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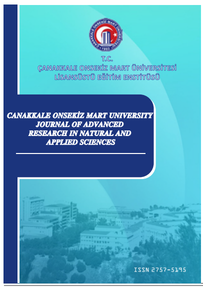

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Performance Analysis of Dimming Methods in Visible Light Communication Systems

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Abstract − The Visible Light Communication (VLC) has been taken very attentions from many researchers due to its efficiency substructure. In specially, the VLC systems provide both lighting and data transmission at the same time. This paper has investigated the performance analyses of modulation schemes which support the brightness control for Visible Light Communication. In this sense, it has been focused on performance differences between M-ary VPPM (M-ary Variable Pulse Position Modulation) scheme and VPAPM (Variable Pulse Amplitude Position Modulation) which was proposed to ensure the multilevel transmission for VPPM scheme. In particular, a performance comparison has been given for both techniques with respect to Bit Error Rate by considering the same bit length consisted in a symbol. The investigated M-ary VPPM is modified by generating the signals of two power levels. Moreover, a VPAPM based-transmission model has been proposed to assure the accurate dimming target values under condition of long runs of same bits (1 s or 0 s) that encode the signal amplitude. However, the proposed system has lower data rate when compare to traditional VPAPM. Moreover, a receiver scheme has been suggested to decode received VPAPM signals. The performance of VPAPM demodulator architecture has been observed in terms of BER versus transmission distance between receiver and transmitter.

Keywords *− Demodulator design, dimming methods, m-ary vppm,vlc, vpapm*

1. Introduction

With the rapid popularization of wireless communication devices, the spectrum regulation for wireless data transmission need to be further improved. Due to the limited wireless channel sharing, it is expected to emerge new transmission links in the wireless data transmission (Chen, Zhang, Hsu, & Chang, 2020). With the continual technological advances in semiconductor devices such as white light-emitting diode (LED), it is claimed that optical communication systems such as visible light communication (VLC) will overcome the limited communication capacity by integrating Radio Frequency (RF) systems (Küçük, Msongaleli, Akbulut, Kavak, & Bayılmış, 2021; Vats, Aggarwal, & Ahuja, 2019; Alnwaimi & Boujemaa, 2021; Kamat, Khosla, & Narayanamurti, 2020). Even though VLC exhibits many solutions for future integrated communication links, there are still essential technical challenges in nowadays.

It has been proposed the several dimming methods to regulate the LED brightness in the literature since the VLC provide both lighting and data transmission at the same time (Lee W.-C. and Kwon M.-J., 2020; Yawale P., Wagh V., and Shaligram A., 2019; Guo J.-N., Zhang J., Zhang Y.-Y., Xin G., and Li L., 2021; Das B., Bardhan S., Maity T., and Mazumdar S., 2020). For the adjusting the LED brightness, the candidate dimming techniques can be grouped into two general categories, these being analogue and digital dimming methods (Zafar F., Karunatilaka D., and Parthiban R., 2015). The analogue dimming methods are based on amplitude of LED driving signal taking account consideration the data bits while the digital dimming methods are performed by adjusted the duty cycle of driving signal (Zafar F., Kala-vally V., Bakaul M., and Parthiban R., 2015).

Many modulation techniques have been modified to provide dimming support in VLC links (Bui T.-C., Singh R., O'Farrell T., and Biagi M.,2018; Wang T., Yang F., Cheng L., and Song J.,2018; Okumura J., Kozawa

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Y., Umeda Y., and Habuchi H.,2017; Knobloch F., 2015). Especially, digital dimming meth-ods have been widely explored due to their low complexity in experimental systems (Raj R., Jaiswal S., and Dixit A., 2021). Variable On-Off Keying (VOOK) and Variable Pulse Position Modulation (VPPM) schemes can be indicated as basic modulation schemes (Lee K. and Park H., 2011). The VOOK scheme was constituted by modifying On-Off Keying (OOK) method while VPPM technique adjusts the duty cycle of binary PPM schemes to provide the variable LED brightness. In the following years, it has been aim to increase the data rate of VPPM scheme in the literature. To provide the higher data transmission, VPAPM (Variable Pulse Amplitude Position Modulation) scheme has been proposed to ensure both variable illumination and data transmission at the same time (Yi L. and Lee S. G., 2014). This method encodes the amplitude of transmitted signal against to transmitted data bits. Instead of amplitude, it has been considered that the position can be encoded to increase the data rate of VPPM scheme in the literature. This position based scheme has been referred to as M-ary VPPM (Yoo J.-H., Kim B. W., and Jung S.-Y., 2015). M-VPPM consists of wrapped signal scheme to ensure the target dimming level.

