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Dimming Techniques for Visible Light Communication System

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ABSTRACT

Visible light communication (VLC) is an emerging and promising new technology in optical wireless communication (OWC). However, dimming has an adverse effect on the performance of visible light communication system. In visible light communication (VLC) system, illumination and communication both are provided simultaneously using a light emitting diode (LED). The specification for lighting is application specific for which dimming control is required. There are different modulation techniques for dimming control in visible light communication. In this thesis, NRZ-OOK modulation method and 4-QAM-OFDM modulation techniques are investigated for different dimming range, transmission distance, beam divergence angle and bit rate. The result shows that for 13m link range, 5Gb/s data speed is achievable for the 4-QAM-OFDM scheme. The analysis of this research is executed only based on system parameters. The scope of this research excluded the following parameters which are shadowing, mobility, multipath interference and inter-symbol interference for multicarrier modulation. These are the related research topic which can be investigated for future work.

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1. INTRODUCTION

Visible Light Communication (VLC) is a short-range optical wireless communication that uses light to transmit data. The data transmitted through light emitting diodes (LED) and photodetector as the receiver. Since LED can switch faster than the human eye can respond, they can modulate at high data rates; offering not only illumination as well communication capabilities. The technology falls into a visible light spectrum with a bandwidth ranges between 380nm to 780nm (corresponds to a frequency range of approximately 384 THz to 789 THz). VLC is the best alternative for the wireless system due to the limited bandwidth available in Radio Frequency (RF) spectrum, network interference, and interference in sensitive electronics. Table 1 illustrates the comparison between VLC and RF system.

In term of the data communication through light, VLC is getting more attention from a communication service provider point of view. However, the illumination side of it requires consideration since globally, electricity consumption for lighting is projected to increase by 60 percent over the next 25 years [1]. Due to this problem, dimming function is crucial in VLC system since it is working as a source of illumination and also communication. Dimming property can be beneficial regarding energy efficiency, lifespan, and extended lifetime [2].

In this study, we discussed the dimming techniques for VLC using NRZ-OOK and 4QAM-OFDM, modulation methods The subsection begins with a discussion of the dimming technique of LED follows with modulation technique, result, and analysis, and conclusion.

Table 1. The comparison between VLC and RF

Specifications	Visible Light Communication (VLC)	RF Communication
Available spectrum	400THz to 800 THz	3KHz to 300 GHz
Coverage	Limited	Mostly wide
Standards	IEEE 802.15.7	Matured
Distance	Short	Short to long
Security	Good	Poor
EM Interference	No	Yes
Multipath	Low	High
Power consumption	Relatively low	Medium
System Complexity	Low	High
NLOS performance	If the reflected signal is poor, we can not establish any communication.	Communication is possible but performance degraded due to signal fading
External power requirement	No	Yes
Material cost	Comparatively cheap	Expensive
Services	Illumination & Communication	Communication

2. DIMMING TECHNIQUES OF LED

Many lighting applications require dimming control for energy savings and aesthetic requirements. Since LED emits incoherent light which is driven by current, the emitted intensity of LED lights has to be monitored and adjusted according to the functional requirements for us to be able to implement dimming scheme.

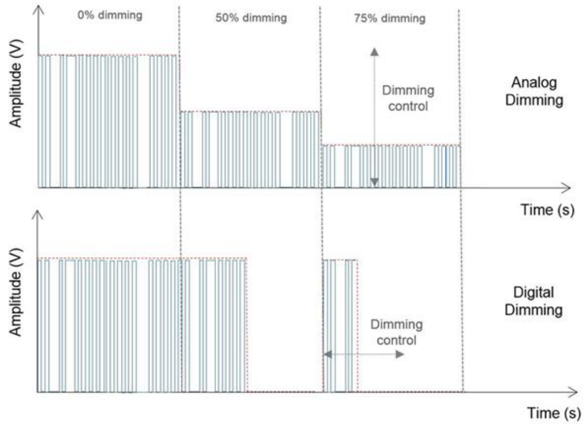

Figure 1. Concept of analog dimming and digital dimming [1]

There are two techniques to implement dimming scheme over LEDs, as shown in Figure1 that are analog dimming and digital dimming. Each technique of dimming has its advantages and disadvantages. We select the analog dimming for evaluation due to the non-complex circuitry, although it can cause chromaticity shift whereas, in digital dimming, chromaticity is not an issue since the signal can maintain higher value. Conversely, the possible data speed decreases when the duty cycle of pulse width modulation (PWM) signal is low [3]. It is imperative to identify the critical features of each method for each application.

