LED Visible light communication system based on FPGA

WANG Feng
College of Electronic Information Engineering
Nantong University
Nantong, China
wfntuchina@163.com

XU Chen
College of Electronic Information Engineering
Nantong University
Nantong, China
xcntuchina@163.com

***Abstract*—On the basis of the physical characteristics research and analysis of white LED and the photodiode including current, amplitude-frequency characteristics and response time, the experimental system achieves the goal of visible light communication successfully with the 115200bps baud rate in distance of 9.6 meters. The experiment is based on the principle of intensity modulation and direct detection (IM / DD), using LOS link design with white LED lighting array 16 * 8, choosing Manchester code as modulation with a good synchronization and strong anti-noise capability to achieve indoor unidirectional downlink communication of lower error rates and long-distance transmission. The transmitter and receiver board have some advantages with a strong mobility, low cost and high sensitivity. Manchester encoding, decoding algorithm and serial communication interface are designed by Verilog HDL. Implemented on Alter FPGA development system DE2.**

Keywords—Visible light communication; Manchester encoding; FPGA; White LED; LOS link; IM / DD

I. INTRODUCTION

In recent years, white LED as a green lighting technology is developing rapidly, causing great concern. Compared to conventional white LED lighting has many advantages of greener, low power consumption, long life, small size, good modulation performance and high response sensitivity[1]. Based on these advantages, the high-low change of the signal light is converted to light and dark variations, in the form of modulated light to transmit information[2].This approach is the Visible Light Communication[2]. Compared to WLAN, Visible Light Communication is faster transmission speed, wide-bandwidth use, low radiation, high security performance, safer. It has attracted wide attention and research scholars.

II. SYSTEM MODEL

The system mainly consists of the transmitter and receiver modules as shown in Fig. 1.

In the transmission, the data transmit to the FPGA development system by the PC serial communication interface. After Manchester encoding, the message then output to the LED driver circuit. Optical signal from the LED array 16 * 8 is transmitted to the photo-detector. At the receiving end, the optical signal is subjected to photoelectric conversion by the photodiode. This signal inputs to Manchester decoded to recover the original data on the other FPGA development system.

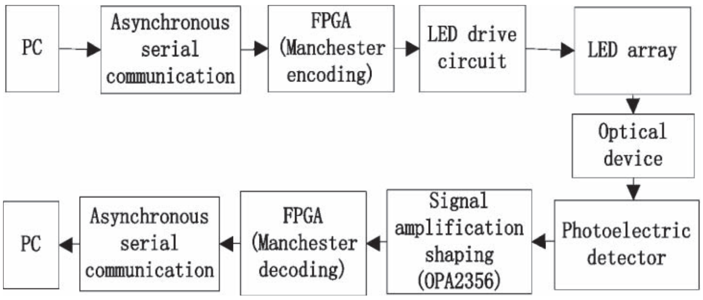

Fig. 1. System flowchart.

A. *Design of Visible Light Communication Channels*

Visible light communication channels include sunlight, fluorescent lighting and other optical noise except the communication source. In order to improve the channel transmission quality and extend the communication distance, we take two steps in the channel. Firstly, light noise is weakened effectively by using an optical device (such as an optical filter, a condenser lens). Convex lens is used to focus on the light, in order to increase the range of the light signal received by the photo-detector. Optical filters can filter out other unwanted light impurities. Secondly, choose directional link (LOS-Light-of-Sight) as the communication link. The design of LOS link allows ambient light noise to be minimal impact on the optical signal transmission also can makes the optical path loss to a minimum. So the design of channel allows the utilization of the signal transmission power is maximized, greatly enhancing the overall optical communication system performance. It can be seen that the presence of the direct and multiple reflection paths between the receiver and the transmitter. To a point in the room normalized impulse response were studied. The percentage of direct light, the first reflected light and second reflected light received light of the total is 95.16%, 3.57%, 1.27% [3]. Data can be drawn that the main impact on visible light communication performance is direct light. Therefore, this study only considers the impact of direct light. Visible IM / DD channel can be used as a wireless optical communication transmission model to build a linear base-band system as shown in Fig. 2 [4].