The one of the disadvantages of VPAPM method cannot assure the desired dimming level if there are long runs of same bits (1 s or 0 s) among the transmitted data signal. Similar problem has been appeared for OOK method in the literature since OOK scheme cannot support a target dimming level under condition of long runs of same bits (1 s or 0 s). To cope with the mentioned challenge, it has been suggested a packet transmission model for VPAPM scheme in the paper. Although the proposed model can support the desired dimming level under condition of long runs of same bits it has lower data rate compared with traditional VPAPM. Addition to this, a demodulator scheme has been performed for received VPAPM signals. The proposed demodulator architecture is analysed in terms of BER versus transmission distance between receiver and transmitter. Moreover, M-ary VPPM has been modified by considering the signals of two power levels. In the last framework of the paper, it has been given a performance comparison with respect to BER for modified M-ary VPPM and VPAPM.

2. VPAPM Method

This section gives VPAPM method which has been proposed to data rate binary VPPM scheme. This scheme allows multiple data transmission by encoding the pulse signal according to data signal. If *n* is defined as bit number by consisted of one symbol, encoded signal number will equal to bit number *n*. A VPAPM signal sample is given in the Figure 1 against to data bits.

In the Figure 1, a M-n-VPAPM signal sequence is given considering the transmitted data symbol. As shown in the figure, both M and *n* get 2 value. The n will be used the 2 for all transmitted signals if the VPAPM

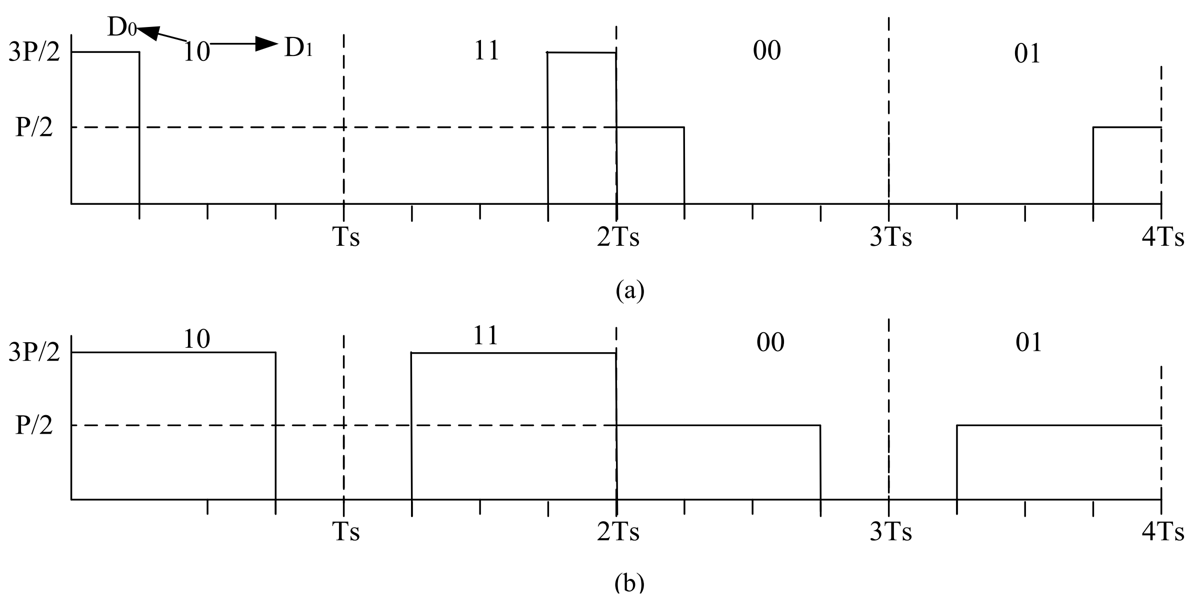


Figure 1. The M-n-VPAPM signal against to data symbols at the dimming ratios of 25 % and 75 %. For 25%. (b) 75%

