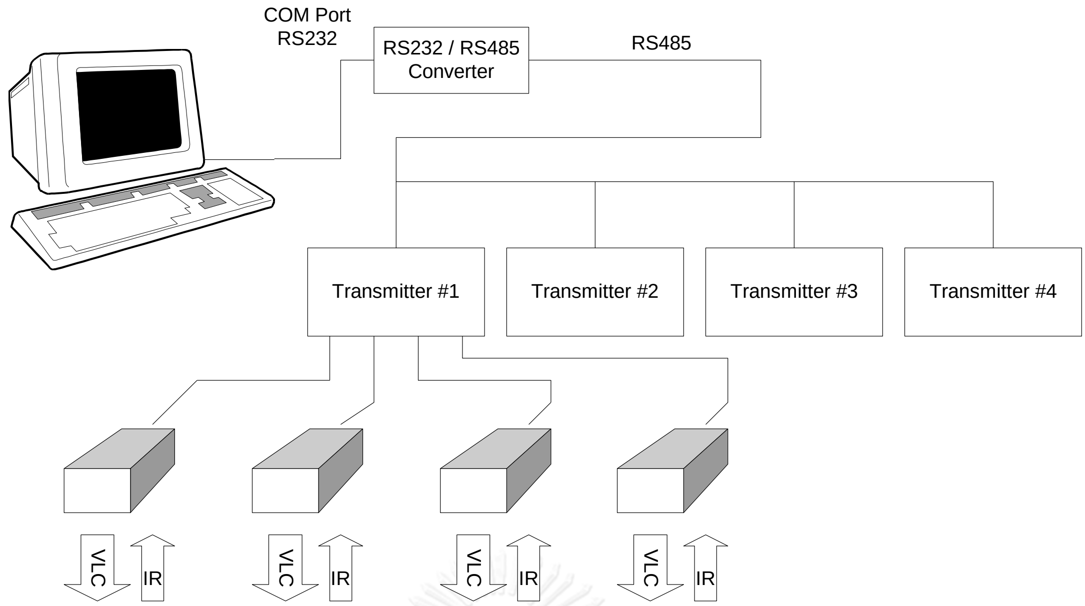

Figure 26 Connection diagram for PC and transmitter

4.1.1 Transmitter software

Software that is written to run in any MCU in this thesis is assembly language and most technique in use is timer tick. The program is separated to 2 main parts, first is Timer interrupt and second is normal program that sticky run in serial communication utility. Time base of interrupt timer in MCS51 (AT89LP4052) is 4.167 micro sec. or 240 kHz. that generate 10 kHz. x 24 slots of duty cycles. Each cycle controls 4 isolated ports that drive 2W LED consisting of 18 LEDs in strip line PCB that can change duty cycle from 0 (switch off) to 24 (full time on). The effective duty cycle that can be used for VLC is 1 slot time (4.16%) to 13 slots time (54.16%). For 1 slot time, the transmit data distance is not far, approximatly 1 meter, because of brightness is not enough to transmit to sensor. For the slot time over 13 the brightness is very good but signal from receiver has so much disturbing noise, making the data coding error. So the most effective slot time is 10 or 41.16% duty cycle to 12 or 50% duty cycle. The highest distance is longer than 10 meters testing under 36W fluorescent lamp.

All 4 isolated ports are always transmitting the same data 8 bits at a time. It will normally send “1” (10kHz.) when no data transmitted, it will generate start bit with “0” (5kHz.) and follow with 8 bits data least significant bit first and end with stop bit “1” (10kHz.). This method is the same concept as normal serial communication UART, the difference is bit data interval time. Serial UART is fixed time interval called BAUD rate, for example most famous used is 9600, 4800. But this thesis uses varying interval bit data interval on data sending 0xFF communication rate is 10k BAUDs and if data is 0x00 communication rate is 5k BAUDs.

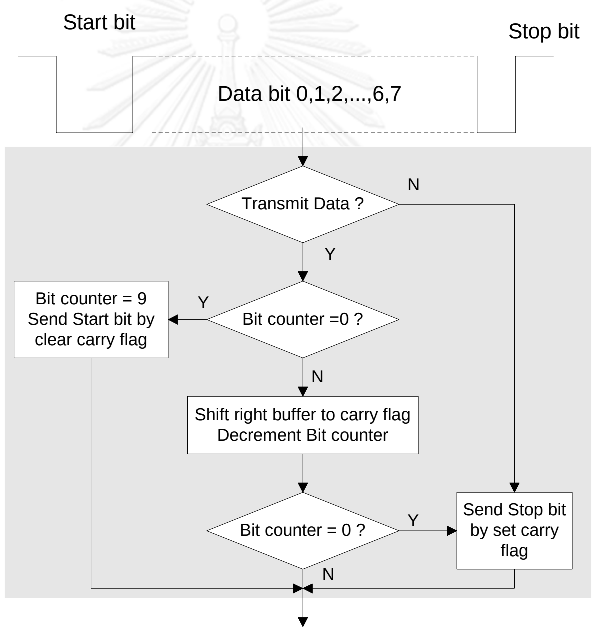

Figure 27 VLC Transmit Data Coding and Flow chart

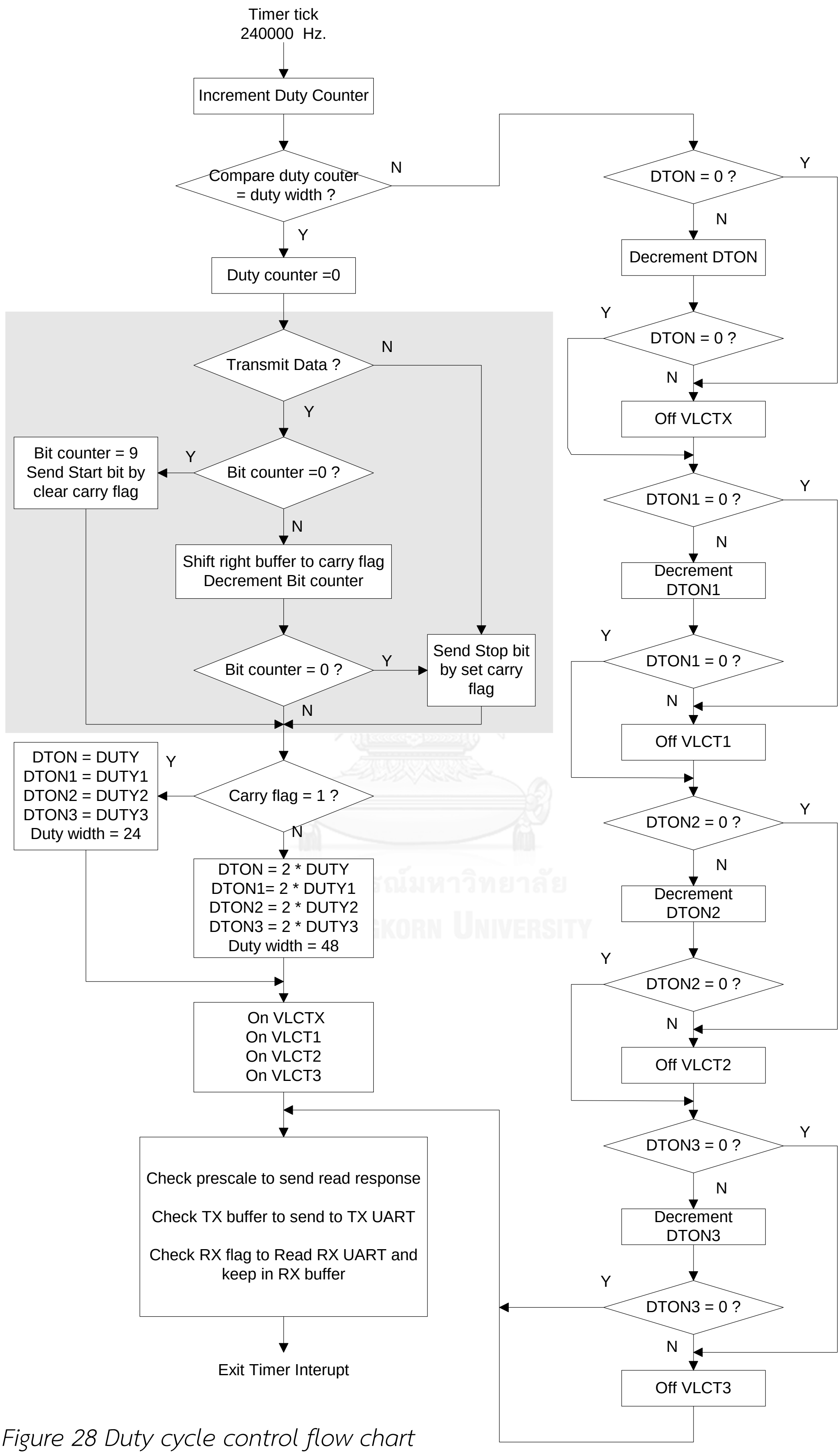

Figure 28 Duty cycle control flow chart

Other features of Transmitter controller is RS485 serial communication part that is designed for using a single twist pair wire to connect with 4 set of transmitter by multi drop connection. Each controller is addressed by set 2 bits dip switch from 00 to 11 than means address 1 to 4. This communication wire will connect RS485 to RS232 converter and RS232 will connect to PC COM port for any application program.

