A compact signal transmitter for UV communication system

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Abstract. Three LED-based signal transmitting schemes were presented to build the transmitter of UV communication system. Microprogrammed Control Unit (MCU) was taken to generate digital driving signal and to accomplish modulation with Keil C51 development tool. The modulated signal with a certain pulse width was sent to a LED driving circuit. High power 365nm UV LED was adopted according to the trade-off between its scattering coefficient and price. Utilization of high power UV LED improved the integration density of printed circuit board (PCB), which was beneficial to assemble a beam shaping system. The whole transmitter was installed on a four-dimensional optical stage for system adjustments and measurements. The radiant optical power of UV LED was measured. Some issues about the PCB design were also discussed. The MCU output waveforms were demonstrated on an oscilloscope and the UV LED output optical pulse were verified by a Hamamatsu APD module. Different modulation data rates were investigated. Experimental result showed that this signal transmitter for UV communication system could transmit optical signal well and greatly shorten the system development cycle.

1. Introduction

Nowadays, research on UV communication systems are greatly stimulated by rapid progresses of semiconductor emitters and detectors operating in ultraviolet (UV) region. Successful UV communication experiments and systems have been achieved by many research groups [1, 2]. Generally, a typical UV communication system consists of a digital data source, a modulator, a light source that can be directly modulated in intensity at fairly data rates, a beam shaping and angular adjustment optical system; a receiving optical system to collect and focus the UV light onto a detector, a signal pre-amplifier and demodulator to recover the data. The acquisition of modulated data is often complicated, because the developer has to consume a large amount of time to make clear how to implement the architecture of hardware. However, the essence of UV communication system is to deliver the UV light pulse at a certain rate corresponding to the required communication bandwidth. So it is essential to find a convenient way to generate the digital signal with required pulse width and modulation scheme, in order to reduce system development cycle and simplify the system construction.

On the other hand, the choice of light source is also essential for a UV communication system. UV gas lamp, UV laser and UV LED are three types of light source currently available. LED is widely

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used due to its small size, low power consumption, high lifetime, high bandwidth, and modulating facility. Meanwhile, for the radiant power of a solar blind region (240 nm-280 nm), UV LED is unique at the moment. A 365 nm UV LED was taken as the UV source because it has a relatively high optical power and an appreciable scattering coefficient.

The scope of this paper will cover an introduction to the transmitter schemes, design, and the hardware required to construct a working transmitter prototype of UV digital communication system. Also, a compact signal transmitter will be described and its modulation performance will be observed.

2. Three digital signal processing schemes

The subject of digital communications involves the movement of information from the source equipment to the terminal equipment. At the transmitter side, the information is processed into digital bit stream through software or coder chips. Since the LED is peak-power limited, the data must be compressed and transmitted at low rate in order to make achievable energy per pulse larger. Then the bit stream is modulated by the embedded system and sent to an analog circuit to drive the LED.

We put forward three transmitter schemes to implement modulation and compressing of input information.

The first transmitter scheme utilizes a computer as an information processing and delivering carrier, which can handle text, speech or even image information. Figure 1 describes the block diagram of this transmitter with a clear delineation between hardware and software.

![Figure 1. Block diagram of computer-based transmitter scheme.](image)

The information is fed into a computer through the peripheral equipment at the front end. Then the software based on corresponding coding algorithms is used to transform the information into formatted or compressed data. This low rate digital bit stream is transferred into FPGA-based modulation hardware with an RS232 interface. After channel coding by FPGA, the data are taken to drive LED or LED array. As described above, this scheme is neither portable nor scalable, because a computer and certain software are needed during the communication process both at the emitter and receiver sides. It is especially discommodious to conduct outdoor field testing.

The second transmitter scheme based on a special vocoder chip can handle UV speech communication well. Its block diagram is shown in figure 2.

![Figure 2. Block diagram of vocoder chip-based transmitter scheme.](image)

The arrows in figure 2 indicate the data transfer direction. A microphone or an mp3 can be used to generate the analog audio signal. An analog-to-digital converter, integrated with anti-aliasing filter, digital high-pass filter, and an output low-pass filter, collects the audio signal and converts it into digital bit stream. Then the digital bit stream is input into a vocoder chip, such as AMBE-2000. The vocoder chip provides a real-time implementation of the standard-setting voice compression software.
algorithm. It maintains natural voice quality and speech intelligibility at extremely low data rate. At last, the data can be utilized to drive the light source through driving circuits. This transmitter scheme is compact and easy to be performed outside. However, it is time consuming to get familiar with the characteristics of the chips and the FPGA digital communication system, which will lengthen the UV system construction cycle.

In the UV non line of sight (NLOS) communication system, the channel path loss and bit error rate (BER) are the most important properties. To analyze them, a series of digital modulated optical pulses should be sent out at the transmitter side, and the received optical pulses are measured and recorded at the receiver side. According to comparison with the source binary codes, the path loss and BER characteristics can be deduced. Figure 3 gives another workable transmitter scheme. Different with the other two schemes, all the digital processing work is managed by one MCU chip.

