A Low-complexity of VLC System using BPSK

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Abstract—The design, implementation, and demonstration of visible light communication (VLC) system using Binary Phase Shift Keying (BPSK) modulation has been presented in this short paper. Our system is applied for indoor environment purpose. The test result shows that our VLC system able to work properly as expected, the BPSK constellation can be formed wirelessly through a visible light link. We obtained 13.4 kbps of maximum data rate transfer.

Keywords—BPSK, Indoor application, VLC

1 Introduction

Nowadays, there is growing academic interest in visible light communication (VLC) studies. According to a report from **[1]**, the scientific documents in 'Google scholar database' and 'IEEE Xplore digital library' are tend to increase in every year (from 2010 to 2015). We observe the research area of VLC in terms of indoor applications, it can be divided into several focuses including 1) the exploitation of hybrid-communication technologies, like hybrid RF-VLC, PLC-VLC, IR-VLC, and etc.; 2) indoor positioning system by light; 3) high-speed VLC system up to Tens of Gbps; 4) robust-VLC system against the optical influence, 5) modulation modeling, 6) re-engineering design for low-complexity VLC system purpose and etc.

There are various modulations that employed for VLC system contains the digital- and analog-modulation **[2]**, such as

- SCM-based (*e.g.* OOK, PWM, M-PAM, M-PPM, CAP, and etc.),
- Color-based (CSK and CIM), and
- OFDM-based with different mappers (*e.g.* BPSK, QPSK, QAM-16, QAM-64, and etc.).

The OFDM is the most popular technique for high-speed and efficient data transfer of VLC system. There are various types of OFDM **[2]**, such as:

- DCO-OFDM,
- Inherent unipolar type (*e.g.* ACO-OFDM, PAM-DMT),
- Superposition OFDM type (eU-OFDM and LACO-OFDM),
- hybrid OFDM type (RPO-OFDM and HACO-OFDM), and etc.

Associated with the modulation for VLC, in our previous work, we have been performed a VLC system with certain modulations, specifically a digital modulation: Pulse Width Modulation **[3-6]**, Pulse Position Modulation **[7]**, and the simplest modulation, OOK **[8-10]**. According to the comparison results among them, the mentioned modulations are wasteful in utilizing the available bandwidth, thus the communication speed is very limited **[11].** One of the solutions is employed the multiplexing technique such as OFDM scheme to thrift the optical system's bandwidth **[12]**.

In this work, we implement the simple OFDM scheme with Binary Phase Shift Keying (BPSK) mapper. The BPSK was chosen because of the most powerful of all types of PSK. It takes the highest distortion level to make the demodulator perform the wrong decision. The rest of this paper has been organized as follows, second section discusses the methodology. Third section looks to the successful demonstration. The last part is closed by fourth Section, that is conclusions and references.

2 Methodology

2.1 Modulation Design

(a)	(b)
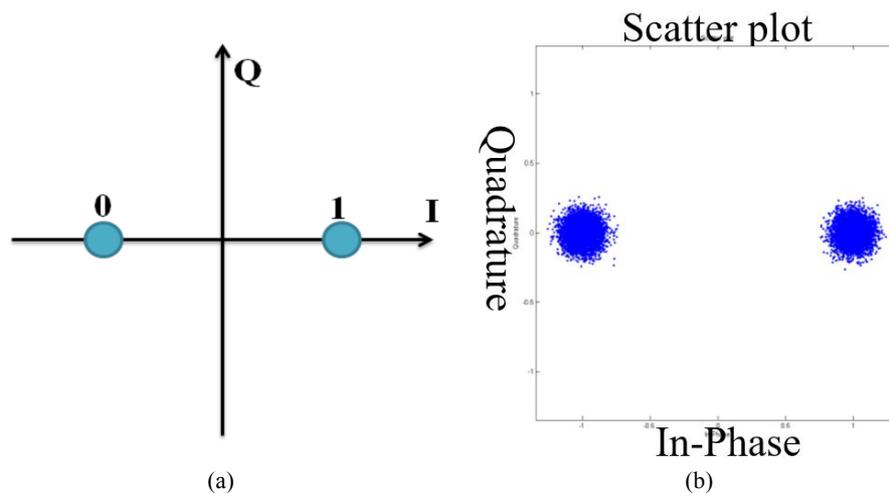
Fig. 1. Constellation diagram for gray-coded BPSK: (a) an illustration, reproduced from [13]; (b) simulation in MATLAB with signal-to-noise ratio (SNR) = 20 dB