4.1.2 IR Receiver software

Because of Transmitter is to handle 4 isolated Lamps, it causes problem about time interval decoder MCU speed cannot handle all 4 ports on time. So I dedicated a small MCU PIC12F635 for keeping reading signals from IR module and checking time interval from rising edge to rising edge by starting with preamble state for training IR module.

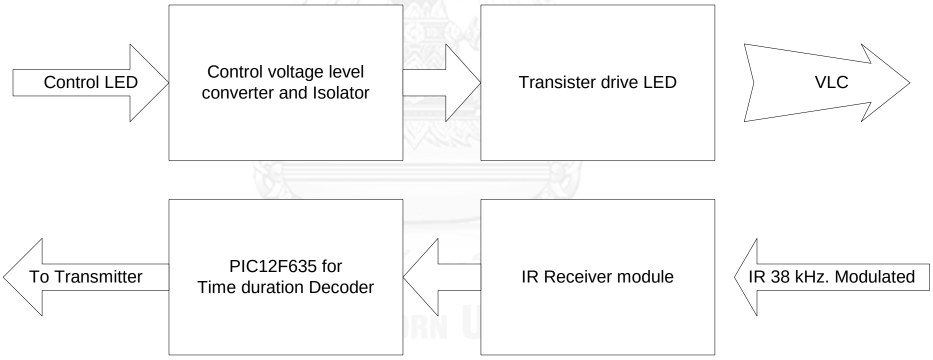

Figure 29 LED Driver and IR Decoder diagram

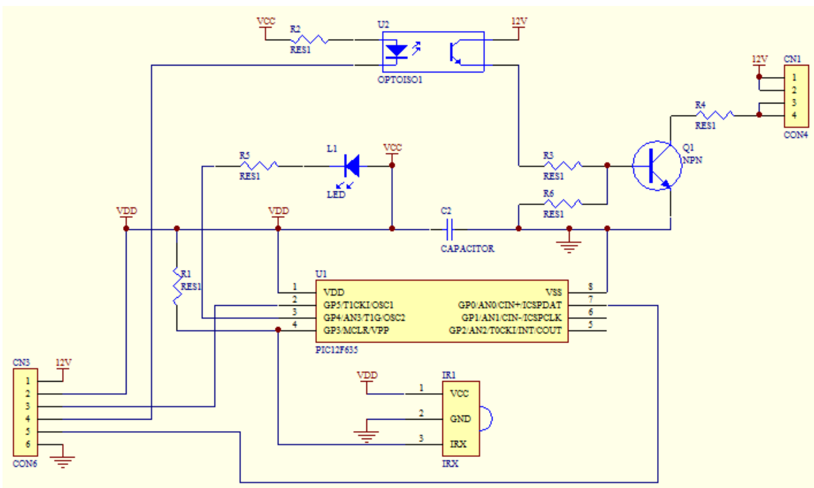

Figure 30 LED Driver and IR Time Duration Decoder schematic

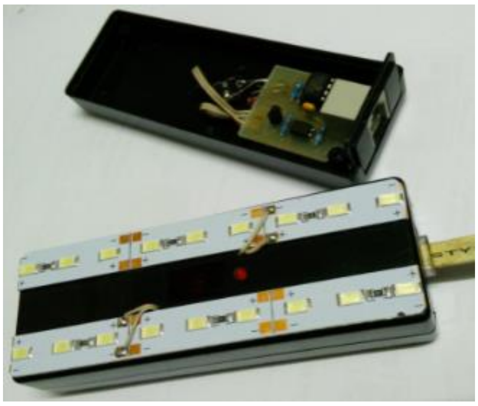

Figure 31 LED driver and circuit inside

After receiving rising edge MCU PIC12F635 will start counting time and when next rising edge found. It will read counting time to calculate time interval and code to be a couple bit of data as shown in figure 32, by the detail describe in table 1 and then start next count again for next rising edge. By the interval count from the first start pulse if MCU gets 4 pulses or rising edge that means getting 8 bits data and MCU do this same thing 4 times will get 4 bytes at time as the following figure 33. Preamble width is 2 ms and start bit is 0.7 ms.

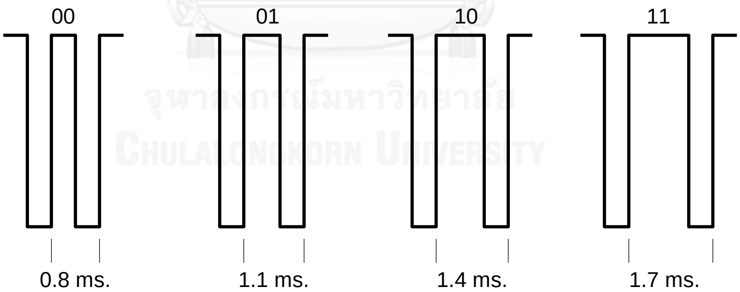

Figure 32 Time Duration Coding

Table 1 Time measurement from rising edge to rising edge to coding data

Time interval from rising edge (ms.)	Decoding (2bit)
0.8	00
1.1	01
1.4	10
1.7	11

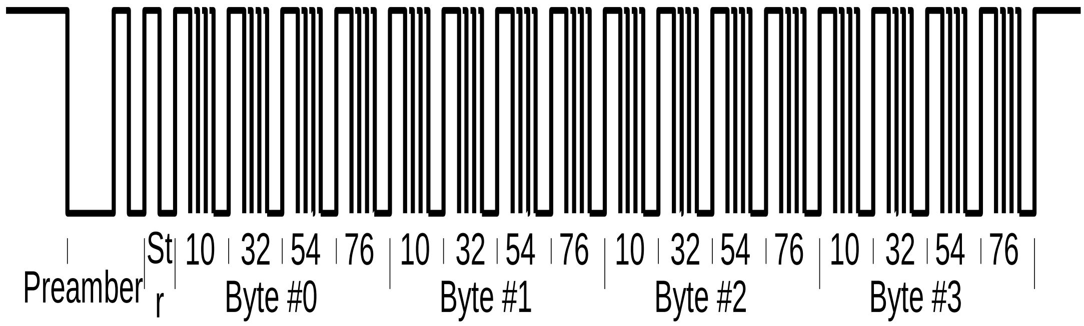

Figure 33 Time Duration Coding

4.2 Receiver Circuit

Receiver circuit is designed to use Microchip MCU PIC16F688, control LCD display 16 characters 2 lines by serial LCD technique, input 2 push button switch and input one-wire temperature sensor ds1820 from Dallas, visible light sensor used photo transistor SFH3410 to sense signal change of light pass through filter and amplified by Universal Quad Op-amp LM324. The last thing is IR LED driver to send response signal 38kHz. back to the transmitter.