![Figure 3. Block diagram of MCU-based transmitter scheme.](image)

The principle of the MCU-based transmitter scheme is as follows: first, the text information to be sent is input into the MCU; then, a program of C stored in the MCU changes the source information from ASCII format to binary format; after that, the binary data stream is modulated by the same program and sent to the IO ports of MCU; finally, the IO ports are connected to the control pins of the driving circuit, making the light source emit modulated optical pulses.

All the above UV transmitters use LED or LED array as light sources. But from the complexity perspective, the third scheme can be implemented easily and can process text information well. So a demonstration system is constructed to verify its performance.

### 3. The MCU-based UV transmitter system

A picture of our MCU-based UV transmitter is presented in figure 4. It consisted of three components: a printed circuit board (PCB), an angular adjustment stage, an LED and lens. The PCB was made up of a high constant current LED driver, a manual “transmit” button and an external 5V power. Signal integrity was not concern much because this design operated at relatively low speed. Power decoupling capacitors were placed around the power sockets and each digital component. MCU and LED were designed on two PCBs. The LED board was vertically stacked above the MCU board to provide enough space for optical system design.

![Figure 4. MCU-based UV transmitter system. This transmitter scheme emphasizes flexibility and modularity, providing the capability to transmit text information at adjustable data rate.](image)
The PCBs were mounted on an optical stage to adjust the pitching angle. The lens was installed on a cross-post adaptor to achieve the regulation of beam divergence angle.

SETI now offers deep UV LEDs with peak emission wavelengths in the range of 240 to 400 nm [3]. To implement outdoor UV communication, the peak wavelength of UV LED should be in the solar blind region. But in this region, a single commercial LED typically consumes electrical power of 100 mW and only radiates an optical power of less than 1 mW. Meanwhile, a solar blind UV LED is extremely expensive. We have taken Nichia’s high power 365 nm UV LED as the UV source since it has a comparable scattering coefficient with solar blind region UV LED. For instance, the scattering coefficient of 275 nm UV radiance is approximately 0.47 km⁻¹, while the scattering coefficient of 365 nm UV radiance is 0.27 km⁻¹[1]. The electrical and optical characteristics of Nichia 365 nm UV LED is shown in figure 5[4].

![Figure 5](image)

**Figure 5.** Specifications for Nichia high power 365nm UV LED.

4. Experimental result

In our experiments, the text information “Shanghai EXPO” was stored in the MCU and modulated by several popular modulation schemes at different data rates. We examined the performance of the transmitter and checked out the communication data rates from 1k to 125k bps.

4.1. The optical power of LED

Received optical power for various transmitter and receiver (Tx-Rx) separation distances under the condition of point to point line of sight (LOS) link were examined. Using a LabMax TOP laser power meter, we recorded the power at different Tx-Rx separation distances ranging from 0.02 m to 5 m. The LED was driven at a current of 500 mA, 3.6 V DC. The optical sensor was OP-2 UV type, having a spectral response range of 250 to 400 nm and an active area of 28 mm². Figure 6 shows the relationship between the optical power arrived at the photosensitive surface and the Tx-Rx separation distance. It is noticed that the power density decays sharply as separation distance increases. At the range of 5 m, the received optical power by the OP-2 UV sensor is only 81 nW.
4.2. The results of different modulation schemes
Modulation schemes are judged on the following criteria: power efficiency, flexibility, bandwidth efficiency, and complexity. Baseband modulation schemes, including on-off keying (OOK) and pulse position modulation (PPM), are commonly used in NLOS UV communication. They can offer good power efficiency and bandwidth efficiency. In this section, the performances of OOK and 4PPM modulation are investigated. We modulated the text information “Shanghai EXPO” by both OOK and 4PPM schemes. The output waveforms of MCU were shown in figure 7. Since the LED is peak power limited, employing OOK modulation for a fixed data rate will upgrade the bandwidth efficiency.

4.3. Data communication rates test
A Hamamatsu APD module C5331-12 was used to examine the optical pulse emitted by the Nichia 365 nm LED. The optical pulse width was set to 8 μs, with the OOK data rate of 125 kbps and the 4PPM data rate of 62.5 kbps. APD module was put in front of the LED and the output waveforms were probed with an oscilloscope. Pictures observed from the oscilloscope are presented in figure 8. We can see that the digital signal can be recovered well by the APD module. But the transmitting distance is only within 0.5 m, because the module has a low gain at 365 nm wavelength.

![Figure 8](image)

**Figure 8.** The output waveforms of APD module. (a)OOK, data rates 125 kbps. (b) 4PPM, data rates 62.5 kbps. Note that the 4PPM waveform was reversed.

5. Conclusions
In this article, three transmitter schemes of UV communication system were summarized. An MCU-based UV communication system was built up using Nichia high power 365 nm UV LED. Different UV communication modulation schemes were also achieved on this transmitter system. Data transmission bit rate can reach 125 kbps using OOK modulation. However, this system would certainly be further developed in the near future. The receiver with high sensitivity and proper bandwidth should be built in order to detect the weak scattering signal. Also, the BER property should be investigated with a BER analyzer. Finally, the optical concentration system would be embedded into the receiver system to realize the scattering communication, which is the ultimate goal of UV communication.

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