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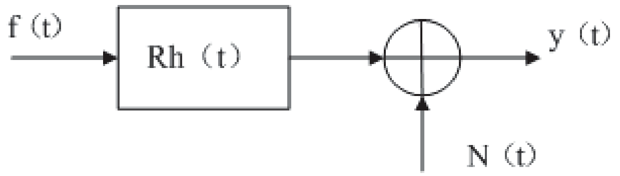

Fig. 2. The linear baseband transmission model of wireless optical communication system

Fig. 2 f (t) is the instantaneous power of the input signal. R is the response efficiency of the photo-detector. y (t) is the output current. h (t) is the base-band impulse response of the channel. N (t) is white Gaussian noise. The expression is as in (1):

(1)

When the transmitter and receiver positions remain unchanged, the frequency response of the visible light channel is close to DC. Therefore the received power Pr of the receiver can be expressed as in (2)[5]:

(2)

In the formula, Pt is the transmit power. H (0) represents the channel DC gain. If only consider LOS optical link, white LED lights meet Lambert radiation model, the H (0) is as in (3) [5]:

(3)

In the formula, m is the radiation pattern of light source which is the half intensity value of a LED light emitting. n is the reflective index. A is the receiving area of the photo-detector. D_d is the distance between transmitter and receiver. Φ is the angle of incidence. φ is the emission angle. $T_s(\Phi)$ is the optical filter gain. ψ_c is the receiver FOV. The light source radiation pattern (m) can be expressed as show in (4) [6]:

(4)

In the formula, $\theta_{1/2}$ is the transmit power half angle that the angle between the direction and the vertical direction in this case when a strong light from the light source in a certain direction drops to half the normal light intensity. When $\theta_{1/2}$ = 60 deg time, m = 1. Therefore the larger m is corresponding to a narrow beam.

B. Manchester Coding

To ensure visible light communication with advantages of high-quality and long-distance, choose Manchester to encode data. Generally, the high level output of the digital signal represent “1” by source coded data and the low level is expressed as "0".This data sequence is called the natural binary code [7]. Because of these shortcomings that low-frequency component and a DC component are not suitable in capacitive coupling circuit and low frequency transmission limited channel, it can not get the synchronization information. Natural binary code is not suitable for the requirements of the subject. Consider a variety of pattern features and difficulty of the research, system selection Manchester encoded. The main advantages are as follows.

- (1) Each encoded symbols have hop changed in the middle so that no DC component, which is conducive to the transmission of information. Also it has a strong resistance to outside interference and noise immunity [8].
- Extracte from the edge of the ongoing transition to achieve synchronization.
- Manchester code with a certain error detection capabilities.

C. Amplifier OPA2356 Amplitude-frequency Characteristics

The experimental device, as shown in Fig. 3, conducts an experiment to test the operating frequency of the amplifier.

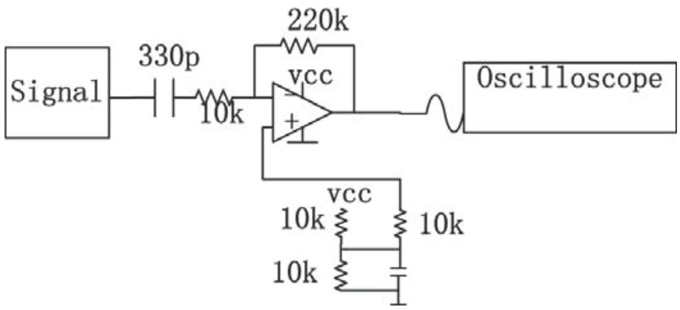

Fig. 3. Experimental circuit diagram

The results are discussed and analyzed: It draws a conclusion based on the experimental measured data that magnitude of amplifier is more stable in 100Khz to 900Khz frequency. At this point the amplitude-frequency characteristics is good, signal is suitable for transmission. When being less than 100Khz and more than 900Khz, signal amplitude has obvious attenuation and it’s not suitable for transmission. When coupled 1pf capacitance and working in 120Khz to 300hz frequency, the signal amplitude is stable and it ‘s suitable for transmission. When being less than 120Khz and more than 300Khz, the signal amplitude has obvious attenuation and it ‘s not suitable for transmission.

D. The amplitude-frequency analysis of combinational circuit of light-emitting diodes and photodetectors

In the visible light communication experiment, another core part is a photoelectric conversion at the transmitter and receiver.

In the experiment about combinational circuit performance of light-emitting diode and photo-detector, when the operating frequency is 50Khz or less, the voltage amplitude values changed little. When the operating frequency is 80Khz to 1Mhz, amplitude changes significantly and response fast. In the process of continuing to increase the frequency, the magnitude of the oscilloscope display is almost zero. Therefore, the frequency response of photo-detector is below 1Mhz in the actual work.

III. The System Test and the Analysis of Simulation Results

A. *transmitter circuit and receiver circuit*

The system constructs transmitter circuit as shown in Fig. 4 and receiver circuit as shown in Fig. 5.The transmitter circuit is composed of 74HC244 chip, where each chip drive eight LEDs. Therefore, white LED array of a 16 * 8 is as the transmitter.