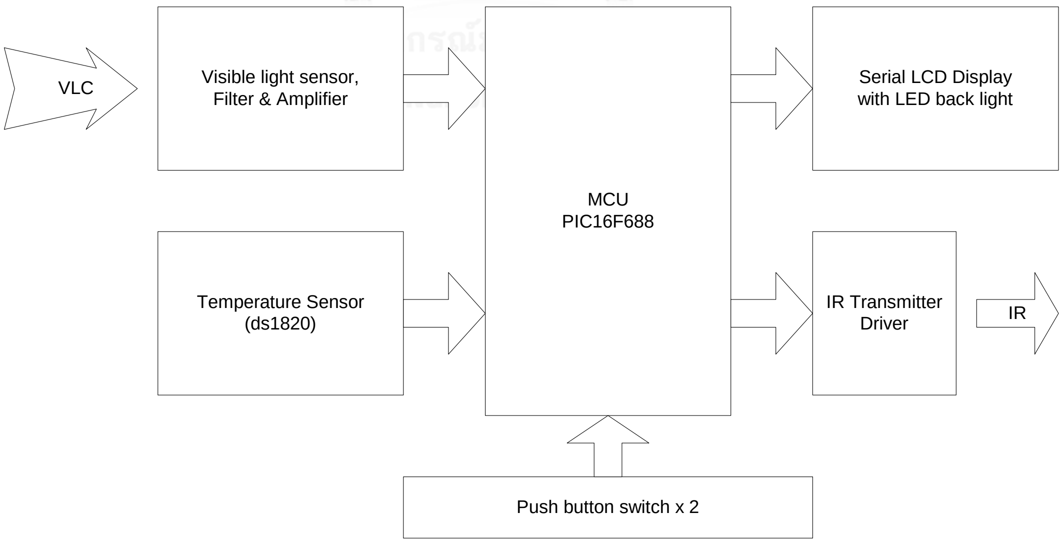

Figure 34 Receiver Device circuit diagram

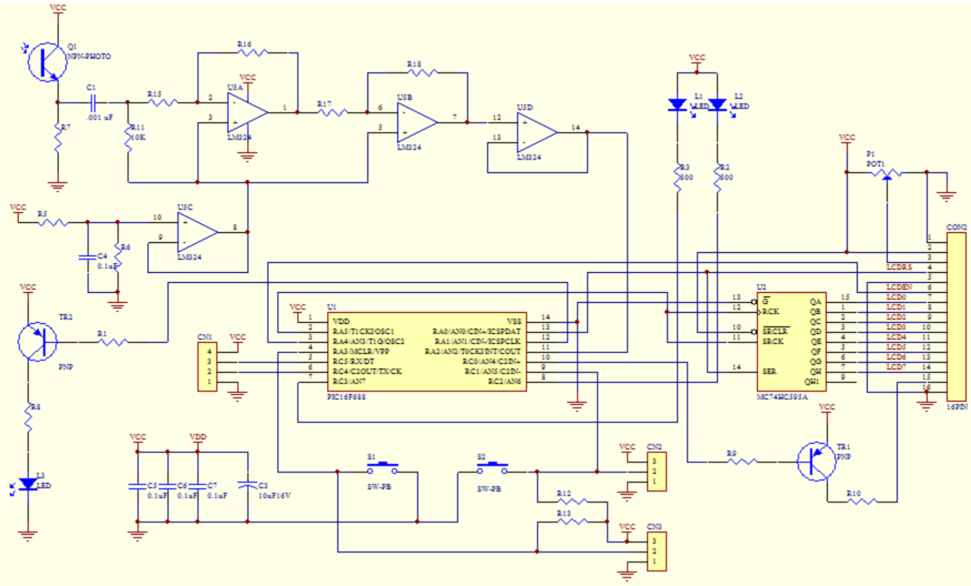

Figure 35 Receiver schematic

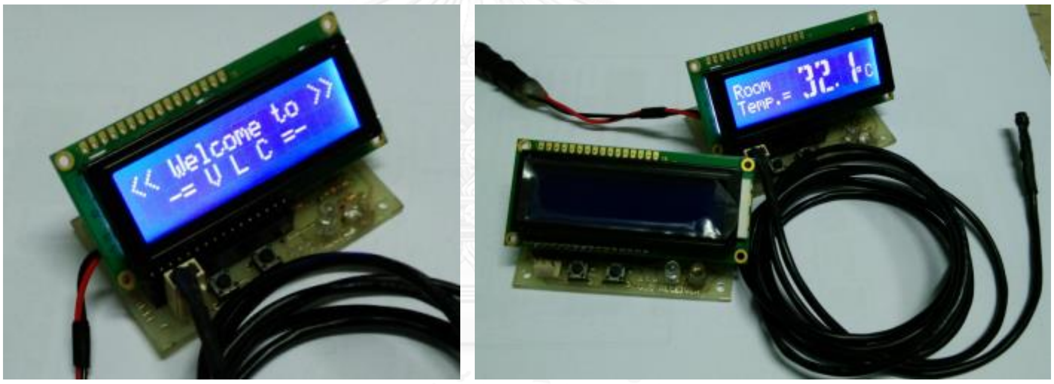

Figure 36 Completed Receiver circuit board

4.2.1 VLC Sensor

Light sensor is the most important component part of VLC. But there are various types of sensor and the sensors are effective in various spectrum of light. The types of sensors that selected are described below.

4.2.1.1 LDR (Light Dependent Resistor) [2]

LDR or Light dependent Resister is the inversely dependent resister that changes on light intensity shined on it. It is famously known as photo resistor or photoconductor. LDR has 2 type produces from Cadmium Sulfide

(CdS) and Cadmium Selenide (CdSe). Most of LDR is CdS type that sensitivity is in visible light of mostly green color. The CdSe can also use to sense visible light but the sensitivity is shift to IR zone of mostly red color as the figure 38. Because of LDR characteristic is resister that changes inversely depending on intensity. Resistance is highest in dark and lowest brightness. The simple circuit to sense light is voltage divider that causes nonlinearity problem and occurs delay signal about 30 msec frequency response in high frequency should be concerned. However sensitivity of LDR is very good.

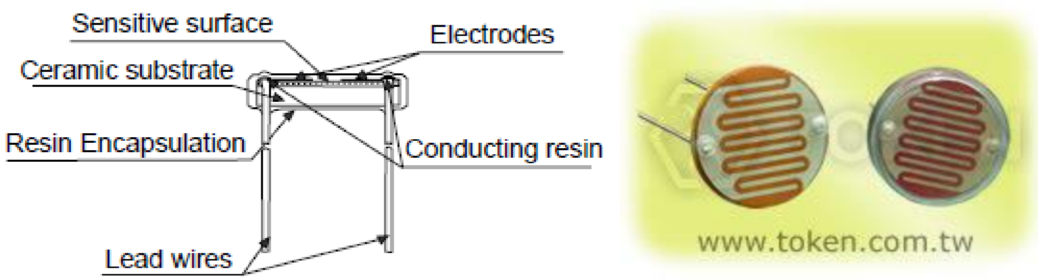

Figure 37 LDR Light Dependent Resister [2]

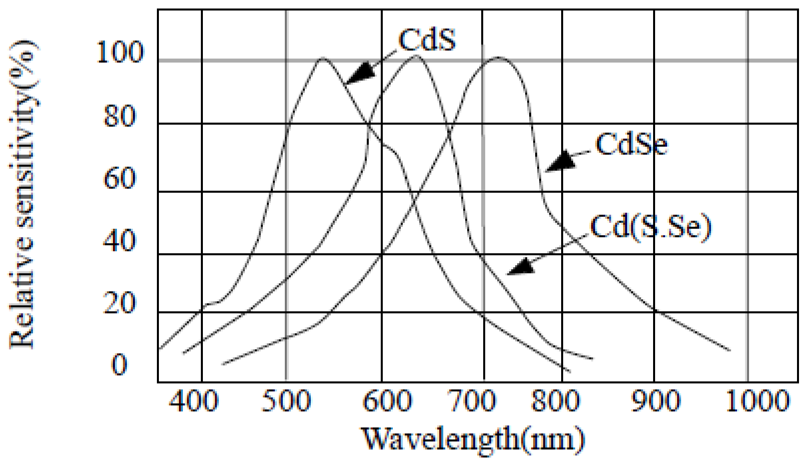

Figure 38 LDR Sensitivity

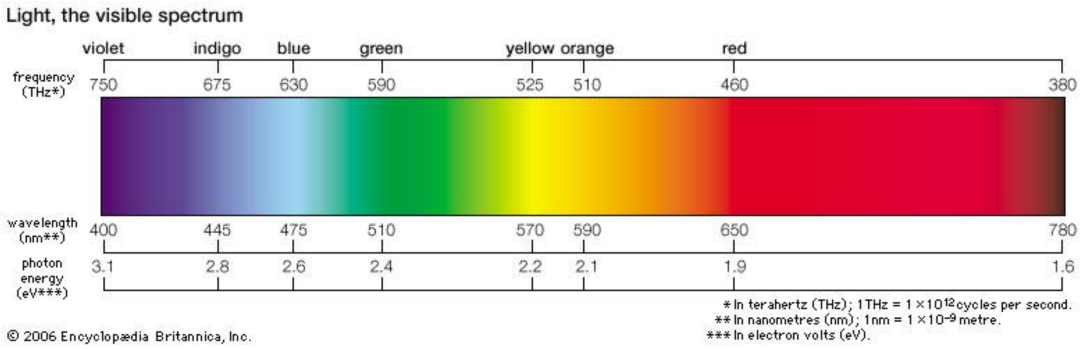

Figure 39 Visible spectrum

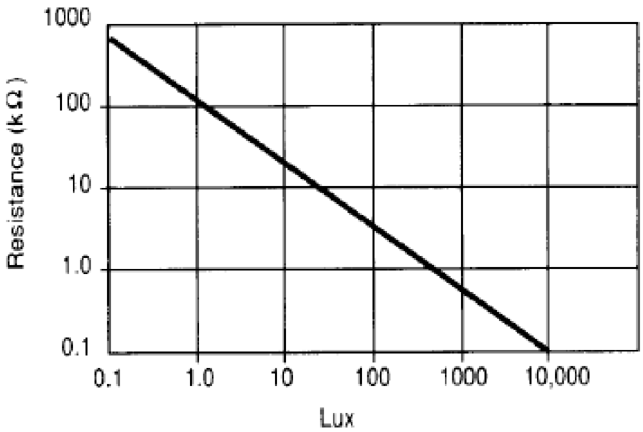

Figure 40 Brightness to Resistance transfer of LDR 1M Ohm.

