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Ahfayd, Mostafa H., Farhat, Zohaib A., Sibley, Martin J.N., Mather, Peter and Lazaridis, Pavlos

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Original Citation

Ahfayd, Mostafa H., Farhat, Zohaib A., Sibley, Martin J.N., Mather, Peter and Lazaridis, Pavlos (2018) Visible light communication based system using high power LED and dicode pulse position modulation technique. In: 25th Telecommunications Forum: TELFOR 2017, 21-22 November 2017, Belgrade, Serbia.

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Visible light communication based system using high power LED and dicode pulse position modulation technique

Mostafa H. Ahfayd, Zohaib A. Farhat, Martin J. N. Sibley, Peter J. Mather, and P. I. Lazaridis

Abstract — In this paper a dicode pulse position modulation (DiPPM) technique has been successfully implemented for an indoor visible light communication (VLC) based system using an FPGA and a commercial high power white LED (30 W). A data rate of 13 Mbps has been achieved with a bit error rate (BER) $<10^{-11}$ at a free space distance of 1.2 m through a basic transceiver circuit, and 14.5 Mbps with 1.15×10^{-6} of BER. Furthermore, a data rate of 13 Mbps has been successfully transmitted over a distance of 1.8 m with BER of 10^{-5}. This proves that the application of DiPPM is a viable modulation system over free space communication links.

Keywords — Dicode; FPGA; LED; PPM; Receiver; TIA; Visible light communication

I. INTRODUCTION

IN the last few years, the idea of using light emitting diodes (LEDs) for both lighting and data communications has led to a growing area of research in to visible light communications (VLC). Optical wireless communications (OWC) and VLC technique which use LEDs for high data transmission are potentially faster than systems such as radio frequency (RF) or infrared (IR) [1-3]. The benefits of using LED technology are; extensive durability, greater brightness than other bulbs, higher data rate and bandwidth, data security and low power consumption [4]. Additionally, VLC equipment is usually lightweight and occupies less space compared to RF equipment, which also has a crowded spectrum and is more expensive. Recently, VLC research focus has been based on different modulation techniques such as On-Off keying (OOK) and orthogonal frequency division multiplexing (OFDM). In [5] demonstration of VLC, based on OOK non-return-to-zero (OOK-NRZ) with full-duplex wireless is made, where a 1 W white LED is used between two computers with the upper limit of transmission rate achieving 2 Mbps and BERs being lower than 10^{-6}. Alternatively, in [6] the real-time OFDM technique using a compact size phosphor white LEDs has been implemented and investigated throughputs over 0.5 m free space transmission. An OFDM system using a 1 W LED has been installed in the laboratory and in the course of experiments its reliability has been demonstrated [7]. A VLC system [8] using white LED (3 W) achieved a data

rate of 111 kbit/s at a free space distance of 1.5 m, where LED was proposed as a strong candidate for indoor VLC systems. Another VLC system using OFDM for intensity modulation was demonstrated in [9], which considered high brightness LEDs. The experiments were conducted using only a single LED, achieving a BER of 10^{-3} at a distance of 1 m. However, it was also suggested that using an array of similar LEDs would achieve a better BER and a greater range. In order to increase the data rate to reach up to hundreds of Mbps, post-equalization technology and pre-emphasis have been added to the receiver and transmitter, respectively [10-13]. 10 Mbps with a BER of 10^{-10} has been achieved through VLC based on white LED using a first-order RC-equalisation, with 1 MHz bandwidth [14]. The drawbacks of using OFDM techniques include sensitivity to carrier offset and drift, and also a high peak to average power ratio.

Pulse position modulation (PPM) is defined as an orthogonal modulation method and it belongs to the family of pulse modulation. Power efficiency of OOK is improved with the method of PPM modulation but it requires higher bandwidth and is more complex [4]. For the improvement and mitigation of transmission quality and the effects of inter symbol interference (ISI) respectively an investigation was conducted with dicode pulse position modulation technique (DiPPM) [15]. In previous experiments by the others, offset pulse position modulation technique has been implemented using a 30 W LED based VLC equipment achieving a data rate of 11 Mbps [16].

To conclude from the previous studies, in order to improve data rate transmission, it is necessary to take into account the type of LEDs, modulation techniques, use of optical filters and the distance between receiver and transmitter. In this paper, the VLC based on high power LED (30 W), using a simple transceiver circuit, has been successfully investigated, where the DiPPM (non-coherent modulation) technique has been implemented, resulting in expensive and complex carrier circuits not being required, as is in the case OFDM or OOK.