signal is observed as M-n-VPAPM. The VPAPM method provides higher data rate compared to VPPM scheme since it encodes the amplitude of pulse signal by taking into account data signal. A VPAPM signal can be given by,

$$x(t) = nAP\sum_{k=0}^{n-1} c_k p\left(t - \frac{kT}{n}\right) \tag{2.1}$$

where, *x(t)* is VPAPM signal. The c_k, *T* and *n* are defined as codewords, filled slot duration and chip number. In the Eq.2.1, *A* is amplitude of modulated signal. The VPAPM signal detected from the photodiode can be decoded by using the receiver algorithm given in the Figure 2.

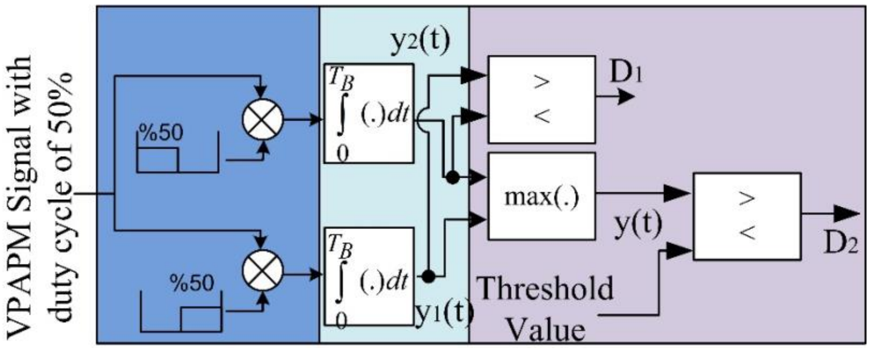


Figure 2. A receiver architecture for the VPAPM

The modified demodulator given in Figure 2 can be considered as a sample architecture for decoding of 2-2-VPAPM signals. In the first stage, the received signal is multiplied by a given masking signals to investigate the position of pulse. Afterwards, the signal is passed through integrator blocks which generates outputs of $y_1(t)$ and $y_2(t)$. In last stage, both signals are applied on a comparison unit. The first bit, which can be referred to as position bit, is appeared at output of comparator block. The two levels including P/2 and 3P/2 is generated to encode the data bit which is *D2* as depicted in the Figure 2. To determine the level of *D2*, it is necessary a threshold value for M-2-VPAPM. Therefore, an optimum threshold value that can be adjusted as mean value of both transmission level. Under user mobility condition, an adaptive detection threshold method must be applied on receiver system since this condition causes the receiver power being dynamic levels. Addition to this, the received optical power can change under ambient light effect hence threshold level can be dynamic levels. Moreover, the ISI (Intersymbol Interference) problem can be observed when the data rate is increased. The received *x(t)* signal is added to noise signal at the output of optical detector, hence the outputs of multiplications given in the Figure 2 can be expressed by (Noh J., Lee S., Kim J., Ju M., and Park Y., 2015),

$$y_1(t) = \int_0^{Ts} \left(x(t) + n(t)\right).m_1(t) \tag{2.2}$$

$$y_2(t) = \int_0^{Ts} \left(x(t) + n(t)\right).m_2(t) \tag{2.3}$$

Where (inEqs2.2, 2.3), $y_1(t)$ and $y_2(t)$ are defined as outputs of integrators. The noise signal is depicted by *n(t)*. The $m_1(t)$ and $m_2(t)$ is masking signals which are used to multiply by received M-2-VPAPM signal. The decision can be made as follows:

$$\left(y_2(t) < y_1(t) \rightarrow D_1 = 1\right) \wedge \left(y_2(t) > y_1(t) \rightarrow D_1 = 0\right) \tag{2.4}$$

Where (inEq2.4), it is performed a comparison of $y_1(t)$ with $y_2(t)$ to decide the level of *D1*. A maximum value is determined in the decision stage. To detect D2 bit, it must be compared a threshold value with this maximum value that is chosen from among the $y_1(t)$ and $y_2(t)$. Therefore, *D2* bit can be determined by

$$y_{max} = max(y_1(t), y_2(t)) \quad (2.5)$$

$$(th < y_{\max} \rightarrow d_{i+1} = 1) \wedge (th > y_{\max} \rightarrow d_{i+1} = 0) \quad (2.6)$$

Where (inEqs.2.5, 2.6), y_{max} is described as maximum value that can be determined from among the output values of integrators.