4.2.1.2 Photodiode

Photodiode is made of semiconductor that can absorb photons and convert to current without bias. A small photon current will related to brightness as figure 42. The output voltage is given $V_{OUT} = I_P \times R_L$. This utilizes the photovoltaic effect by increasing the photodiode area, it will be the basis of photovoltaic cell or solar cell. However photodiode is most sensitive in infrared area, to use this device should consider the target wavelength.

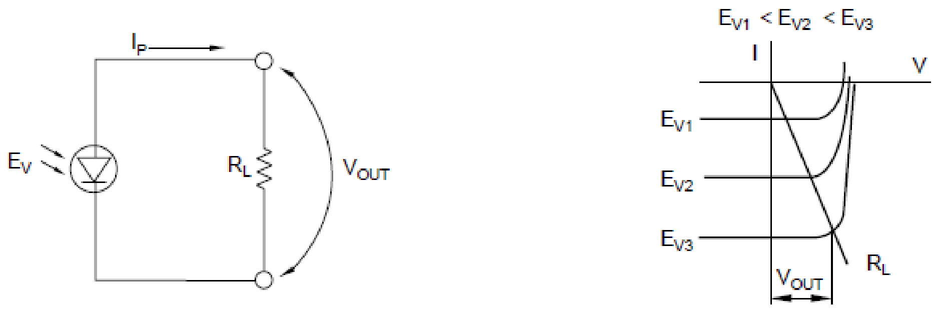

Figure 41 Fundamental Circuit of Photodiode (Without Bias) [11]

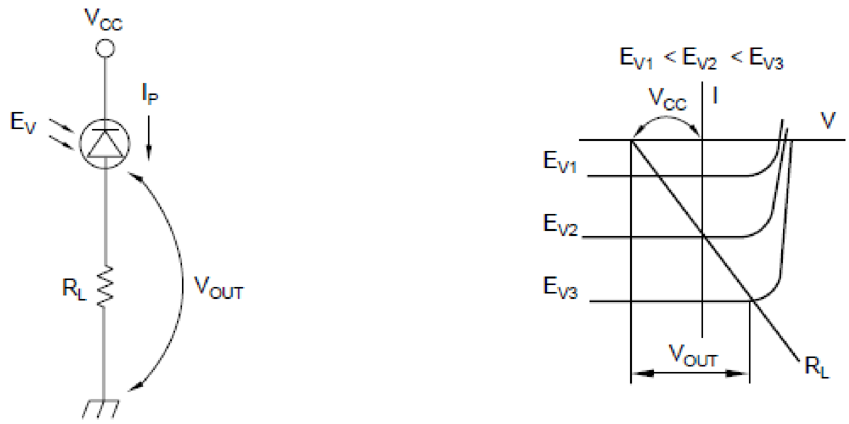

Figure 42 Fundamental Circuit of Photodiode (With Bias) [11]

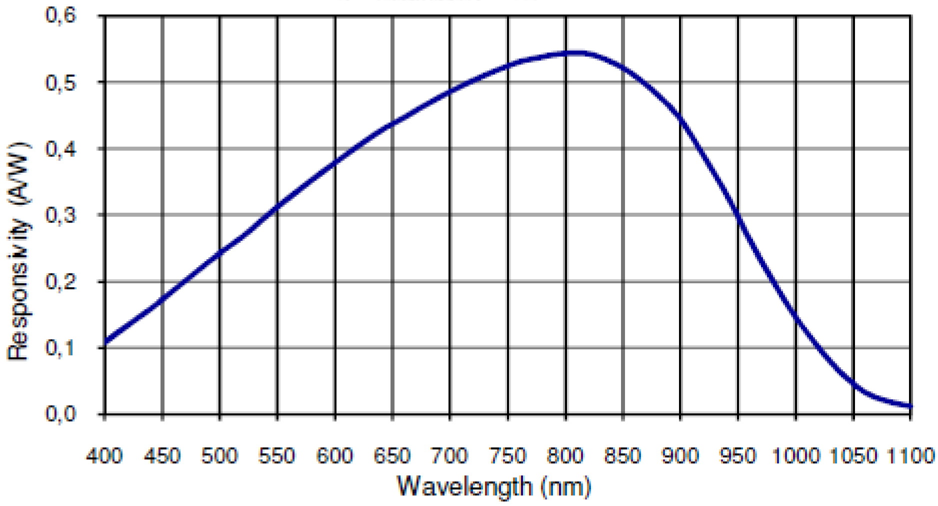

Figure 43 Photodiode Sensitivity

4.2.1.3 Phototransistor

Phototransistor is transistor that when light is incident on base of transistor, the electrons that are generated by photons at base-collector junction of transistor causes the output to change by the current that is driven by corrector and emitter of transistor. It causes higher sensitivity than photodiode. However most of phototransistor are sensitive to infrared area that still need to consider about target wavelength.

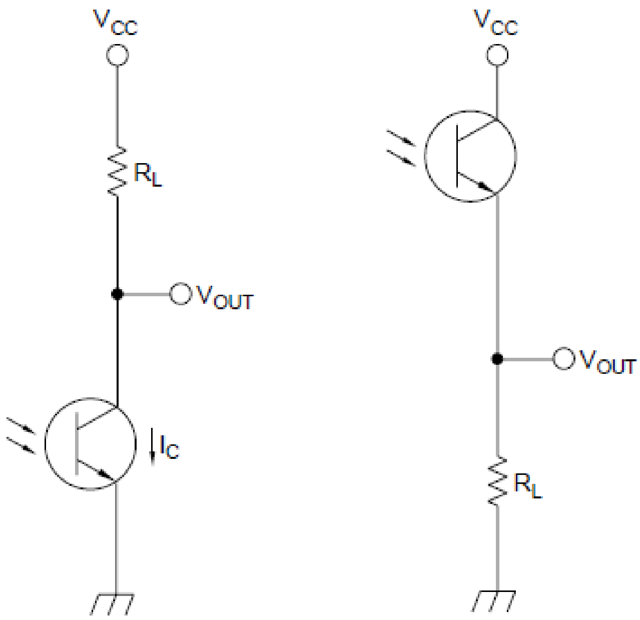

Figure 44 Fundamental Phototransistor Circuit

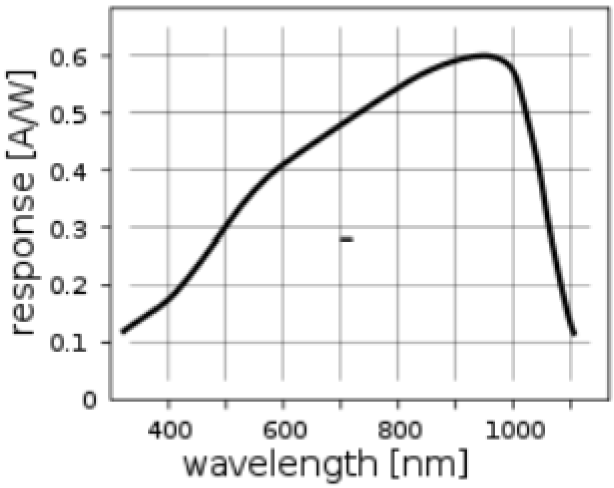

Figure 45 Phototransistor Sensitivity

4.2.1.4 Selected Photo Detector for VLC in this thesis

After searching through the datasheet and working on Thai electronic component market. I found the interested type that match wavelength of visible zone. That was LDR and phototransistor especially in SFH3410 from OSRAM [12] . After testing hardware and bringing signal to show on oscilloscope, the finding was that SFH3410 had a bit better signal than LCD. After I did optical improvement by cutting the head of LED and glue on top of SFH3410, it could increase effectiveness on receiving distance up to longer than 10 meters.