II. THE DICODE PULSE POSITION MODULATION (DiPPM)

Satellite, optical fiber and intensity modulation optical communication systems utilize digital pulse position modulation (DPPM) extensively [17]. DPPM and dicode signaling were combined in order to develop DiPPM. Although, DPPM has a higher sensitivity than DiPPM due to low mark-space ratio, M bits of data is transmitted using a single pulse by positioning it in one of the 2^M bits.

DPPM suffers from large bandwidth expansion problem leading researchers to investigate alternative techniques like DiPPM.

Table 1 shows the signal representation of DiPPM [17]. For DiPPM signals, data transition of one to zero is encoded as a Set pulse (S), and transition of zero to one as a Reset pulse (R). No change occurs in DiPPM format when the data is at a constant high or low level. The S pulse is positioned in slot 1 (when clock is high) and the R pulse in slot 0 (when the clock is low). Figure 1, exemplifies the generation of DiPPM signal from a pulse code modulation (PCM) signal.

TABLE 1. SYMBOL ALPHABET OF DiPPM [17]

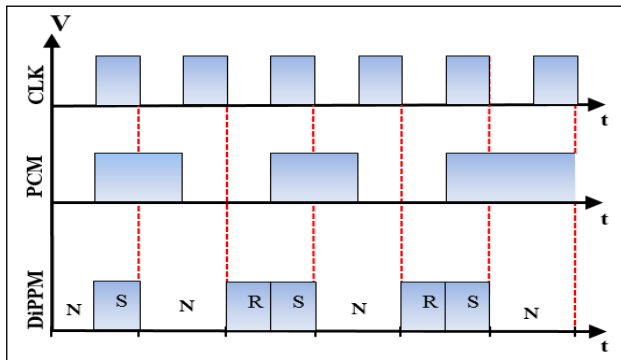| PCM	DiPPM
00	No pulse (N)
01	Set (S)
10	Rest (R)
11	No pulse (N)

Fig. 1. Conversion of PCM data into DiPPM.

The performance of DiPPM has been analysed and compared to that of DPPM and PCM. It was found that DiPPM can be considered as an alternative modulation technique for free space links as it outperforms PCM [15, 17]. In order to improve the sensitivity of DiPPM, Reed Solomon (RS) codes or maximum likelihood sequence detection (MLSD) technique can be implemented [18, 19].

III. RECEIVER CIRCUIT DESIGN

The developed receiver, in this work, uses a commercially available Si PIN (BPW34) photodiode for optical to electrical conversion with 7.5 mm^2 sensitive area and $\pm 65°$ angle of half sensitivity. The generated current is converted to a voltage by a trans-impedance amplifier (TIA), which is applied to a comparator (MAX942) to convert the receiver output, to either 0 V or 5 V. Figure 2, shows the circuit of a simple emitter follower trans-impedance preamplifier. An amplifying circuit (Q2) between two buffers (Q1 and Q3) is designed for the Si PIN preamplifier receiver. A common-collector (CC) front-end receiver was used to obtain a wideband response with high sensitivity. The advantage of employing a CC front end is that the first-stage Miller capacitance is eliminated. Additionally, the response is not significantly affected by high values of base spreading resistance which

may be encountered when operating at low bias current or when using high-current-gain transistors. In this design the current gain and output impedance of the CC stage are sufficiently high for the second-stage noise to be insignificant compared with the first-stage noise.
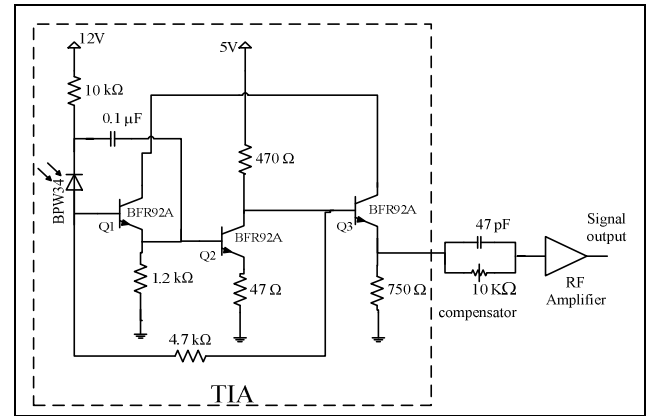

Fig. 2. Receiver circuit design.

The TIA response was upgraded by adding an RC lead compensator on the same board of TIA with dimensions (55 mm x 50 mm) in order to improve system response by reducing the rise time, and then the output of lead compensator was connected to an RF amplifier by a 50 Ω SMA Plug to amplify the signal. The resistor and capacitor in RC lead compensator have been chosen and calculated in order to extend the LED bandwidth above 2 MHz. A capacitor of 47 pF has been selected in order to match a 50 Ω load resistor for a wide bandwidth. Then, the variable resistor (10 kΩ) has been calculated and adjusted to 1.69 to give 2 MHz bandwidth.