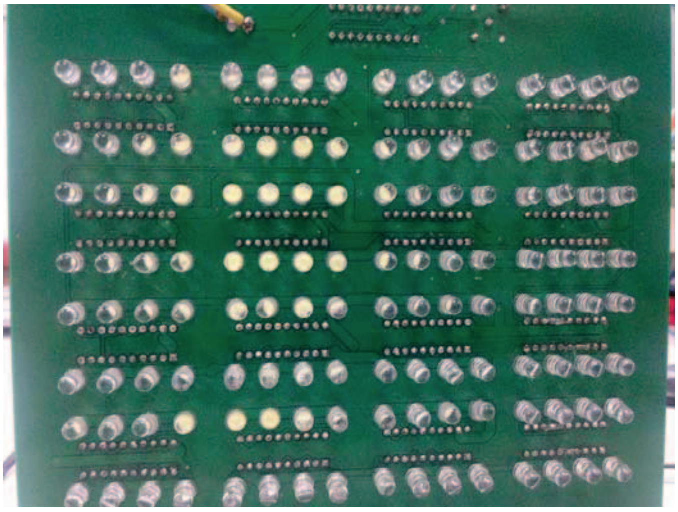

Fig. 4. transmitter circuit

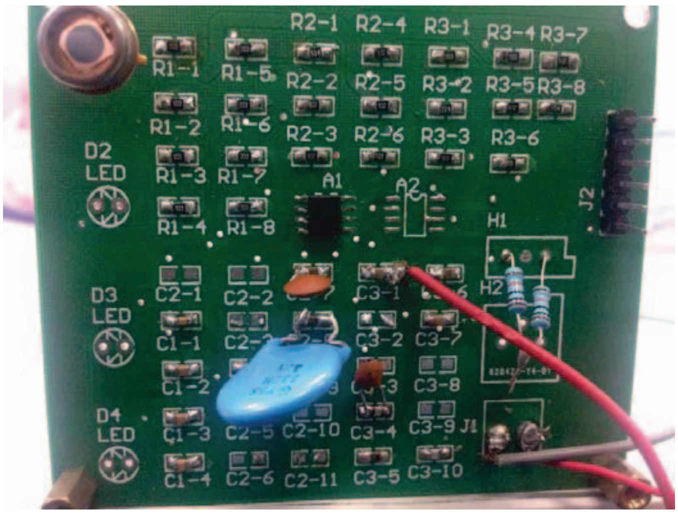

Fig. 5. receiver circuit

Encoded data transfer to the receiver circuit (schematic shown in Fig. 6). The photo-detector is first to convert optical signal to level signal [6]. Because the received signal decays obviously through long-distance transmission, the capacitance filtered the signal. Amplifying and shaping the signal through two-stage amplifier of OPA2356. The output signal is input to the DE2's GPIO port and then decoded by the FPGA.

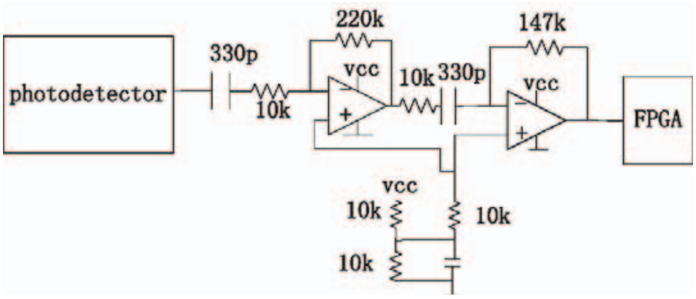

Fig. 6. receiver circuit schematic

B. *The Test and Results of System*

PC communicates with the FPGA by serial debugging assistant. Set the baud rate of 115200bps. LED array and photo-detector is in the distance of 9.6 meters. Following the protocol of asynchronous serial communication, a set of information is transmitted containing 1 start bit, 8 data bits, 1 stop bit. The sender PC sends a group of data "0f0f0f0f0f0f0f0f0f0f0f0f0f0f0f0f".An output waveform is shown in Fig. 7after FPGA encoded data.

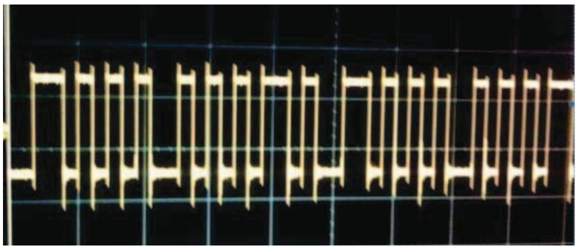

Fig. 7. Waveform output

The output waveform is shown in Fig. 8 that the encoded data is shaped and amplified by the receiver circuit. Then the signal is input to another one DE2 in order to decode. Waveform is shown in Fig.9. It can be seen that idle is high level in the waveform figure. It meets asynchronous serial communication protocol. The output 0f decoded data is '0f0f0f0f0f0f0f0f0f0f' by the second DE2 block. Compared the received data and the send data, they are identical as shown in Fig. 10, Fig. 11.