3. M-ary VPPM Method

M-ary VPPM scheme is a digital dimming method while VPAPM is defined as hybrid dimming method that consists of analogue and digital dimming methods. The M-VPPM can adjust the LED brightness by changing duty cycle of modulated signal while VPAPM regulates the amplitude of signal to reach the desired dimming level. Therefore, it can be claimed that M-VPPM has simpler structure than that of VPAPM since it can be considered that the changing of duty cycle is more efficient method to adjust the dimming level of signal compared to setting of signal amplitude. In Figure 3, it is given a M-VPPM signal at the dimming ratio of 50% for *M*=4.

It is shown from the Figure 3 that the filled pulse is rotated by decimal value of transmitted symbol. It is provided the target dimming level under overflow condition. As observed in Figure 3, there is given a M-VPPM signal which has dimming ratio of 50%. The symbol of "11" has caused an overflowing condition. In this condition, the overflow signal is applied on the first slot, hence it is emerged a wrapped signal condition. it is given the traditional M-VPPM demodulator architecture for *M*=4 in the Figure 4. According to the figure, it can be stated that the number of integrator and multiplication block in the traditional M-VPPM demodulator dependents on M of modulation order.

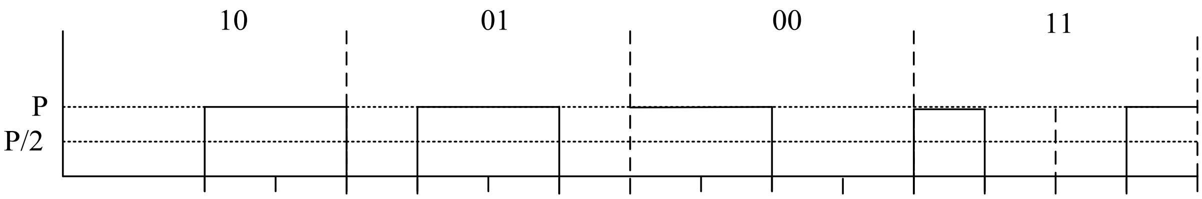


Figure 3. 4-VPPM signal against to data symbol at the dimming ratio of 50%

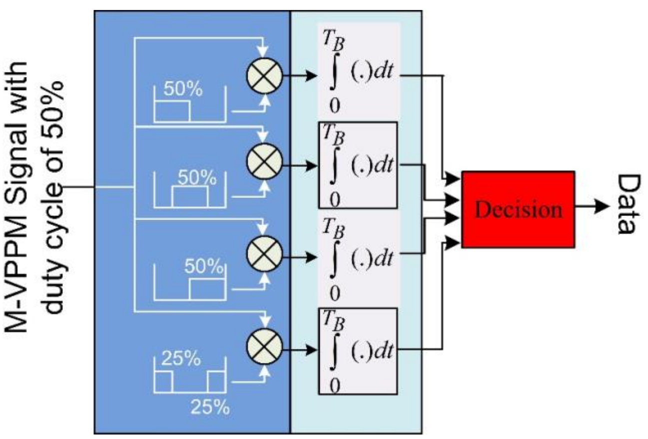


Figure 4. A M-VPPM receiver model for M = 4

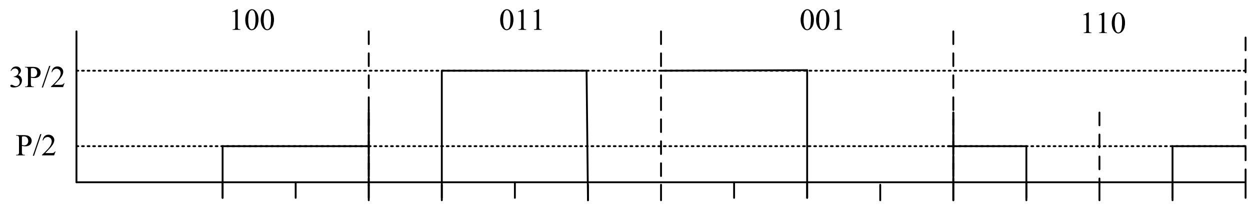