Figure 46 Silicon NPN Phototransistor with V_λ Characteristics from OSRAM

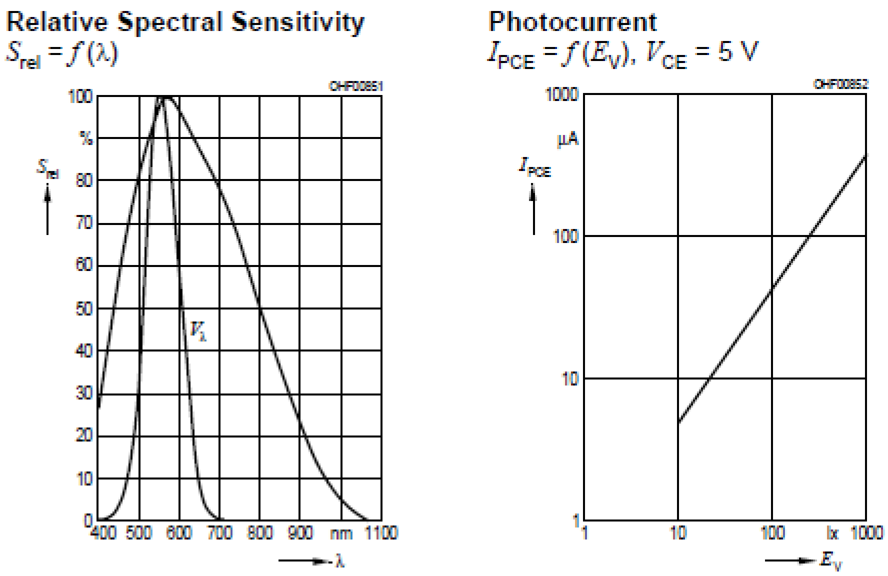

Figure 47 SFH3410 sensitivity (most sensitive at yellow color) and transfer en characteristics

For the first prototype, the light sensor is used LDR 10kOhm type. After being filtered and amplified the signal output can get result the same as sensor SFH3410 but the effective length of SFH3410 is better than LDR. And after improving sensor by adding lens on top of SFH3410, by cutting LED's lens and glue on SFH3410, the effective length is increased twice to normal. The signal will go to PIC16F688 input port using falling edge to trig interrupt program and then count interval time from falling edge to falling edge and change the interval to data. After receiving signal the receiver then search for start bit "0" and follow with 8 bits of data, most significant first, end with stop bit "1". The stream data byte after receive will be compare with protocol that control output or do some other missions.

4.2.2 Receiver software

The receiver controller can control serial LCD by using shift register 74HC595 that shift stream data and latch to parallel that can control LCD module. This LCD will be used for showing message such as price tag or label price, temperature monitoring, voting system or even view data that were sent directly by VLC.

The receiver has 2 push button switches used for many purposes. There are 4 combinations of the switches control.

1) Click
2) Click and hold 3 sec.
3) Double click
4) Double click and hold

At first the receiver needs to setup address by pushing double click hold on left button then to set address by right button, click for address increment, double click to address decrement if click hold or double click hold it will fast increment/decrement.

After setting up address already the receiver can be accessed or controlled via VLC under lamp. And also use click left button to control dimming lamp down and double click to switch off lamp, click right button to dim lamp up and double click to switch on lamp. And click hold left button to show temperature.

4.3 Hardware Specification

Table 2 Hardware specification of VLC transmitter and receiver

Parameter	Value	Unit
No. LED lamp	4	lamp
LED lamp power	2.1	Watts
No. LED per lamp	18	bulbs
Communication downstream	5k. to 10k.	Bits/sec.
Communication upstream	1k.	Bits/sec.
Communication with PC	RS485/9600	Bits/sec.
Transmitter power consume with 4 lamps on (100%)	12	Watts
Transmitter addressing	4	address
Receiver addressing	255	address
VLC Receiving distance	> 10	meters
IR Receiving distance	1.5	meters

CHAPTER 5

TESTING

5.1 Testing on no data transmission

The assembly the hardware has been finished. The completed board was tested on driving of LED lamp (Active low or low logic means the lamp is on) and on sensing signal from the receiver at distance of 1 meter from the LED lamp after the signal passed through amplifier part and catch signal to show on digital oscilloscope as the figure 47. The upper yellow color line shows signal from transmitter and the lower blue color line shows signal from receiver.

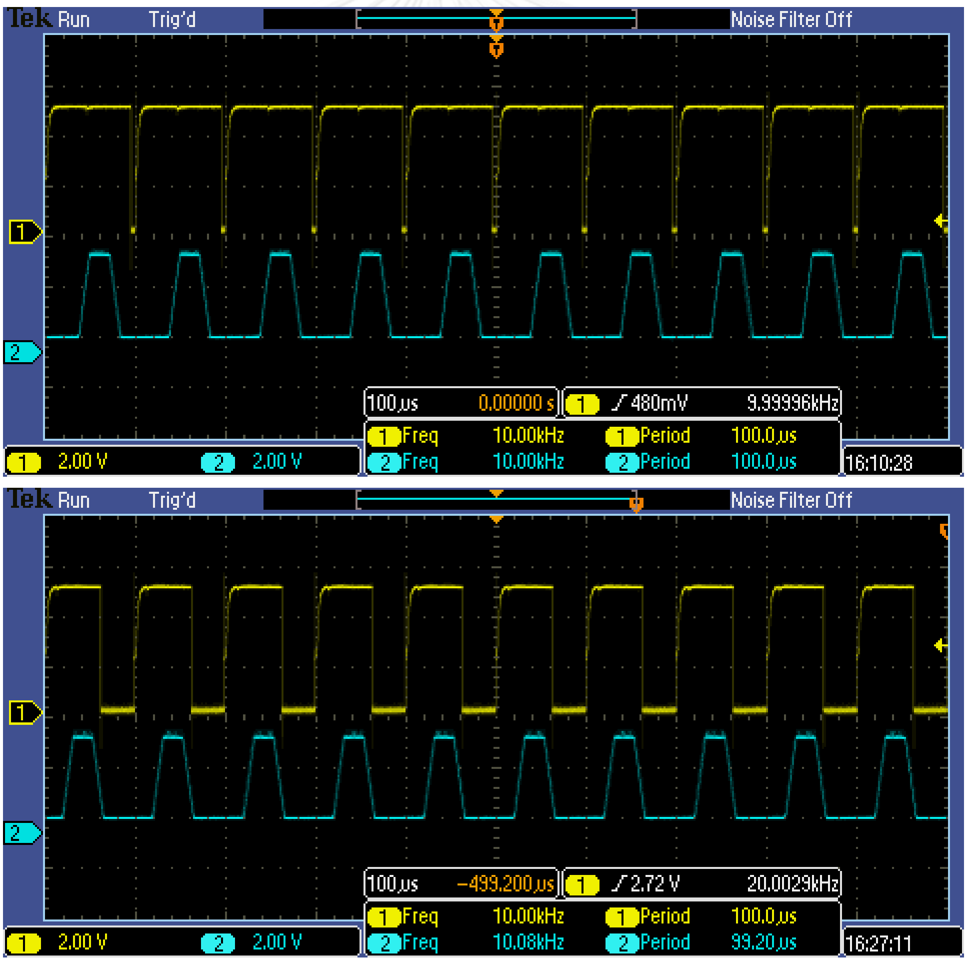

Figure 48 Transmitter signal and Receiver signal at Duty 5% (Up) and Duty 30% (Down).

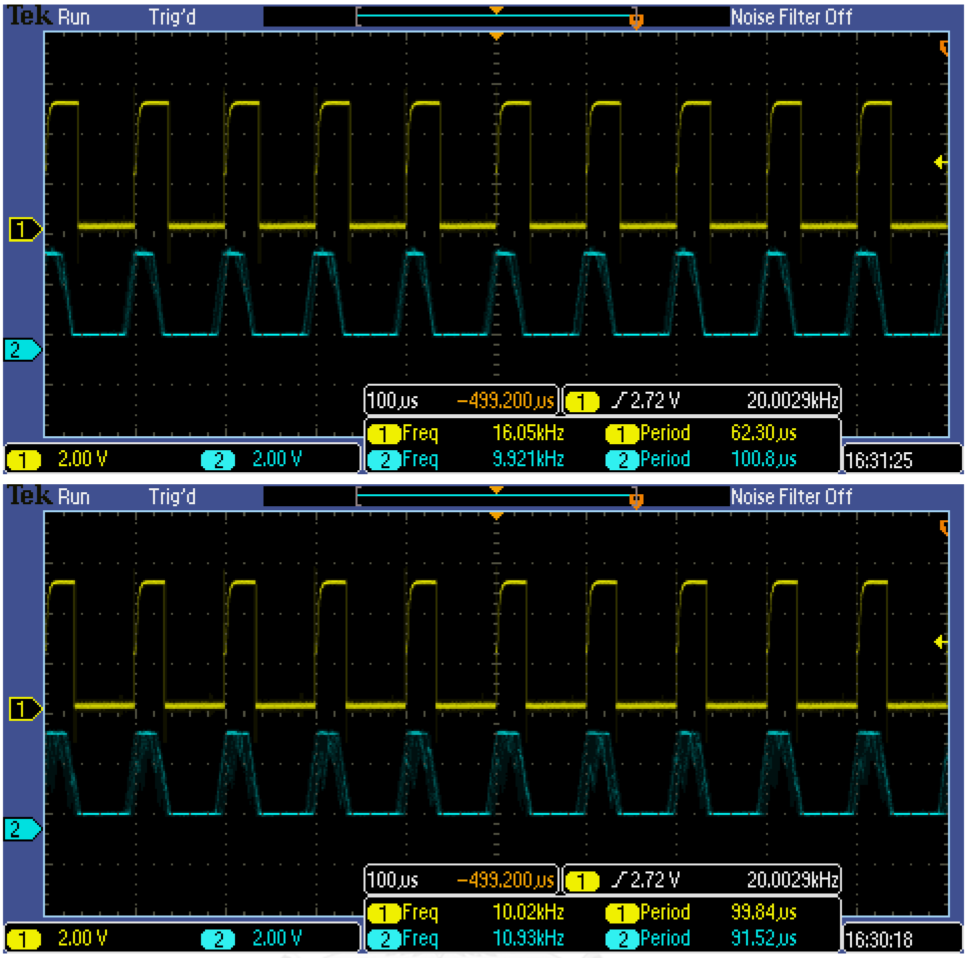

Figure 49 Transmitter signal and Receiver signal at Duty 60% (Up) and Duty 70% (Down) both duty cycle occur noise high duty is high noise