Fig. 8. Amplified waveform at two times

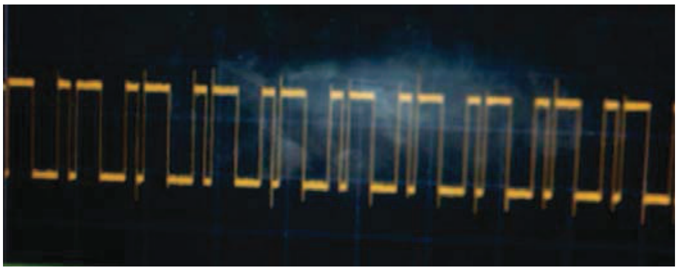

Fig. 9. Decoded waveform

IV. Conclusion

In the experiment, it derived experimental parameters by researching various characteristics of the device. It provides a method about optical communication tests for future. This experiment chooses the devices with high frequency response and strong anti-jamming based on the research, .Also select the appropriate baud rate of the system based on the results of experimental tests of the hardware. While, the white LED array and the design of two-stage amplifier in receiver ensure the distance and quality of the data transmission. The design of LOS link makes the optical path loss minimized, thereby improving the utilization of signal transmission power. Select Manchester coding in order to solve problems of synchronization and the interferences of other light noise. Meanwhile Manchester encode data transmission have error detection function. The results show that the experimental system achieves the goal of visible light communication successfully with the 115200bps baud rate in distance of 9.6 meters.

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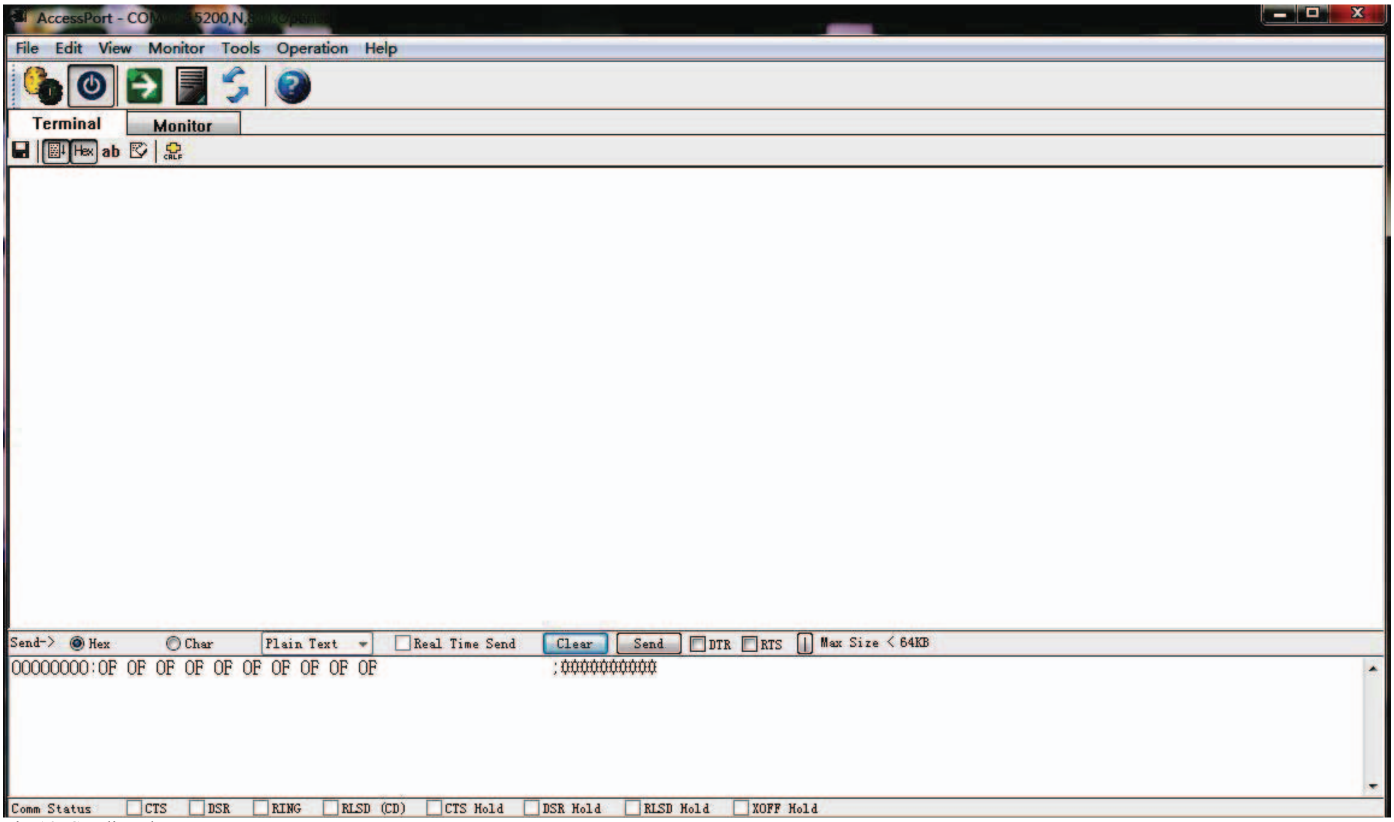