Figure 5. 2-n-VPPM receiver model for n = 4

4. Modified M-ary VPPM method

This section gives a model to increase the transmission performance of M-ary VPPM. In contrast to M-n-VPAPM, the *M* fixed at the 2. The modified model performs the generating of two amplitude levels while the number of position can get dynamic values. Therefore, modified M-ary VPPM can be defined as M-n-VPPM where the M value gets 2. A M-n-VPPM scheme is given in the Figure 5.

The number of slot can be increased for the architecture given in the Figure 5, instead of amplitude when compare to M-n-VPAPM. Although the signal consists of four slots, it is transmitted by considering the two amplitude levels. Therefore, it is considered that the transmission performance can be increased by fixing the number of amplitude level to 2 when compare to 4-VPPM scheme presented in the Figure 3.

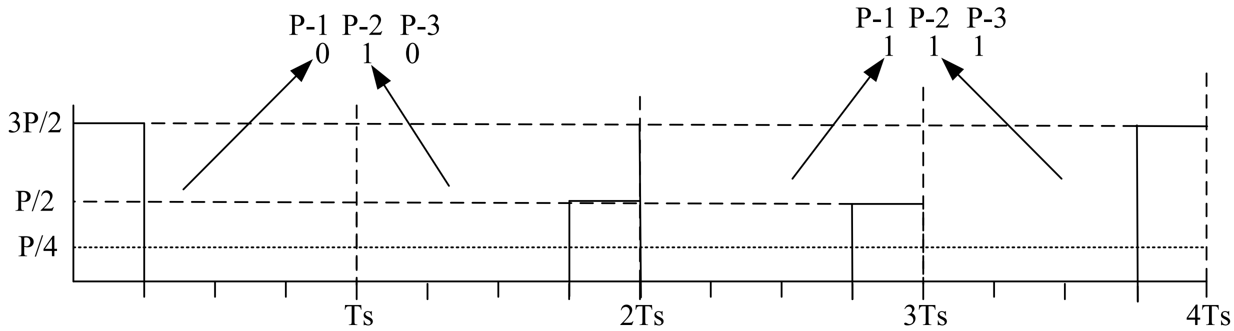


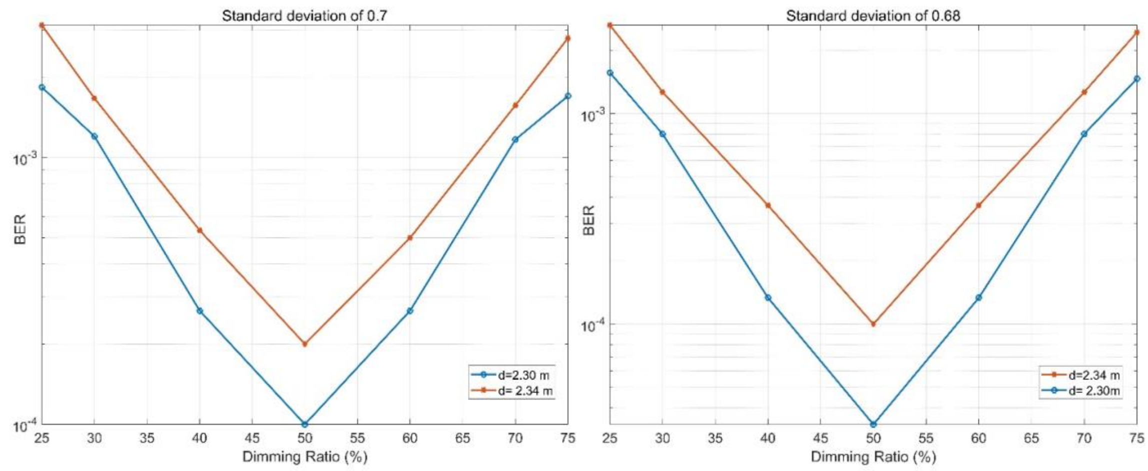
Figure 6. Modified 2-2-VPAPM scheme

As shown in the Figure 6, it is consisted of three data bits in a symbol or a packet while the traditional 2-2-VPAPM can transmits four data bits over two modulated signal. Therefore, 2-2-VPAPM has superior with respect to data rate when compare the modified scheme. However, the modified scheme gives static dimming levels at the transmission during since it consists of serial high and low powers. The optical power can get P/4 for dimming ration of 25% at the all transmission during. The *P3* position bit encodes the positions of signals which have powers of 3P/2 and P/2.