5.2 Transmit data 0x31 testing

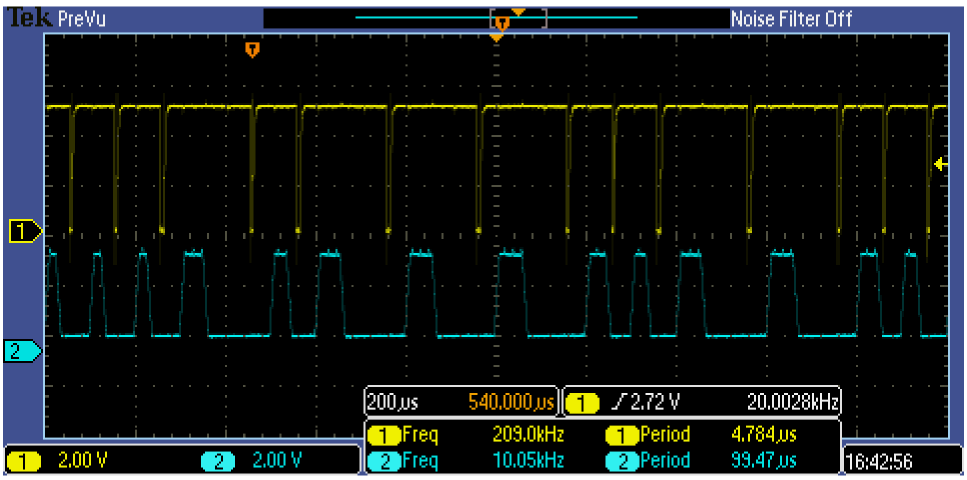

Figure 50 Transmitter signal and Receiver signal at Duty 5% while send data 0x31

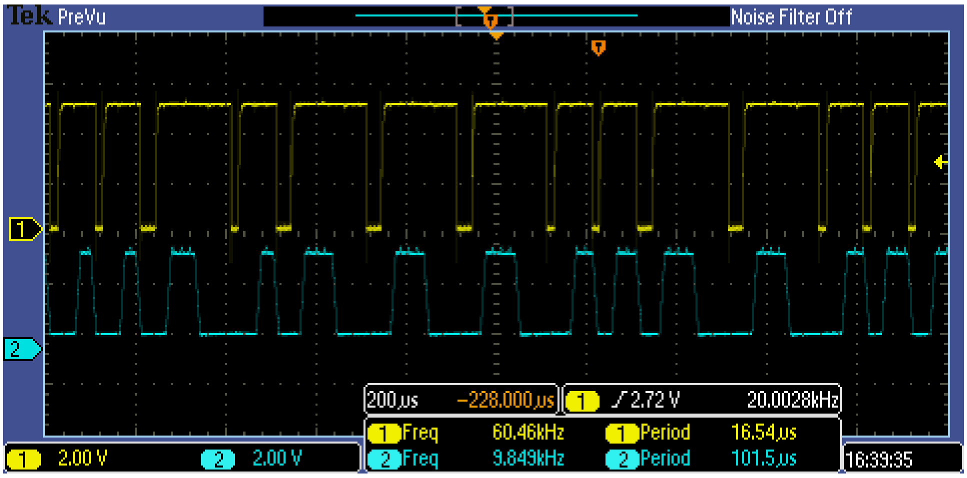

Figure 51 Transmitter signal and Receiver signal at Duty 30% while send data 0x31

5.3 Transmit error and effective length testing

By sending character “U” or ASCII 0x55 that has alternate logic 1 and 0 in 1 byte. It can easily occur error while sending data. Testing by transmit 450 bytes of data “U” to receiver while the receiver also compare receive data with data “U” and count receive counter. After finish sending data then compare the different number with receiver counter it will be error of transmit VLC. The testing will vary duty cycle from 1 to 24, each duty cycle will vary position of receiver from 15 cm. and do sending “U” process until occur error. The longest length that has no transmit error will be effective transmit length.

Table 3 Test effective duty cycle for transmit length by sending "U" 450 bytes.

L\D	1	2	3	4	5	6	7	8	9	10	11	12	13
15	450	0	0	0	0	0	0	0	0	0	0	0	0
24	450	0	0	0	0	0	0	0	0	0	0	0	0
32	450	450	450	450	0	0	0	0	0	0	0	0	0
41	450	450	450	450	0	0	0	0	0	0	0	0	0
53	450	450	450	450	450	279	0	0	0	0	0	0	0
62	450	450	450	450	450	450	0	0	0	0	0	0	0
70	450	450	450	450	450	450	63	0	0	0	0	0	0
82	450	450	450	450	450	450	200	0	0	0	0	0	0
90	450	450	450	450	450	450	450	450	450	0	0	0	0
99	450	450	450	450	450	450	450	450	450	450	450	0	0
108	450	450	450	450	450	450	450	450	450	450	450	450	242
115	450	450	450	450	450	450	450	450	450	450	450	450	0
127	450	450	450	450	450	450	450	450	450	450	450	0	0
136	450	450	450	450	450	450	450	450	450	450	450	0	0
145	450	450	450	450	450	450	450	450	450	450	450	0	0
155	450	450	450	450	450	450	450	450	450	450	450	0	0
164	450	450	450	450	450	450	450	450	450	450	450	0	0
173	450	450	450	450	450	450	450	450	450	450	450	285	0
183	450	450	450	450	450	450	450	450	450	450	450	368	0
192	450	450	450	450	450	450	450	450	450	450	450	314	0
201	450	450	450	450	450	450	450	450	450	450	450	313	0
211	450	450	450	450	450	450	450	450	450	450	450	0	0
220	450	450	450	450	450	450	450	450	450	450	450	0	0
229	450	450	450	450	450	450	450	450	450	450	450	0	0

Table 4 Maximum duty cycle for transmit length.

Length (cm.)	15	24	32	41	53	62	70	82	90	99	108	115
DUTY	1	1	4	4	5	6	6	6	9	11	12	12
% DUTY	4.17	4.17	17	17	20.8	25	25	25	37.5	46	50	50

Length (cm.)	127	136	145	155	164	173	183	192	201	211	220	229
DUTY	11	11	11	11	11	11	11	11	11	11	11	11
% DUTY	45.8	45.8	46	46	46	46	46	45.8	45.8	45.8	45.8	46

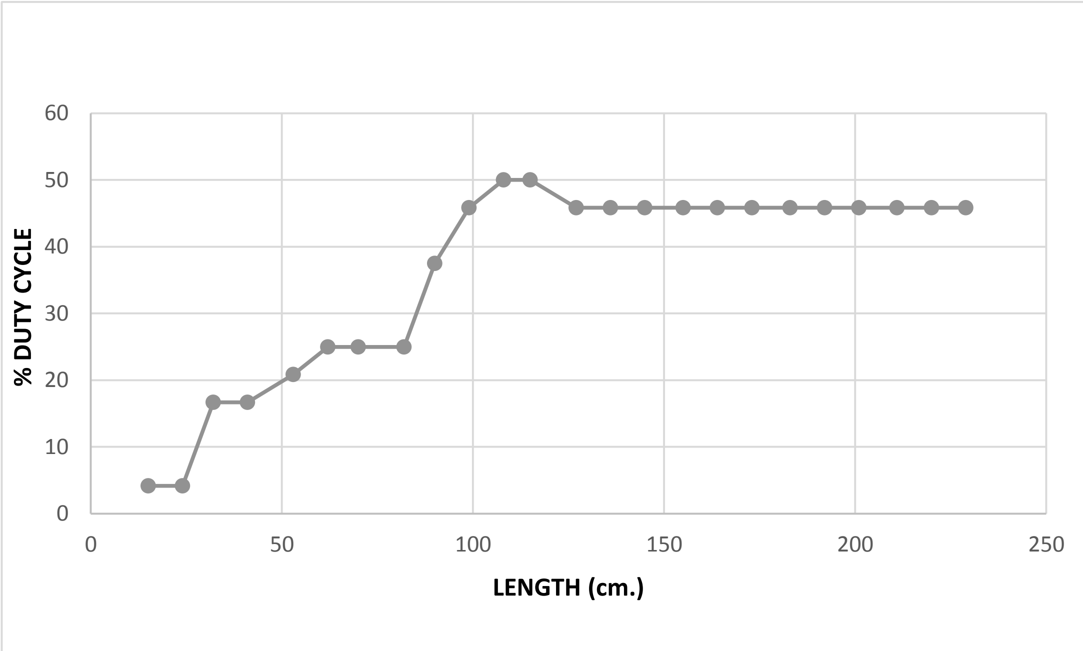

Figure 52 Maximum duty cycle for transmit length

After testing maximum duty cycle for each length, I try to find the maximum length of each duty cycle but until 229 cm. height of testing lamp, testing cannot go further in vertical so I do it in horizontal but after test duty cycle 1 (4.1%) the length is over 10 meters it still effective and the testing cannot go further because of limitation of space.