2.1. Analog Dimming

Analog dimming is known as a continuous current reduction (CCR) which performs by reducing the forward current through LED. We can adjust the intensity of emitted light LED by varying the forward current at a possible lowest level to attain the desired output. This method is easy to implement because of the driver circuitry is not complex, but it requires the right controller to achieve accurate control over current to provide an efficient dimming. The forward current of LED is varied directly in analog dimming which causes the chromaticity shift.

2.2. Digital Dimming

The digital dimming is pulse width modulation (PWM) where pulses are modulated digitally to drive the LED at a constant current level. PWM modulates the duty cycle of the pulse which is the time interval when the pulse is ‘on’ state, the only state the data transmission occurred [4]. All the LED light is on with the highest brightness when the duty cycle is '1'. We can achieve desired dimming percentage by reducing the duty cycle of PWM signal. Digital dimming is the most preferable and shared approach to VLC due to its significant dimming precision. It also reduces the light intensity of LED more linearly than analog dimming and requires higher dimming accuracy and data transmission at lower brightness level [5].

3. MODULATION TECHNIQUE

The data is modulated onto a carrier signal by modulation techniques to transmit the data through LED. There are many variants of modulation methods and the performance of different modulation technique that we can evaluate by analyzing the modulation schemes based on the changes of various system parameters. In our work, we analyzed the performances of NRZ-OOK, M-ary PAM and M-QAM-OFDM schemes based on bit rate, beam divergence, transmission distance and duty cycle or dimming. All the simulation parameters were maintained constant throughout the simulation for all modulation techniques. However, in this preliminary study, we are going to present the data analyzed with NRZ-OOK modulation technique only. The analysis is done using Optisystem simulation software. The block diagram of the simulation circuit is as shown in Figure 2.

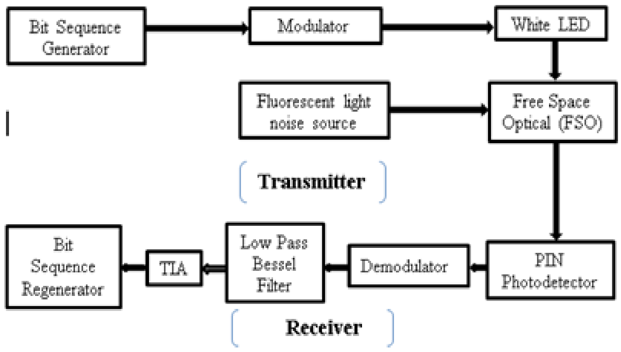

Figure 2. Block diagram of VLC simulation design

The VLC system consists of VLC transmitter, a free space optical channel and VLC receiver. It uses intensity modulation and direct detection (IM/DD) for data transmission through LED. Transmitted data is modulated by intensity modulation based on the instantaneous power of LED and converts the electrical to optical power. Photodiode performed direct detection technique which transforms the received optical power to electrical power [6]. The demodulator demodulates the data and transmits through filter and amplifier. The filter used to remove the undesired frequency from the signal and amplifier amplifies (Transimpedence Amplifier, TIA) the weak current signal from the photodiode. Then the bit sequence regenerator recovers back the original data. These are the entire process of transmitting and receiving information in a VLC system. Table 2 illustrated the simulation parameters along with the assigned values for the Optisystem components.