IV. SYSTEM IMPLEMENTATION

Figure 3, shows the experimental setup of the proposed system. The DiPPM coding system was programmed into the Field Programmable Gate Array (FPGA) development board via the Quartus II software using VHDL. A pseudorandom binary sequence (PRBS) signal was modulated by the FPGA through the Quartus II software, which was delivered directly to a high power LED (30 W LED floodlight, LED lighting, waterproof IP65) via a Bias-T (Picosecond Pulse Labs 5575A). A 1.2 m free space distance has been taken between the photodiode (PD) and LED, where an optical convex lens (60 mm focal length) was fixed in front of the PIN photodiode (BPW34) which has been built into the trans-impedance preamplifier (TIA) board. The RF amplifier with a 0.01 – 1000 MHz bandwidth and a 32 dB gain, was used to further amplify the output voltage of the TIA. A low power, high-speed comparator (MAX942) has been used to compare the voltage levels, which applied to the FPGA board to compare with the transmitted PRBS signal, and then showed the result on the PC through the USB cable via the signal tap II of the logic analyser. Finally, the signals have been plotted and analysed using a digital oscilloscope with four channels (Rohde & Schwarz RTO1044 Oscilloscope; 4 GHz).
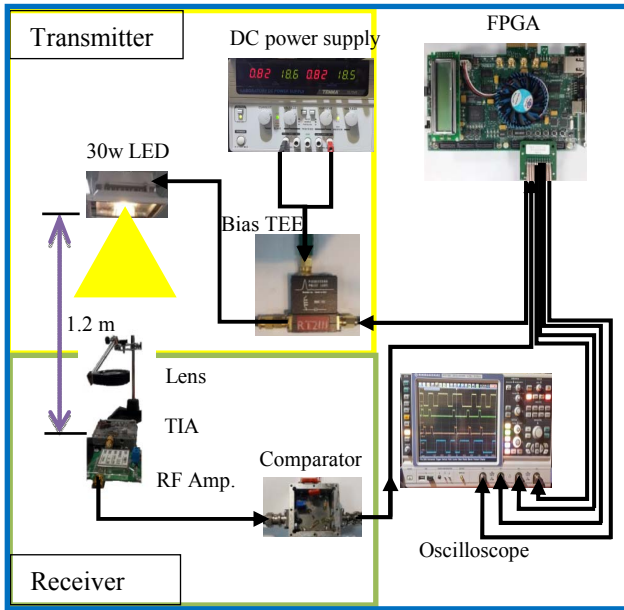
Fig. 3. Experimental setup

V. IMPLEMENTATION OF DICODE PULSE POSITION MODULATION (DiPPM).

Figure 4, describes the schematic block diagram of the experimental VLC system based on DiPPM using 30 W LED. It comprises two parts: hardware and software. In the software part, VHDL code is implemented to generate a data signal via a PRBS, BER measurement, DiPPM coder and decoder in the FPGA. Afterwards the PRBS signal is encrypted by the DiPPM encoder, which is sent to the LED via bias Tee. The hardware part encompasses the VLC transmitter and receiver circuits. In the transmitter circuit, the high power LED (30 W) has been connected to the data and power supply via a bias Tee.
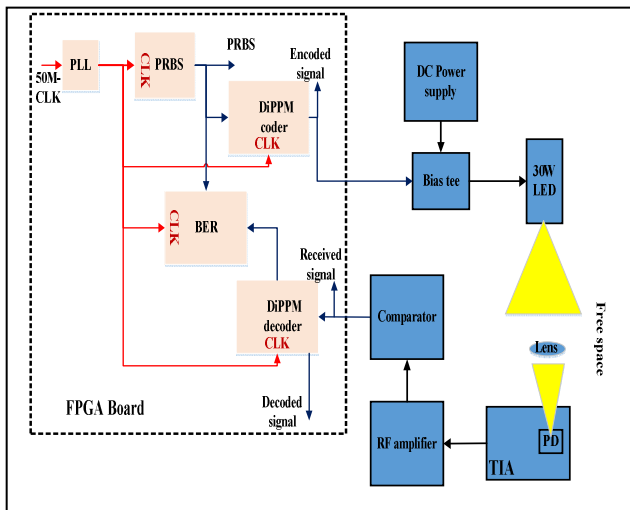

Fig. 4. Block diagram of the DiPPM based on VLC.