BPSK only uses two separate phases as far as 180°, so it can be called as 2-PSK. The determination of the point location in constellation diagram is free anywhere. However, it must with a specific requirement that the two points are separated as far as 180°. Fig. 1(a) shows the two points are located on the real axis (at 0° and 180°). In BPSK modulation, the signal is reflected in two possibilities: signal '1' is represented by giving a phase-shift of a carrier signal with 0°. Whereas the signal '0' is represented by shifting the signal phase carrier with 180°. Fig. 1(b) depicts the simulation of

BPSK in MATLAB. The BPSK is only able to modulate '1 bit' per symbol so it is not suitable for high-speed data rate applications.

2.2 Analog Front-End Design

Fig. 2 depicts the whole system of our VLC system. The USB is employed to connect the computer to the VLC module. The microcontroller STM32F4 was chosen as the main controller. We used components with a low-cost factor in order to meet the low-complexity requirement of VLC system. The antenna is utilized a commercially white LED while the PIN photodiode was employed as a photo-sensor.

As shown in Fig. 2, the physical layer of our VLC system contains a low-cost Bias-T and analog front-end receiver that has been realized by Op-Amps configuration. The Bias-T blocks consist of gain buffer, voltage reference circuit, DC-offset adder, and current amplifier. We discuss the design and implementation of Bias-T clearly in [14-18]. While the receiver blocks consist of TIA circuit [19-21], Pre-Amp, DC-offset adjuster with auto and manual mode, analog filter [22-24], and automatic gain controller circuit [25-26].
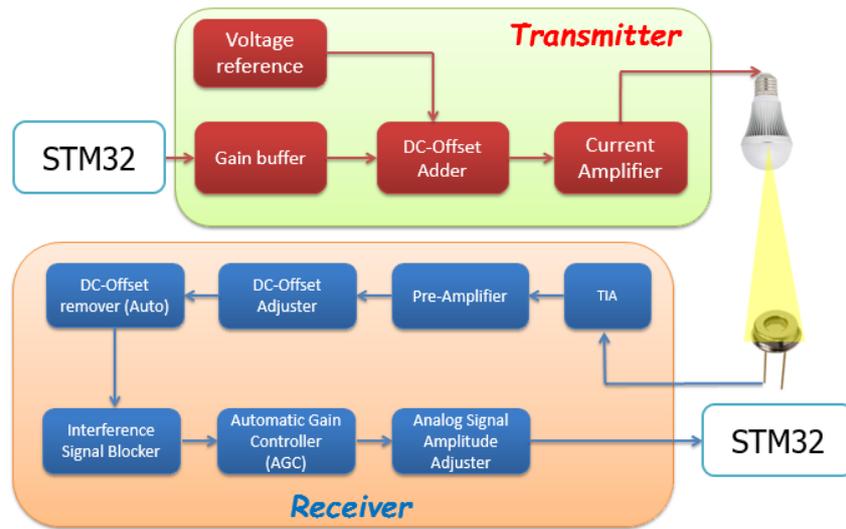

**Fig. 2.** The VLC transceiver blocks

3 Results

Fig. 3(a) visualizes the demonstration of our VLC system using BPSK modulation in which the parameters for testing are referred to Table 1. It contains of seven variables (*i.e.* LED, Photodiode, channels setting, topology of link used, the environment condition of the performance test, initial optical angle, and distance of channel). There are 2 computers used for displaying the transmitted and received BPSK signal.

Based on the performance test as shown in Fig. 3(b), we can conclude that the BPSK constellations can be formed through visible light link. However, those constellations that viewed from Fig. 3(b) are too small, thus we zoomed-out the achieved data as depicted in Fig. 4 for various distances of the optical channel. It can be concluded that the longer optical distance the higher error at receiver. The optical distance is about 50 cm for the best option.

The user interface was developed by the Delphi 7.0 software which is installed in PC transmitter as well as PC receiver. In summary, we obtained 13.4 kbps of data rate, this is the maximum speed transfer using BPSK modulation. The measurement methodology of available bandwidth and its SNR are discussed in separate papers (Please see the following references [28-29]). While the obtained bit rate and bit-error rate (BER) are discussed in [30-31].