5. Results and Discussion

In this section, it is presented the performance analyses for 2-n-VPAPM and M ary MVPPM in terms of BER and distribution of dimming level. In the first consideration, the 2-2-VPAPM has been investigated at dimming levels between 25% and 75% against the transmission distance between receiver and transmitter. It has been get similar results to VPPM in the simulation. The Figure 7 gives the BER performance of 2-2-VPAPM technique versus transmission distance. The simulation results have been obtained by using the architecture given in the Figure 2. According to simulation results, similar BER performances are observed at the dimming ratios of a% and (100-a)%.

As shown in the Figure 7, it can be performed the 2-2-VPAPM system at the distance of 2.30 m and dimming ratio of 40% instead of the distance of 2.34m and dimming ratio of 50%. The performances at these distance and dimming ratios are close to each other's.



(a) (b)

Figure 7. The BER performance of 2-2-VPAPM versus dimming ratios between 25% and 75%. (a) The standard deviation of 0.7 for noise. (b) The standard deviation of 0.68 for noise

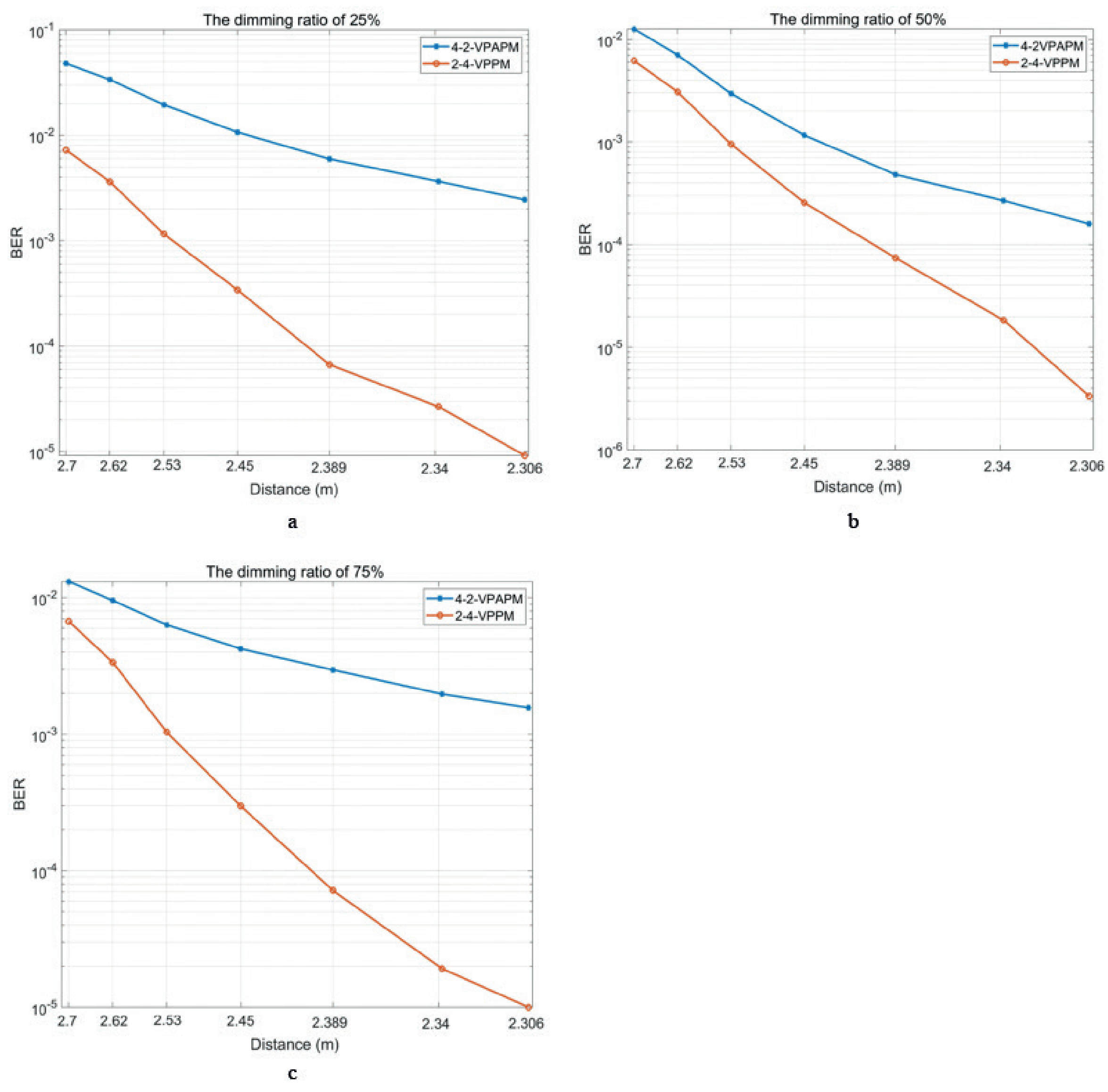


Figure 8. The BER performance comparison of 4-2-VPAPM and 2-4-VPPM versus transmission distance and dimming ratio.(a) Dimming ratio of 25% (b) Dimming ratio of 50% (c) Dimming ratio of 75%