Fig.10. Sending data

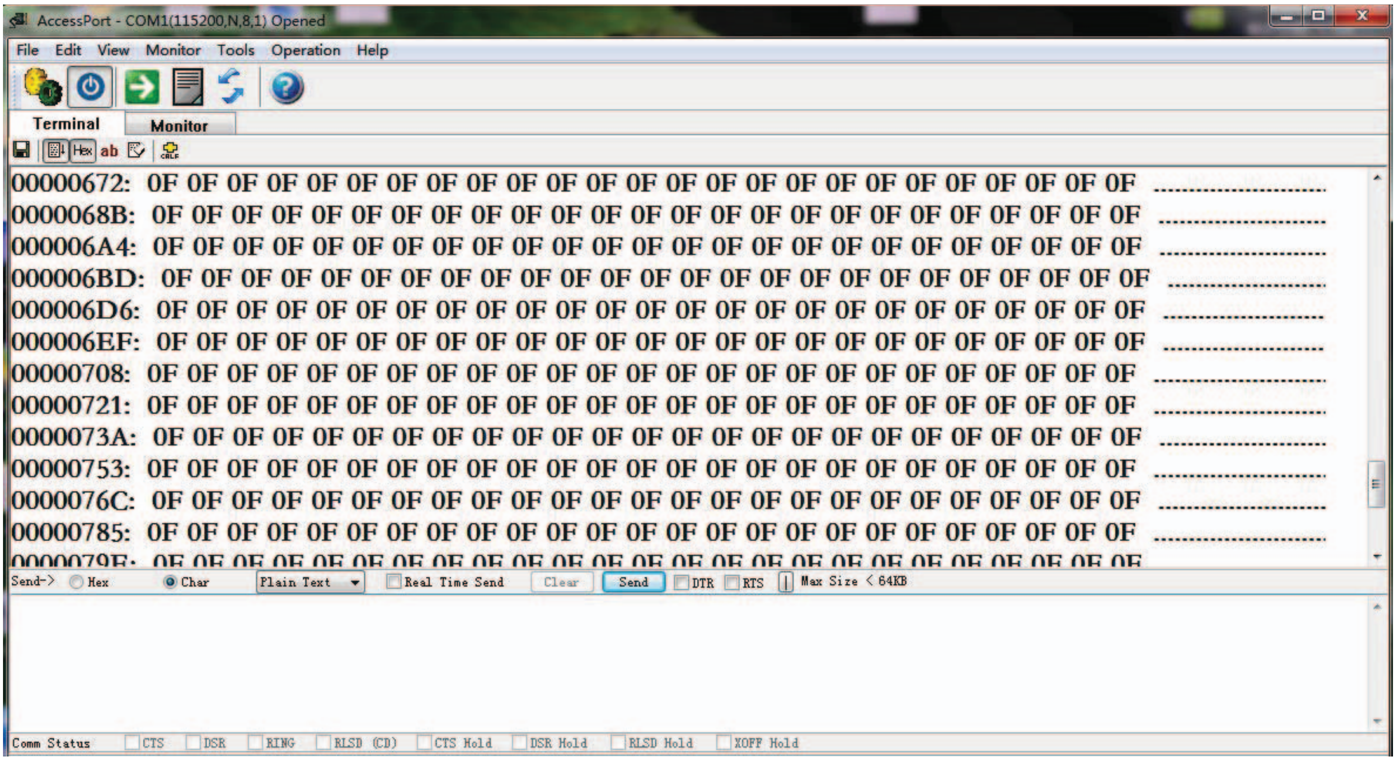

Fig.11. Receiving data