Furthermore, the receiver circuit comprises a photodiode (PD) and a trans-impedance amplifier (TIA) with a gain of 10 dB to recover the signal, which is observed using a digital oscilloscope. Finally, the received signal from the comparator is fed to the FPGA to retrieve the coded signal.

VI. RESULTS AND DISCUSSIONS

Dicode PPM was implemented in a practical system, for the first time within a VLC based system, at a maximum working data rate of 13 Mbps and a free space distance of 1.2 m using a 30 W commercially available white LED. Figure 5, illustrates the measured signals from oscilloscope at the date rate of 13 Mbps. It can be seen that, there is a similarity between the transmitted signal and the received signal, resulting in the decoded data from the received signal being identical to the original PRBS signal.
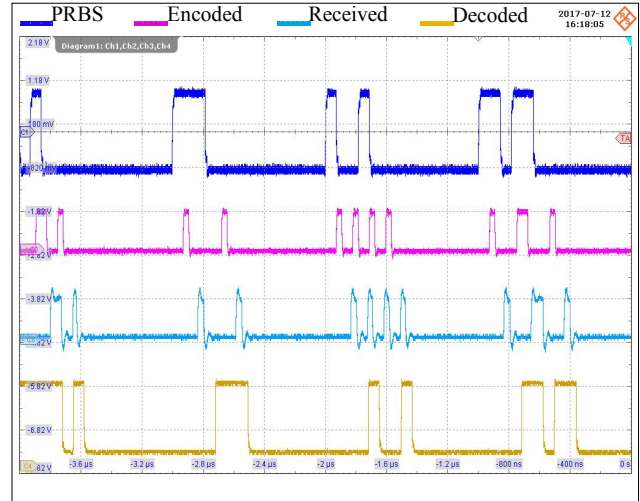

Fig. 5. Measured transmitted and received signals.

Further verification of system operation was performed, with the FPGA board being connected to a PC to display the simulation signals through the signal tap II logic analyser using Quartus II software as shown in Figure 6. The BER was less than 10^{-11} up to 13 Mbps and at 14.5 Mbps the BER was increased up to 1.15×10^{-6}, but increases for frequencies above 13Mbps as the transmitted signal suffers from intersymbol interference resulting in the received signal being no longer identical to the transmitted signal.
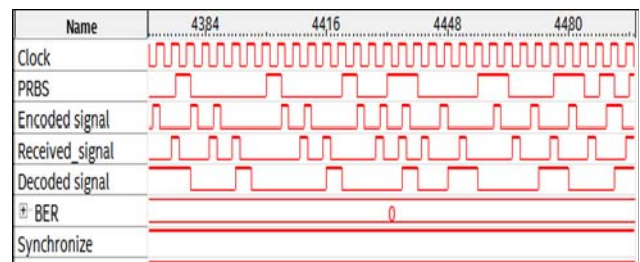

Fig. 6. Waveforms of the DiPPM simulation.

Figure 7, presents the BER performance versus different transmission distances keeping data rate constant at 13 Mbps. It can be found that the BER sharply increased as distance increases above 1.4 m. However, the system is able to work over greater distances than 1.2 m with acceptable BER of approximately 10^{-5} up to a distance of 1.8 m.
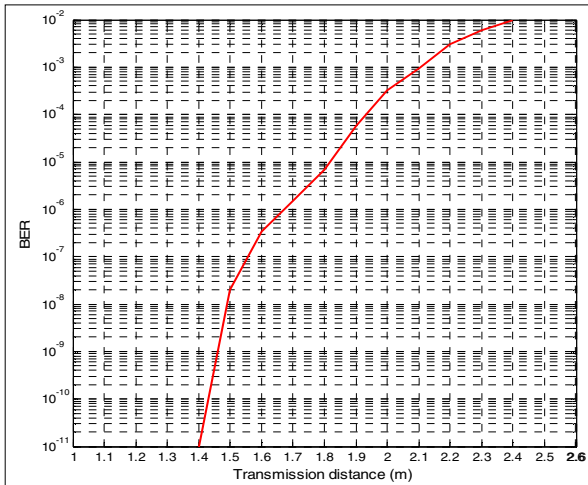
Fig. 7. BER versus different distances.

VII. CONCLUSION

This work presented the practical implementation of DiPPM coding scheme on a VLC based system, using an FPGA and high power 30 W LED. At a data rate of 13 Mbps, the measured error rate was better than 1 error in 10^{11}. As the transmission distance is increased, the BER also increases, at a distance of 1.8 m the BER was 10^{-5}. This work proves that DiPPM holds the potential for free space communication.

With the improvements of hardware circuitry, ISI levels will be reduced, and higher speeds and greater distances will be a possibility. The incorporation of MLSD technique or RS codes can also be implemented in order to reduce the BER.

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