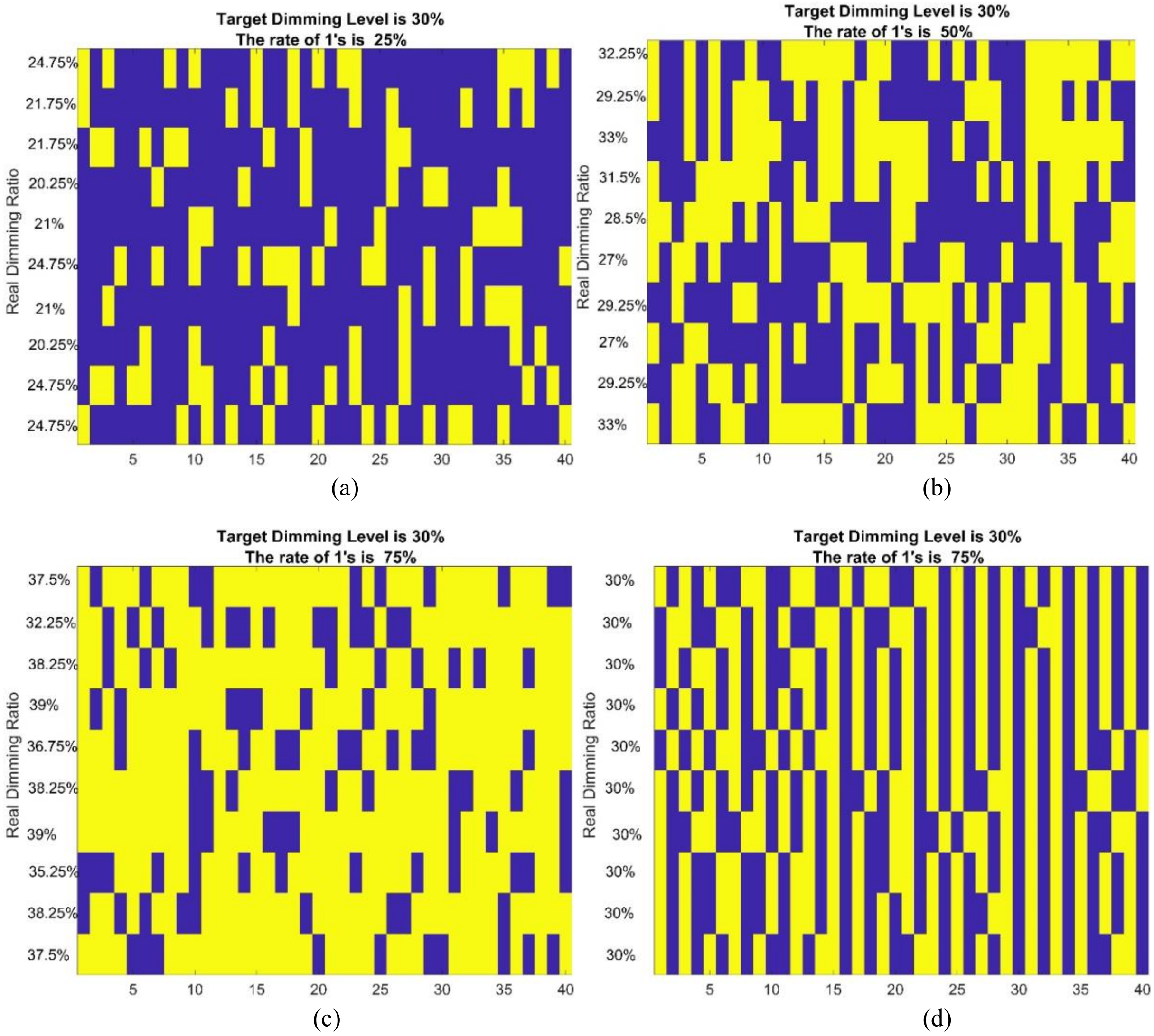


Figure 9. The target dimming performance of 2-2-VPAPM and modified VPAPM in terms of various input ratio of '0' and '1' bits. (a) The input ratio of '1' bits is 25% for 2-2-VPAPM (b) The input ratio of '1' bits is 50% for 2-2-VPAPM (c) The input ratio of '1' bits is 75% for 2-2-VPAPM (c) The input ratio of '1' bits is 75% for the modified VPAPM.

The Figure 8 depicts another performance comparison between 4-2-VPAPM and 2-4-VPPM. As mentioned in previously, the 2-4-VPPM is proposed by modifying the M-ary VPPM scheme. It is illustrated from simulation results that it is growing the difference of BER performance between both systems while the dimming ratio used in the systems is increasing. The similar comparison can be observed between results obtained in the Figure 8 (a) and (c). It can be asserted the 2-4-VPPM can increase the transmission distance at the BER of 10^{-3} and lesser where the system has meaningful BER performance. As shown in the Figure 8 (b), the transmission distance is increased from 2.306m to 2.389m at the BER of 10^{-4} when compare to 4-2-VPAPM. From the simulation results obtained in the Figure 8, it can be claimed that modified M-ary VPPM (2-4-VPPM) has superior in terms of BER performance compared to 4-2-VPAPM. Addition to this, it is shown from simulation results that the modified M-ary VPPM (2-4-VPPM) can be increased the transmission distance under all dimming levels.

In the Figure 9, it is shown that it is given the comparison of dimming ratio performance according to input ratio of input ratio of '0' and '1' bits for 2-2-VPAPM and modified VPAPM. The input ratio of '1' bits has been chosen 25%, 50% and 75%, respectively. It has been adjusted the