Table 2. Simulation parameters of Optisystem components

Parameters	Value
White LED	Frequency: 450nm Bandwidth: 1 MHz Electron life time: 1ps RC constant: 1ps Quantum efficiency: 0.65
Ambient light noise	Frequency:50Hz Power: 36W
FSO	Attenuation:0.008 dB/km
PIN photodiode	Responsivity: 0.22 A/W Dark current: 10nA
Low Pass Bessel Filter	Cut off frequency: 0.75*Bitrate
Transimpedance Amplifier (TIA)	Voltage gain: 90 ohm Bandwidth: 240MHz

4. EVALUATION OF NON-RETURN TO ZERO ON-OFF KEYING (NRZ-OOK)

As described before, there are two ways to implement dimming in a modulation method that is digital dimming and analog dimming. We implement and analyze the analog dimming in NRZ-OOK modulation scheme for our VLC system. In NRZ-OOK, the probability of binary symbols has 50% average light intensity. The 'OFF' symbol intensity can be moved from 0% to 50% intensity for 75% dimming [7],[8] by varying the forward current of LED in analog dimming. The forward current of LED increased with the increase of threshold voltage. The threshold voltage is also called the turn-on voltage, and the range of the LED turn-on voltage is 1 to 4 Volts. We evaluated the BER and Q factor for different dimming levels for NRZ-OOK modulation technique.

In the benchmarking research [9], the researcher used NRZ-OOK modulation technique for 10kb/s data transmission. The simulation parameters and values utilized in this investigation are set constant throughout the simulation for all modulation techniques which is same as in [9]. Using NRZ-OOK modulation scheme, the researcher in [9] achieved BER and Q factor of 2.48×10^{-33} and 11.9328 respectively for 10kb/s data transmission. From our evaluation and analysis, we managed to achieve better performance of VLC system compare to the benchmarking system. We achieved BER of 8.23739×10^{-278}, and Q factor is 35.5838, as shown in Figure 3, which is better than the benchmarking research for 10Kb/s bit rate and 10m link distance.

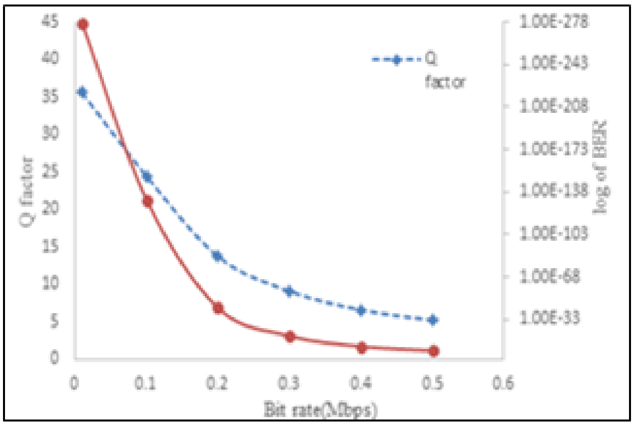

Figure. 3. Q factor vs. bit rate and BER vs. bit rate for NRZ-OOK system

The optical intensity of LED does not return to zero between pulse '1' and '0' where the entire bit interval is occupied by '1' bit and there is no pulse generate for '0' bit [10]. In NRZ-OOK, the forward current of LED is varied to dim the LED which affects the transmitted power. The transmitted power is observed 1.7mW when the achieved BER is 6.47×10^{-11}. By increasing the forward current of LED, the transmitted power also rises to 2.51mW where we acquired BER of 5.69×10^{-270} due to the high intensity of LED. However, in [9], their obtained BER is 2.48×10^{-33} for the transmitted optical power of 2.735mW.

We improved the performance of the NRZ-OOK by removing the rectangle optical filter and increasing the bit sequence length. The bit sequence length is a global parameter which affects all Optisystem simulations. The sequence length transmitted to the system determines the number of bits. Longer bit sequence length improves the performance of BER. It increases the accuracy of BER calculation and computation time as well. However, we achieved 400kb/s data speed using NRZ-OOK which is higher than in [9]. The clear eye diagram represents low BER in Figure 4 for 10kb/s and 10m link distance.

