Optical data transmission using portable USB Li-Fi module (dongle)

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***Abstract* - Wireless communication has become an indispensable part of our lives. Currently, RF spectrum is the only means available and hence is crowded with devices such as microwave ovens, RF communication systems, video devices, radar systems. radio navigation and many more. Due to which the RF spectrum is on the verge of exhaustion. Clearly we need to look out for alternatives to transmit data wirelessly. The most promising alternative seems to be Li-Fi (Light Fidelity) [5]. Li-Fi which is an example of OWC (optical wireless communication) can transmit data at a very high rate, moreover it can overcome certain challenges faced by Wi-Fi. It uses the visible light spectrum which is 10,000 times larger than the entire radio frequency spectrum [1]. Li-Fi can transmit data underwater, in aircraft (ensuring smooth working of its surroundings) and petrochemical industries (where using RF spectrum can prove to be lethal). Also, the light waves are not able to penetrate through walls, thus making it most secured form of wireless communication [1]. We have made a portable prototype of device that can establish a wireless communication between two or more personal computers using visible light spectrum. The portable device is compact and can ensure secured data transmission between devices within a room.**

Keywords - Visible Light Communications (VLC), Li-Fi, LED, Wi-Fi, USB, UART

I. INTRODUCTION

The main objective of our project was to design and implement a Universal Serial Bus(USB) Li-Fi Dongle for wirelessly data transfer between two computer systems. We transmitted data (string of characters) from one computer to another using visible light spectrum. A string of characters is taken as input through MATLAB application interface (commonly known as GUI). The string is converted into an array of 0s and 1s using MATLAB code. This array of 0s and 1s is fed to the USB to UART module. The module transmits the data serially to the LED driver circuitry. This serial data of 0s and 1s is used for switching of LED at a very high frequency (in MHz). The switching of LED occurs at a very high rate (equivalent to the set baud rate of serial transmission), thus making it impossible for the human eye to perceive it. This amplitude modulation of the light is detected by the receiver with the help of photodiode and a comparator. The photodiode detects the change in the amplitude and the output is given to comparator. The comparator converts the analog data into digital depending on data into digital depending on the threshold value. The threshold is a voltage corresponding to the ambient light, set by a voltage varying device like a potentiometer as in our case. This is given as an input to comparator with the other input of the photodiode. If the voltage produced by the photodiode is greater than the threshold, the comparator outputs high voltage level corresponding to a binary 1 and a binary 0 if otherwise. This way the output is reconstructed in the form of serial input. This reconstructed signal is fed to the USB to UART module at the receiving terminal. The module receives the data serially and displays the data on the MATLAB GUI on the receiver computer. Thus, the data is entered by the user, transmitted by the transmitter, reconstructed by the receiver, and displayed on the other terminal on GUI.

II. MATLAB GUI

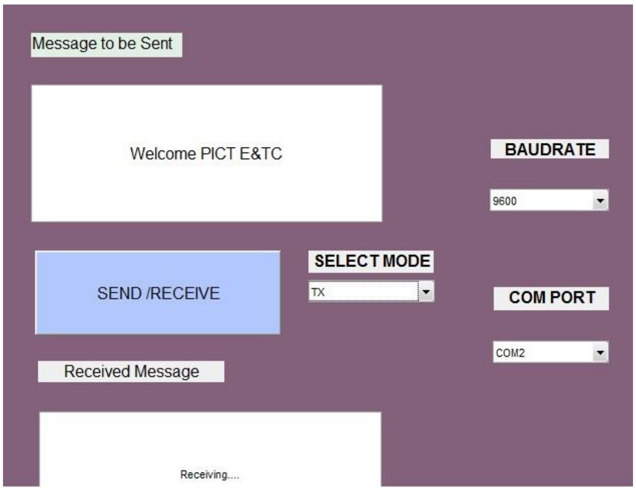


Fig. 1. MATLAB user interface

As data is transmitted from one computer to another, each computer has a MATLAB GUI that invokes the background functions. The user can enter the data string and the select the mode whether the data is to be transmitted or received. Once the data to be transmitted is entered and the SEND button is pressed, a serial object is created. This serial object sends the data present in the text-box to the USB to UART module. User has the freedom to choose the baud rate with which he wants to transmit the data from the drop-down list. Also, he needs to select the COM PORT to which the module is connected.