5.4 Send infrared signal response back testing

By sending data 0x3A, 0x44, 0x41, 0x0D or ASCII “:DA<Ent>” (send 4 bytes at a time) and bringing signal to oscilloscope as following figure 52. The upper yellow line is signal from LED infrared that modulates frequency of 38 kHz and the lower blue line is signal from output of infrared module.

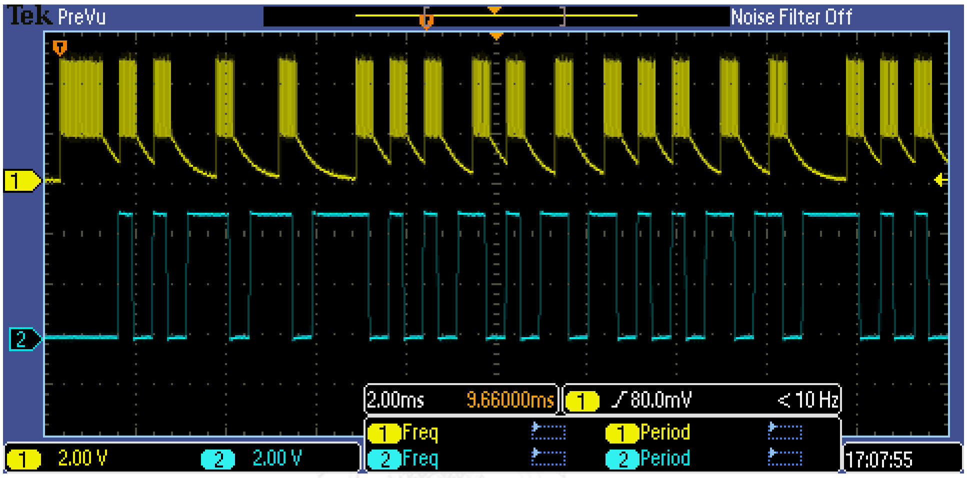

Figure 53 signal IR while send data 0x3A, 0x44, 0x41, 0x0D (ASCII “:DA<ENT>”)

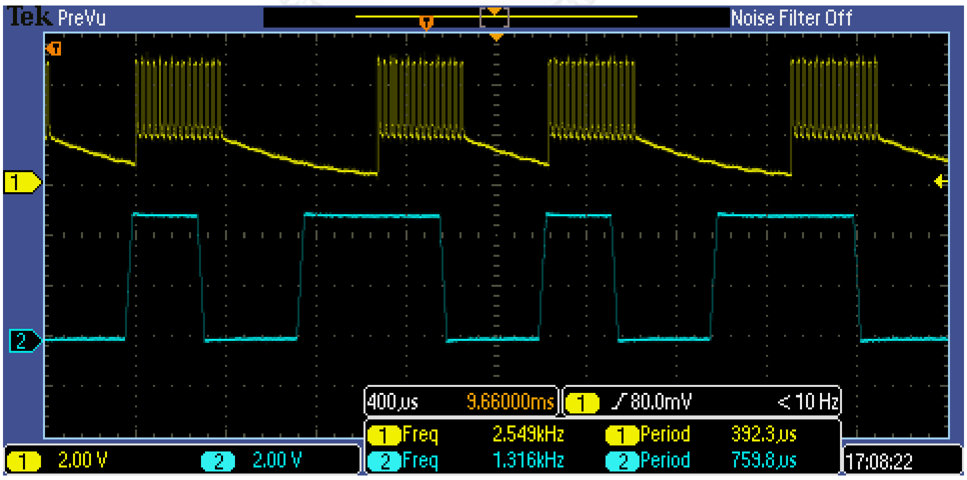

Figure 54 Detail signal from IR LED (Yellow) and output IR receiver module (Blue)

5.5 IR Transmit error

By sending character “U” or ASCII 0x55, the same method as VLC transmit testing process. Testing by sending 450 bytes of data “U” through IR LED to IR module receiver and counting then compare number of receive data “U” from IR with 450. The difference between counting number and 450 will be IR error.

Table 5 Testing IR transmit data error by sending data “U” 450 bytes.

Length (cm.)	RX1	RX2	RX = (RX1+RX2)/2	%ER = (450- RX)*100/450
15	405	392	399	11.4
24	401	397	399	11.3
32	398	379	389	13.7
41	357	350	354	21.4
53	359	385	372	17.3
62	359	358	359	20.3
70	357	344	351	22.1
82	340	330	335	25.6
90	337	322	330	26.8
99	361	351	356	20.9
108	350	330	340	24.4
115	395	387	391	13.1
127	344	340	342	24
136	321	317	319	29.1
145	312	299	306	32.1
155	276	275	276	38.8
164	351	336	344	23.7
173	322	295	309	31.4
183	218	197	208	53.9
192	262	144	203	54.9

Length (cm.)	RX1	RX2	RX = (RX1+RX2)/2	%ER = (450- RX)*100/450
201	201	177	189	58
211	160	135	148	67.2
220	144	120	132	70.7
229	74	66	70	84.4

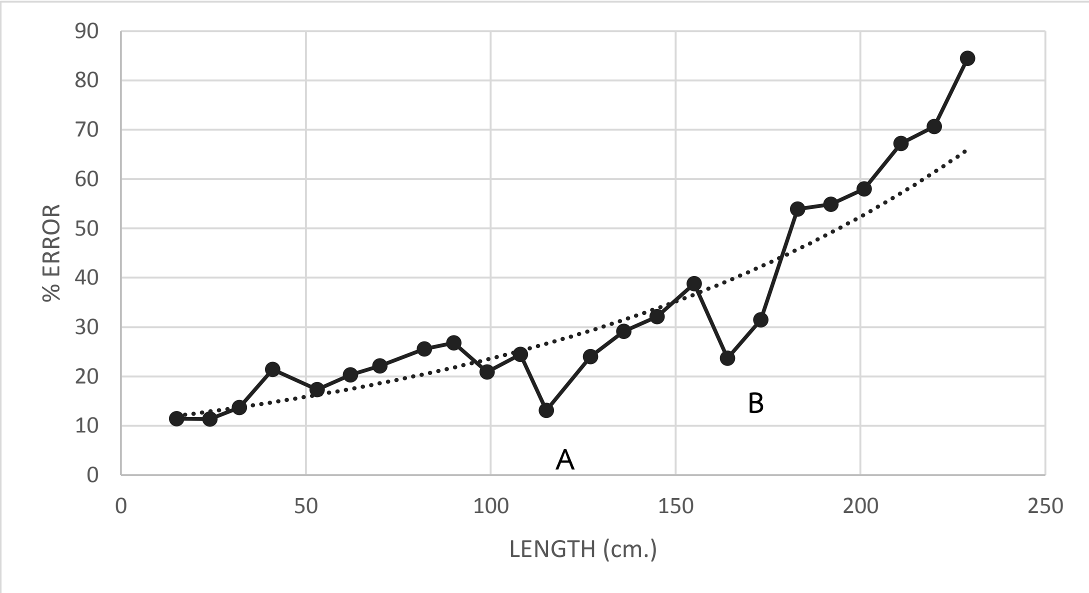

Figure 55 Testing IR transmit data error and approximate curve

The result of % IR error is shown in figure 55. Because of IR LED has head's lens so it need to point to exactly receive position for the best communication quality. The point A and B in figure 55 is missing IR firing point that make data out of trend line. The effective length should has % error not over 30% for reduce number of time to repeat sending data from transmitter that means effective receiver length is not greater than 150 cm.