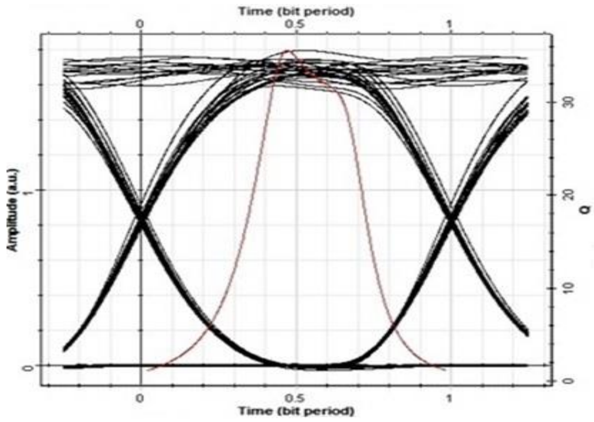

Figure 4. Eye diagram output of 10kb/s NRZ-OOK signal for 10m

Figure 5 shows the value of BER and Q factor by increasing the distance from 10m to 63m, the obtained BER is $6.16656\times10^{-9,}$ and Q factor is 5.6919. In Figure 6, the eye diagram shows for 400kb/s data speed at 10m distance.

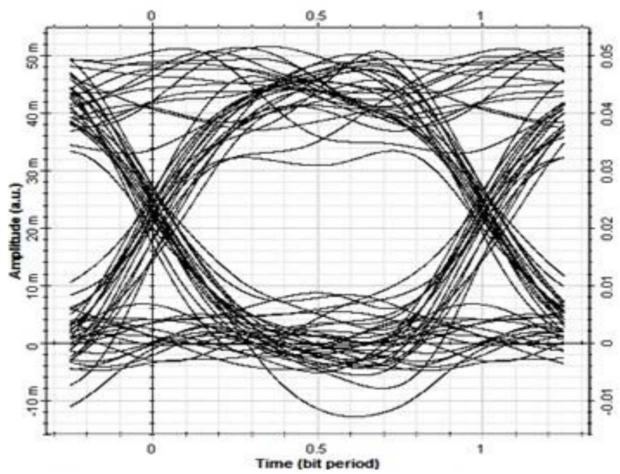

Figure 5. Eye diagram output of 10kb/s NRZ-OOK for 63m

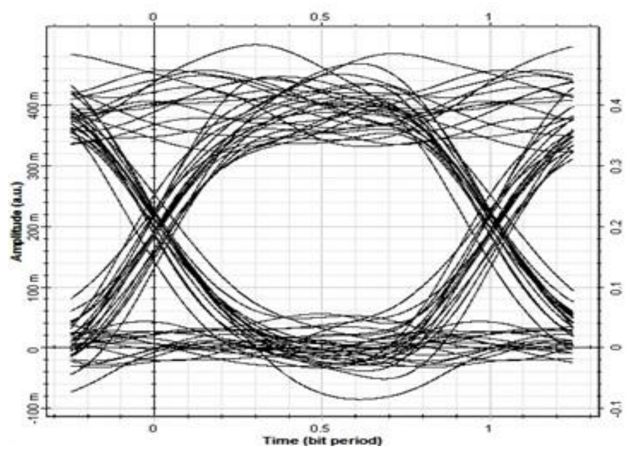

Figure 6. Eye diagram output of 400kb/s NRZ-OOK signal for 10m

However, the achieved data rate is still trivial for the VLC system. We increased the data rate from 400kb/s to 2Mb/s for NRZ-OOK modulation technique. However, the distance between transmitter and receiver decrease to 3m by maintaining BER of 1.33827×10^{-9}. It means that for high-speed data transmission of NRZ-OOK modulation is only for short link distance as shown in Figure 7.