III. USB TO UART MODULE

USB to UART module is used to transmit the binary data serially. It supports full-duplex asynchronous serial communication. When this module is connected to the PC, it creates a virtual COM port using USB. It can be used at various BAUD rates for serial communication, ranging from 75bps to 12Mbps. It works on crystal oscillator frequency of 96Mhz. The biggest advantage of using this module is its TTL compatibility. The serial data is directly available at the Tx(Transmitter) terminal of the module.

IV. TRANSMITTER CIRCUIT:

The transmitter circuit consists of LED, LED driver and power supply to drive the transistor.

A. LED Driver:

An LED driver is an electrical device which regulates the power to an LED or a string (or strings) of LEDs. We have used the 2N4401 NPN high frequency switching transistor, which has a collector current of 600mA and rise time of 20 ns and a very low power dissipation of 625 mW. It is used in common base mode and operates in cutoff and saturation region. Hence, it is mandatory to regulate the current. So, the current controlled transistor is used.

B. LED:

LEDs are current driven devices. We are using a 0.5W led with luminous intensity up to 140 lumens which achieves maximum brightness at 3.3Volts. The led turns on and off as it receives high (3.3V) and low (0V) voltage levels from the driver circuit depending upon the baud rate selected in the MATLAB GUI.

V. TRANSMITTER CIRCUIT DESIGN

R_b is base resistor, I_c is collector current, I_b is base current, V_{be} is the base emitter voltage, V_{in} is the input voltage, V_{ce} is collector emitter voltage, R_c is collector resistor.

I_b = 0.866 mA

For transistor to be in saturation region, $I`_b = I_b * 10$

Therefore I_b`=8.66mA

$$R_b = \frac{(V_{in} - V_{be})}{I`_b}$$

$$R_b = \frac{(3.3-0.7)V}{8.66\ mA}$$

$$Therefore\ R_b = 300\Omega$$

$$I_c = beta * I`_b \qquad (beta = 40\ for\ 2N4401)$$

$$I_c = 40 * 8.66$$

Therefore $I_c = 34.64mA$

$$I_c = \frac{(V_{cc} - V_{ce})}{R_c}$$

Therefore,

$$R_c = \frac{(5-0.7)}{34.64} = 100\Omega$$

VI. RECEIVER CIRCUIT:

A. Photodiode:

Photodiode acts as receiver and it senses the change in intensity of light of LED and generates current accordingly. Here we have used a BPW34 photodiode. BPW34 as it supports high speed operation, up to 3*10^14 Hz. BPW34 has a rise time of 100ns and has a half sensitivity of 65 degrees. It works in the wavelength of range 430 -1100 nm which made it suitable to be used in the receiver module.

B. Comparator:

We used LM339 as the comparator. LM339 has relatively high Slew Rate (5 V/µS) and is TTL compatible Quad Comparator which made the task of interfacing with the USB to UART module less intricate. The maximum input current generated at the comparator pins were also in the permissible range.

VI. BLOCK DIAGRAM:

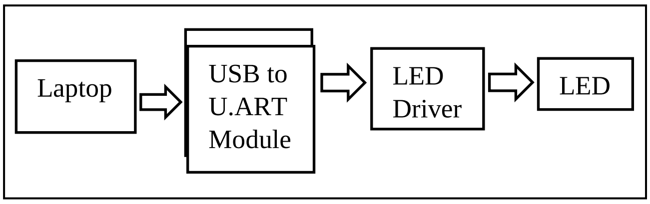
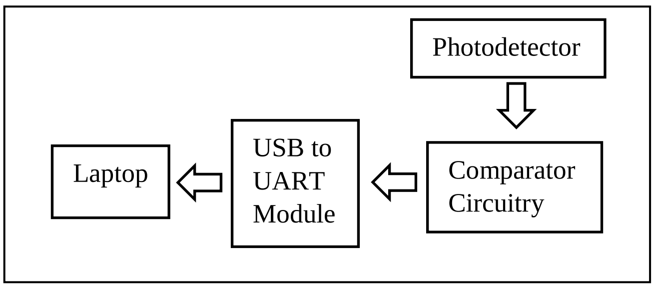


Fig. 2. Transmitter Block Diagram

Fig. 3. Receiver Block Diagram



VII. TRANSMITTER WORKING

The data from one computer is given to the USB to UART module through MATLAB GUI. Then the binary data is given to the transistor in the LED driver module. Here, we are using transistor as a switch. The switch operates in cutoff and saturation mode. In the cutoff state both Emitter Base junction and Collector Base junction are reverse biased, whereas in saturation region both junctions are forward biased. The transmission pin tx of the USB to UART module is given to the base of the transistor through a current limiting resistor $R_{b.}$