Table 1. Parameters of VLC demo

Parameters	Information
LED	Model: Hyrite Coochip® LEDMD-W110C Color: Cool white Type: Phosphorus (pLED) LED Power: 9 Watts
Photodiode	Model: KODENSHI SP-8ML [27] Type: PIN photodiode Short current: 270 µA @ 1000 Lux
Channels	Directed Line-of-sight (LoS)
Link topology	Point-to-point communication
Test condition	Dark
Optical angle	Ideally 0º
Optical channel distance	To be varied

(a)   (b)
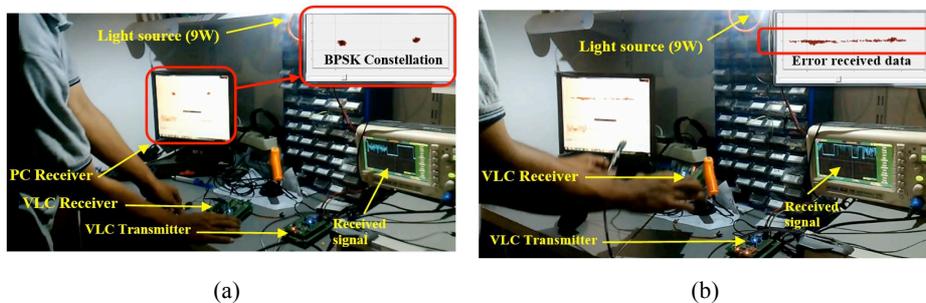
Fig. 3. Demonstration of VLC system based on DCO-OFDM (BPSK mapper): (a) real-time constellation using BPSK at ideal distance; (b) A photograph of experiment when the angle of reception was changed shorter/longer. *Documented by S. Fuada & A. Pradana ©2016.*
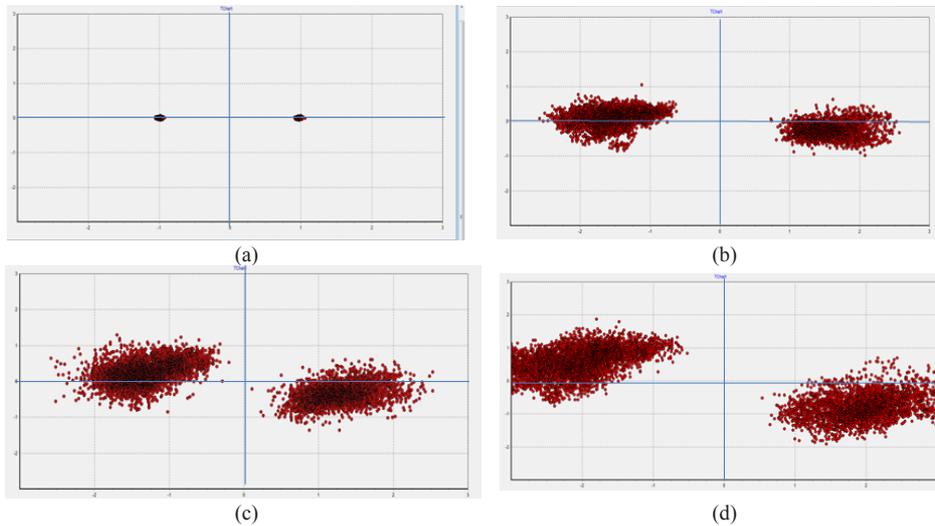
Fig. 4. Constellation of BPSK mapper for: (a) 50 cm; (b) 75cm; (c) 100 cm; (d) 130 cm of optical channel (the distance between VLC transmitter to the VLC receiver)
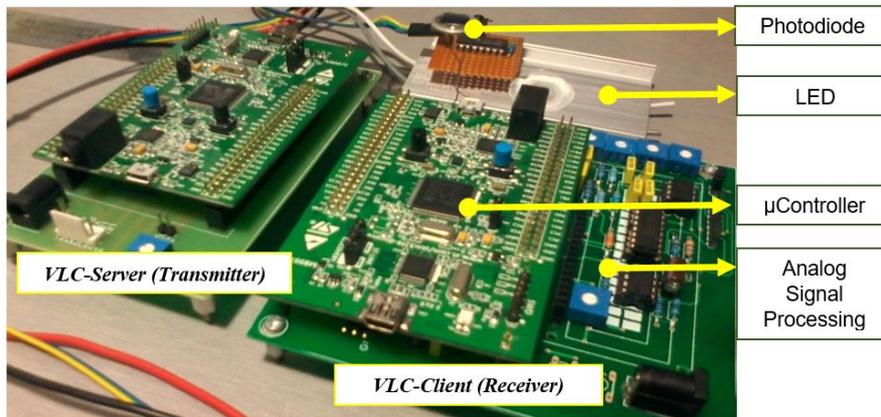
Fig. 5. The Hardware of low-complexity VLC system consisting transmitter (Bias-T circuit and Micro-controller Tx) and receiver module (Analog receiver and Microcontroller Rx), retrieved and fully edited from **[11]** with permission