5.6 Test Application

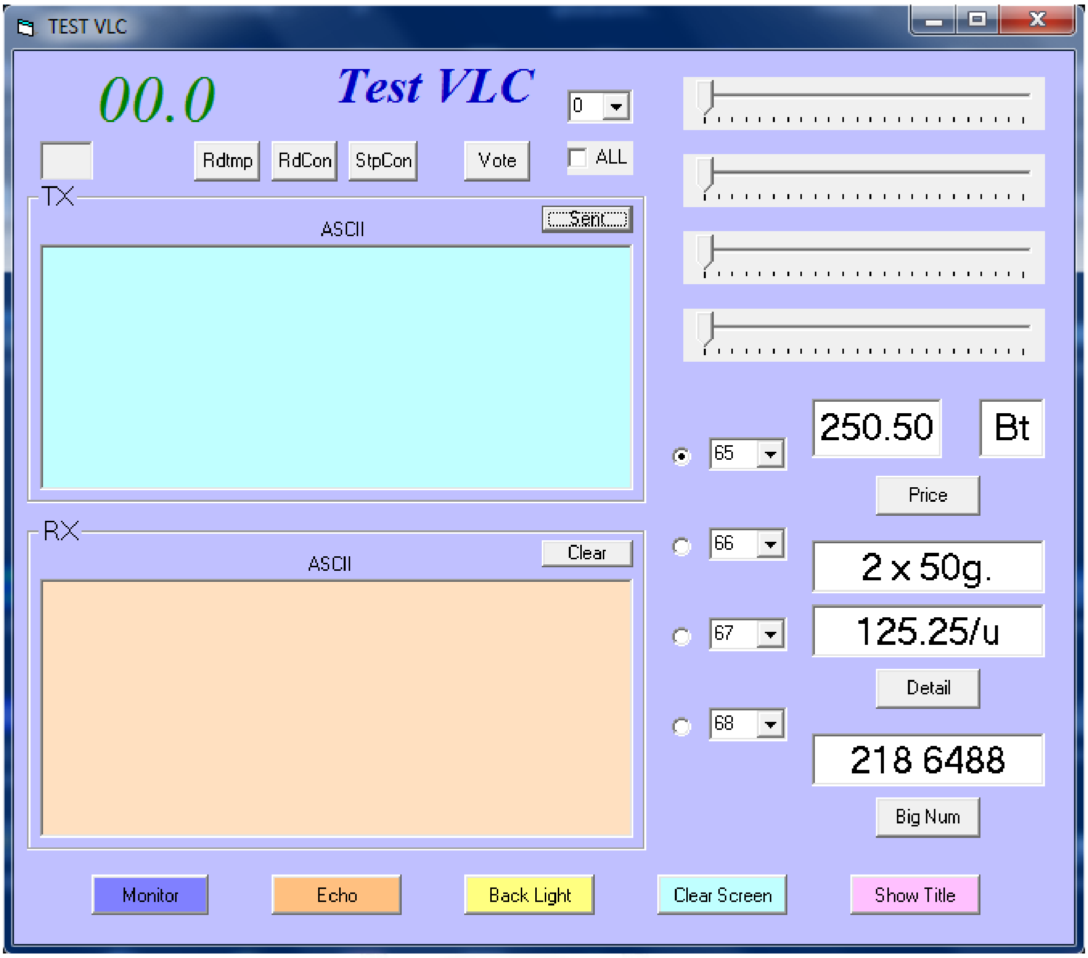

Figure 56 Program for Test VLC

This Testing program is written by visual basic program to test

1. Control receiver's LCD back light to on/off.
2. Control receiver to show title.
3. Control receiver to clear screen.
4. Control receiver to monitor every keyboard typing from PC.
5. Control receiver to echo back every keyboard typing back via IR to show on PC.
6. Display big numbers.
7. Display price area for price tag.
8. Display detail area for price tag.

9. Control receiver to display temperature.
10. Control receiver to send temperature back to PC.
11. Test voting system, sent show voting and wait for vote.
12. Control on 4-target-lamp brightness.

Figure 57 Application for testing Electronic Prices Tag

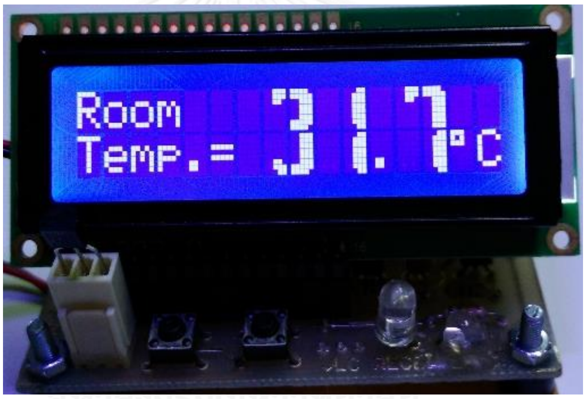

Figure 58 Application for testing Temperature monitoring

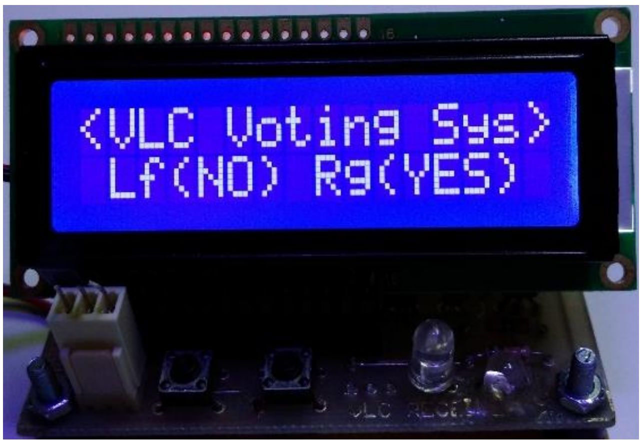

Figure 59 Application for testing Voting System

CHAPTER 6
SUMMARY and SUGGESTIONS

6.1 Summary

Visual or Visible Light Communication (VLC) is a technique to add facility to the LED light source rather than only brightness. This thesis adds dimming facility for energy saving or utilizing of LED light source in various tasks and improves LED's energy saving potentials. The VLC can be able to control communication area via visible light that improves utilization and value to LED lamp. However VLC can be easily interfered by environmental brightness but this problem can be solved by adding lens to the light sensor to focus on LED light source.

6.2 Suggestions

The Visible Light Communication is communication via visible light. The devices that VLC communicate with are not only data but also brightness. The power can be also generated from this brightness too. If the photo sensor is replaced by a solar cell it can save more energy and can make the devices more portable.

REFERENCES

1. *Visible Light Communication*. Available from: http://visiblelightcomm.com/what-is-visible-light-communication-vlc/.
2. *TOKEN: CDS Light-Dependent Photoresistors Datasheet*. 2010.
3. Arnon, S., *Visible Light Communication.* 2015.
4. D. Tsonev, S.V.a.H.H., *Light Fidelity (Li-Fi): Towards All-Optical Networking.*
5. Svilen Dimitrov, G.A.C.D. and U.o.E. Harald Haas, *Principles of LED Light Communications*

Towards Networked Li-Fi. 2015.

6. Sugiyama, H.H., S.; Nakagawa, M., *Brightness Control Methods for Illumination and Visible-Light Communication Systems.* 2007.
7. Frenzel, L., *Understanding Modern Digital Modulation Techniques.* 2012.
8. Jyoti Rani, P.C., Ritika Tripathi, *Li-Fi (Light Fidelity)-The future technology In Wireless communication.* International Journal of Applied Engineering Research, 2012. **7**.
9. Lazaridis, G., *Pulse Position Modulation and Differential PPM.* 2011.
10. *Universal asynchronous receiver/transmitter*. 2010.
11. *SHARP Application Note: Photodiode/Phototransistor Application Circuit*.
12. *OSRAM: Silicon NPN Phototransistor with Vλ Characteristics*. 2007.

APPENDIX

VITA

- Bachelor degree in 1986 from Faculty of Electrical Engineering Chulalongkorn University

- ESID Lab Faculty of Electrical Engineering Chulalongkorn University

- Field Engineer of Thai Sa-nguan Business System Co.,Ltd. Since 1986 to 1988 , Install and Service ATM for Thai Military Bank

- Attended Super Mini Computer TARGON Installation Program of NIXDORF COMPUTER Co.,Ltd in Pader Born German in 1987

- Design Engineer in R&D Department of Philips Electrical Co.,Ltd since 1989 to 1990 , Design and Development Computer Support

- Development and Maintenance Manager of NIPPON PACK (Thailand) Co.,Ltd. since 1990 to 1991 , Maintenance Industrial Machine

- General Manager of KETRON Engineering Co.,Ltd. since 1992 to 1997

- R&D Manager of Automation Service Co.,Ltd. Since 1998 to 1999

- R&D Manager of CIVIC Media Co.,Ltd since 1999 to 2000