- ON = Saturation
- OFF = Cutoff

Transistor will become ON (saturation) when a sufficient voltage Vin (Vin is from the transmission pin tx of the USB to UART module which supplies 3.3V when high and 0V when low) is given to input and OFF when Vin is 0V. During this condition, the Collector Emitter voltage V_{ce} will be approximately equal to zero, i.e. the transistor acts as a short circuit. For a silicon transistor, it is equal to V_{ce} =0.3V. Thus, collector current $I_c = V_{cc}/R_c$ will flow.

VIII. RECEIVER WORKING

The comparator inverting input is connected to the 1 KΩ trimmer port which is also forming the voltage divider circuit where we could adjust the **V-** voltage start from 5 volts down to 0 volt. The non-inverting input is connected to the photodiode output. The photo diode output corresponds to **V+** voltage. If the **V+** is more than **V-** (**V-** being the threshold voltage set with respect to ambient light taken for example 200 mV) the comparator output will swing to the logical high ($V_{out} = V_{cc}$) producing bit 1. When the voltage **V+** drop below **V-**, the comparator output will swing to the logical low (V_{out} GND) producing bit 0.

Fig. 4. Transmitter and Receiver Circuit

IX. CHALLENGES:

Though Li-Fi has great set of advantages over the contemporary RF operated systems and services in terms of bandwidth availability, inherent security and privacy characteristics (since the visible spectrum cannot penetrate through walls) but it comes with its fair share of challenges as well. It is often easy to design a Li-Fi transmitter that broadcast signal in a room and can very well cater to vast number of receivers in there too. It is a great option for a simple, fast, and efficient downlink but the uplink issue persists. The dongle we designed is a point to point line of sight (LOS) link so information can be transmitted to and from without any difficulty. But when more than two devices come into picture forming a networked connection, using Li-Fi for both uplink and downlink would complicate the design of the system rendering it less user friendly when compared to the existing technologies such as Wi-Fi. This problem can be solved by using IR spectrum for uplink [1]. Another solution could be using Li-Fi in tandem with Wi-Fi [4] [10], the former for downlink whereas the later for uplink [3] [11]. The challenge however in using LiFi as a downlink is that of maintaining continuous connectivity which depends on the coverage area of the luminaires and handoffs to be handled effectively in an indoor environment. To account for the movement of device in not so well-lit areas indoors the system should be able to switch to RF (or WiFi) downlink [12]. A Visible Light Communication (VLC) network coordinator is outlined in the given reference [9] which gives a bi-directional interface between RF or WiFi uplink and optical or LiFi downlink. As is know from operators that more than 80% of mobile traffic is generated indoors because of this fact the combination of LiFi and WiFi has a great potential to be a breakthrough technology along with Long Term Evolution (LTE) [7] [8]. Another issue is about the distance of transmission. The effective distance of transmission we got was around 90cm which could be increased further with the help of a lens setup [2]. It also depends on the LED characteristics. An LED with a directed beam can increase the effective transmission distance. The speed of the system we developed peaked at 95Kbps. The speed characteristics depends on several factors such as the slew rate of comparator, speed of photo diode, the switching frequency of the LED driver circuit and the LED characteristics. Another challenge faced is that of adjusting the threshold value of the comparator, with the changing lighting conditions of the environment.

X. FUTURE SCOPE

The module we designed can be used for broadcasting internet to close by devices like that of hotspot technology, but in optical terms with added advantage of it being more fast and secure unlike in Wi-Fi where even the WPS networks are not hack proof whereas amalgamation of LiFi+WiFi systems provide new features, such as enhanced security in

Optical-Small Cells(O-SC) and improved indoor positioning [6]. It could be a faster alternative for thumb or flash drives. Instead of copying data from system to flash drive then to another system, we can get rid of the middle link (i.e. flash drive) which would further increase the overall speed of transmission. This system could be embodied in the PC as an additional connectivity technology, thus creating an ecosystem which will give rise to multitude of gadgets using this technology.

We are also working on a way to make the existing devices like smart phones work with this technology with no additional hardware requirement, by using mobile device's camera and flash as receiver and transmitter respectively, we are calling it LiFi-Direct, which will lead to faster data sharing from device to device.

XI. REFERENCES

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