4 Conclusions

In line with performance test, it can be summarized that the designed BPSK can met the qualification of with the related theories. Our VLC system can perform properly with optical distance up to 40 cm. We carefully designed our system to great deal with low-complexity target. Using BPSK modulation, we obtained the maximum bitrate of ~13.4 kbps. This work is part of Master thesis that can be found in **[11]**.

5 Acknowledgment

6 References

[1] M. Figueiredo, *et al.*, "Lighting the wireless world: the promise and challenges of visible light communication," *IEEE Magz*. October 2017.

[2] M.S. Islim and H. Haas, "Modulation Techniques for Li-Fi," *ZTE Communications*, Vol.14(2), pp. 29-40, April 2016.

[3] A. Pradana, *et al*, "Design and Implementation of Visible Light Communication System using Pulse Width Modulation," *Proc. of the 5th ICEEI*, pp. 25-30, August 2015. https://doi.org/10.1109/ICEEI.2015.7352464

[4] T. Adiono, S. Fuada, and A. Pradana, "Desain dan Realisasi Sistem Komunikasi Cahaya Tampak untuk *Streaming* Teks berbasis PWM," *J. Setrum,* Vol. 6(2), pp. 270-279, Desember 2017.

[5] A. Pradana, S. Fuada, and T. Adiono, "Desain dan Implementasi Sistem *Visible Light Communication* berbasis *Pulse Width Modulation*," *Unpublished.*

[6] T. Adiono, A. Pradana, and S. Fuada "Rancang Bangun Sistem Komunikasi Cahaya Tampak dengan Modulasi 2-PWM berbasis Mikrokontroller," *Unpublished.*

[7] A. Pradana, *et al*. "VLC Physical Layer Design based on Pulse Modulation (PPM) for Stable Illumination," *Proc. of ISPACS*. pp. 368-373. November 2015.

[8] T. Adiono, R.A. Saputro, M. Lutfi, and S. Fuada, "A real-time wireless video streaming based on VLC Technology using FPGA," *Unpublished.*

[9] T. Adiono, R.A. Saputro, M. Luthfi, and S. Fuada, "FPGA Implementation for Real-time File Transfer using Visible Light Communications," *Unpublished.*

[10] T. Adiono, et al., "Visible light communication system for wearable patient monitoring device," *Proc.of TENCON,* November 2016. https://doi.org/10.1109/TENCON.2016.7848 367

[11] A. Pradana, "Rancang bangun layer fisik komunikasi cahaya tampak berbasis DC-OFDM dan PWM," Master thesis, ITB, 2016.

[12] T. Adiono, Yulian Y. Aska, A.A. Purwita, S. Fuada, and A.P. Putra. "Modeling OFDM system with Viterbi Decoder Based Visible Light Communication," *Proc. of ICEIC*, January 2017.

[13] Anonymous, "Comparison of 8-QAM, 16-QAM, 32-QAM, 64-QAM 128-QAM, 256-QAM," Available at: www.electronics.com/info/rf-technology-design/quadrature-amplitudemodulation-qam/8qam-16qam-32qam-64qam-128qam-256qam.php.

[14] S. Fuada, T. Adiono, A. P. Putra, and Y. Aska, "A Low-cost Analog Front-End (AFE) Transmitter Designs for OFDM Visible Light Communications," *Proc. of the IEEE Int. Symposium on Electronics and Smart Devices* (ISESD), pp. 371-375, October 2016. https://doi.org/10.1109/ISESD.2016.7886750

[15] T.Adiono and S. Fuada, "Desain dan Implementasi LED Driver Linier untuk Aplikasi *Visible Light Communication,"* *Unpublished.*

[16] T. Adiono and S. Fuada, "Prototyping Design of Low Cost Bias-T Circuit based-on Op-Amp for Visible Light Communication," *Unpublished.*

[17] S. Fuada, and T. Adiono, "Rancang Bangun Layer Fisik Visible Light Communication Pada Sistem Transmisi Audio," *J. INFOTEL*, Vol. 9(3), pp. 352-360, August 2017. https://doi.org/10.20895/infotel.v9i3.288.