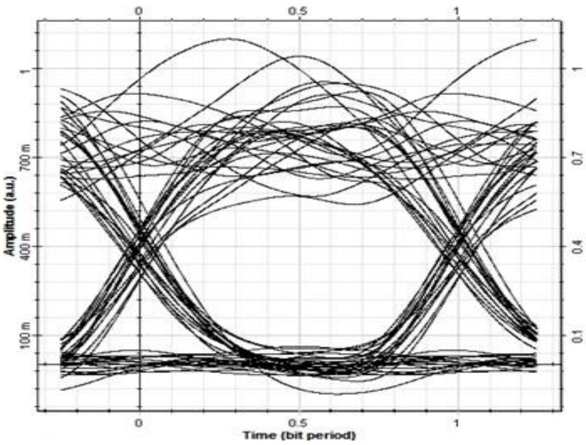

Figure 7. Eye diagram output of 2Mb/s NRZ-OOK signal for 3m

For the consequences of low data speed using NRZ-OOK, we need to evaluate and analyze other modulation methods for dimming techniques in VLC. Among the different system parameters that need to be assessed to find the best performance of the modulation techniques are M-QAM-OFDM, 4- QAM-OFDM, 8-QAM-OFDM and 16- QAM-OFDM.

5. EVALUATION OF 4-QAM-OFDM

Due to low data speed delivered by NRZ-OOK, we investigate M-QAM-OFDM to improve the data rate. We analyzed 4- QAM-OFDM, 8-QAM-OFDM and 16-QAM-OFDM in detail for different system parameters where 4- QAM-OFDM performs best among the three modulation techniques. High-order modulation techniques provide high-speed data rate through parallel transmission and high spectral efficiency. Nevertheless, high-order modulation scheme transmits more per symbol which is more susceptible to noise caused by high BER. With the assistance of 4-QAM-OFDM with 450nm LED, 5Gb/s data rate is obtained at 13m transmission distance with clear eye diagram as shown in Figure 8 and 4.42. 9

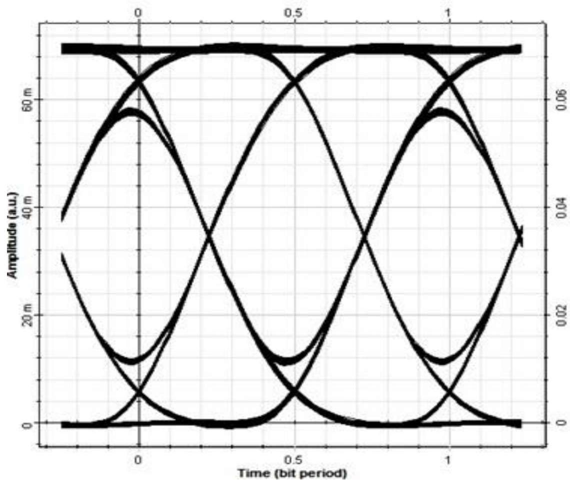

Figure 8. Eye diagram analyzer output for 5Gb/s 4QAM-OFDM signal

Figure 9 showing achievable BER of 10^{-23} for 5Gb/s 4-QAM-OFDM system where the other modulation techniques performed poorly with increasing value of system parameters. The reason behind the poor performance of 8-QAM-OFDM and 16-QAM-OFDM is due to transmitting more bit per symbol at a time which more prone to error. Due to the interference of adjacent constellation points, it is preferable to employ 4-QAM-OFDM over other high order modulation techniques.