brightness ratio of 30. However, the system where the input ratio of '1' bits becomes 50% is more close the target dimming of 30%. The real dimming ratio moves away from target dimming level while the input ratio of '1' bits becomes distant from 50%. Compared to 2-2-VPAPM, the modified system provides the target dimming ratio for whole of input ratio of '1' since average dimming ratios of sequential signals are fixed at the target dimming levels.

6. Conclusion

It is considered that M-n-VPAPM scheme has a challenge related to the adjusting of target dimming ratio in the paper. To overcome the problem related to the adjusting target dimming ratio, therefore, it has been proposed a packet transmission model for 2-2-VPAPM scheme in the paper. Although the modified VPAPM scheme can assure the desired dimming level under condition of long runs of same bits it has lower data rate compared with traditional VPAPM. Moreover, a receiver scheme has been presented to decode the received VPAPM signals. The introduced demodulator architecture is analysed in terms of BER versus transmission distance between receiver and transmitter. Addition to these, M-ary VPPM has been modified by taking into account the signals of power levels. The modified M-ary VPPM generates the modulated signal at the two power levels. In this paper, it has been given a performance comparison with respect to BER for modified M-ary VPPM and VPAPM.

Author Contributions

Süleyman Börekoğlu: Conceived and designed the analysis, collected data and performed the analysis.

Mehmet Sönmez: Conceived and designed the analysis, collected data and performed the analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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