[18] S. Fuada, T. Adiono, A.P. Putra, Y. Aska, "LED Driver Design for Indoor Lighting and Low-rate Data Transmission Purpose, *Optik-Int. J. for Light and Electron Optics*, Vol. 156, pp. 847-856, 2017, https://doi.org/10.1016/j.ijleo.2017.11.180.

[19] S. Fuada, A.P. Putra, Y. Aska, and T. Adiono, "Trans-impedance Amplifier (TIA) Design for Visible Light Communication (VLC) using Commercially Available OP-AMP," *Proc. of the 3rd Int. Conf. on Information Tech. Computer, and Electrical Engineering* (ICITACEE)*, pp. 31-35, October 2016. https://doi.org/10.1109/ICITACEE.2016.7892405

[20] S. Fuada, T. Adiono, A.P. Putra, and Y. Aska, "Noise Analysis in VLC Optical Link based Discrete OP-AMP Trans-Impedance Amplifier (TIA)," *Jurnal of TELKOMNIKA*, Vol. 15(3), pp. 1012-1021, September 2017. https://doi.org/10.1109/ICITACEE.2016.7892405

[21] S. Fuada, A.P. Putra, Y. Aska, and T. Adiono, "Noise Analysis of Trans-impedance Amplifier (TIA) in Variety Op Amp for use in Visible Light Communication (VLC) System," *International Journal of Electrical and Computer Engineering* (IJECE), Vol. 8(1), 2018

[22] T. Adiono, A. Pradana, R.V.W. Putra, and S. Fuada, "Analog Filters Design in VLC Analog Front-End Receiver for Reducing Indoor Ambient Light Noise," *Proc. of the IEEE Asia Pacific Conf. on Circuit and Systems* (APCCAS), pp. 581-584, October 2016. https://doi.org/10.1109/APCCAS.2016.7804058

[23] T. Adiono, and S. Fuada, "Optical Interference Noise Filtering over Visible Light Communication System Utilizing Analog High-Pass Filter Circuit," *Proc. of the 2017 Int. Symp. on Nonlinear Theory and Its Applications* (NOLTA), pp. 616-619, December 2017.

[24] S. Fuada, A.P. Putra, Y. Aska and T. Adiono, "A First Approach to Design Mobility Function and Noise Filter in VLC System Utilizing Low-cost Analog Circuits," *Int. J. of Recent Contributions from Engineering, Science, and IT* (iJES), Vol. 5(2), pp. 14 – 30, 2017. https://doi.org/10.3991/ijes.v5i2.6700

[25] T. Adiono, S. Fuada, and R.A. Saputro, "Automatic Gain Control Circuit for Mobility Visible Light Communication System using LM13700" *Proc. of the IEEE Int. Symposium on Electronics and Smart Devices* (ISESD), Yogyakarta, Indonesia, October 2017.

[26] T. Adiono, A. Pradana, and S. Fuada, "Employing LM13700 as AGC for Mobile Visible Light Communication System,"*Unpublished.*

[27] T. Adiono and S. Fuada, "Karakteristik PIN Photodiode KODENSHI SP-8ML untuk Aplikasi Visible Light Communication," *Unpublished.*

[28] S. Fuada, "Design and Implementation of Analog Front-End Transceiver Module for Visible Light Communication System," M.T. thesis, Dept. Elect. Eng., School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia, 2017.

[29] T. Adiono, S. Fuada, and S. Harimurti, "Bandwidth Budget Analysis for Visible Light Communication Systems utilizing Commercially Available Components," *Proc. of the 10th Int. Conf. on Electrical and Electronics Engineering* (ELECO), pp. 1375-1380, December 2017.

[30] T. Adiono, A. Pradana, and S. Fuada, "A Low-Cost Hardware Implementation for QAM-16 Visible Light Communications," *Unpublished.*

[31] T. Adiono, A. Pradana, and S. Fuada, "Visible Light Communications System using Quadrature Phase-Shift Keying," *Unpublished.*

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