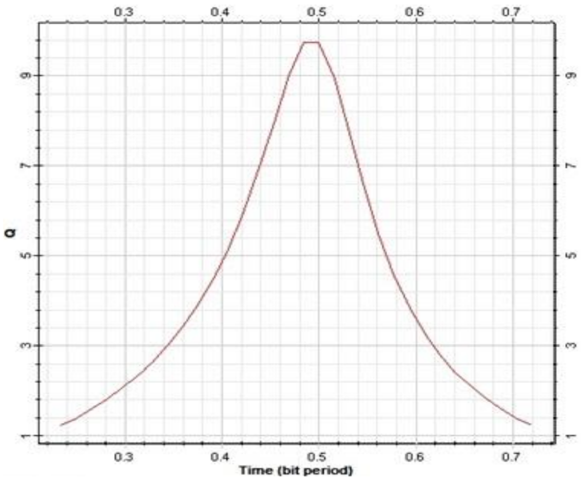

Figure 9. BER analyzer output for 5Gb/s 4QAM-OFDM signal

The following figures showing the performance evaluation for 4-QAM-OFDM under Dimming Control. Figure 10 is an illustration for BER vs. distance, by using the 4-QAM-OFDM scheme to transmit 5Gb/s data from 1m to 13m for 10% duty cycle and 100% duty cycle. We can observe from Figure 10, that BER is lower for 100% duty cycle than 10% duty cycle. For 90% dimming level, we achieved BER of 1.55×10^{-15} by transmitting 5Gb/s for 13m distance. On the contrary, 1.03×10^{-22} of BER is obtained for 5Gb/s data transmission and 13m link range at 100% brightness level of LED. It is obvious that better BER is achievable with 100% brightness of LED in VLC system.

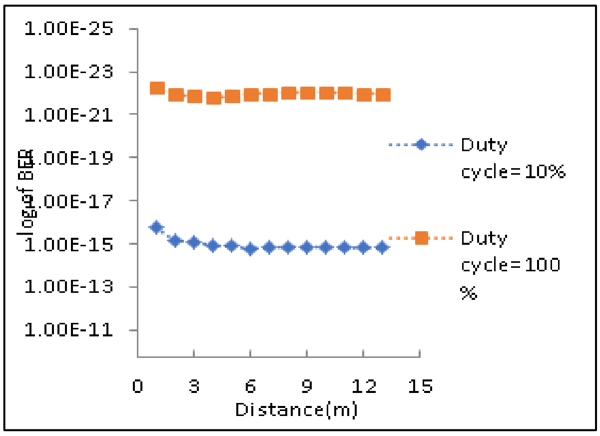

Figure 10. BER vs distance of 5Gb/s 4QAM-OFDM for 10% and 100% dimming

The received power is also evaluated on distance for 10% duty cycle and 100% duty cycle to transmit 5Gb/s data using 4QAM-OFDM scheme. By assuming 100% duty cycle, the received power is 24.0048dBm for 5Gb/s data transmission and 13m link range where -15.9863dBm is the received power for 10% duty cycle as shown in Figure 9. Figure 11 shows received power versus distance of 5Gb/s 4QAM-OFDM for 10% and 100% dimming.

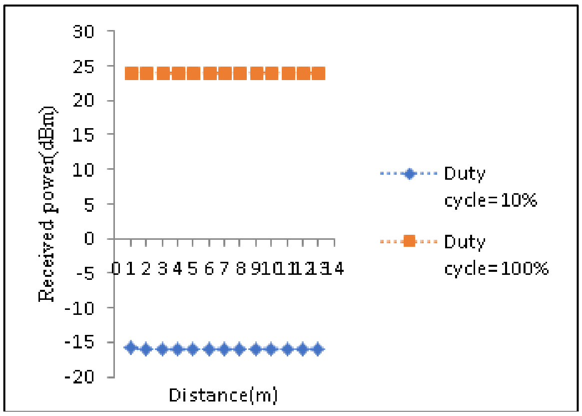

Figure 11. Received power vs. distance of 5Gb/s 4QAM-OFDM for 10% and 100% dimming

When 90% dimming is applied, the power consumption is lower compared to 0% dimming of LED. It is evident from Figure 4.44 for the 4QAM-OFDM scheme.

6. CONCLUSION

From the comparisons, simulation scenarios and observations for different system parameters on the systems we can conclude that 4-QAM-OFDM showed the best performance for all system parameters. Therefore, it is better to use low order modulation techniques to achieve high-speed data with fewer errors by satisfying the dimming and communication requirements. Moreover, we should go for an appropriate and profound modulation technique that is suitable for channel quality to transmit high-speed data in long distance efficiently under dimming control. Duty cycle, bit rate, beam divergence and transmission distance are the considering parameters for good communication link. The analysis shows that 4-QAM-OFDM is better than other modulation techniques to achieve high data rate in low duty cycle. Next chapter is the conclusion and recommendations for future work.

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