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Analysis of multi-pulse modulation techniques for visible light communication systems

Görünür ışık haberleşme sistemleri için çoklu darbeli modülasyon tekniklerinin analizi

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Abstract
In this paper, a performance analysis is given for standard OPPM (Overlapping Pulse Position Modulation), W-OPPM (Wrapped OPPM) and Multilevel PPM (MPPM) schemes. The Bit Error Rate (BER) performances of modulation schemes are achieved in terms of transmission distance. From simulation results, it is shown that standard OPPM has better spectral efficiency compared to the MPPM and W-OPPM. Additionally, MPPM, W-OPPM and standard OPPM transmit a packet data during 19.29, 30.85 and 38.41us, respectively if the sample number per slot is taken as equal for modulation techniques. The methods are also designed in Field Programmable Gate Arrays (FPGA) complier Quartus to observe modulation and demodulation processes. Especially, it is achieved the practicable demodulator architectures in the paper.

Keywords: Multilevel PPM (MPPM), Overlapping PPM (OPPM), Visible light communication (VLC), Wrapped OPPM (W-OPPM)

Öz
Bu çalışmada, standart OPPM (Örtüşen Darbe Konum Modülasyonu), Sarılı OPPM ve Çok seviyeli PPM şemaları için bir performans analizi verilmiştir. Modülasyon şemalarının Bit Hata Oranı (BHO) performansları iletim mesafesine göre elde edilmiştir. Simülasyon sonuçlarından, MPPM'in OPPM ve W-OPPM den daha iyi bir performansa sahip olduğu görülmektedir. W-OPPM ve MPPM ile karşılaştırıldığında, standart OPPM daha iyi spektral verimliliğe sahiptir. Ayrıca slot başına örnek sayısı modülasyon yöntemleri için eşit alınırsa; MPPM, W-OPPM ve standart OPPM bir paket veriyi 19.29, 30.38 ve 38.41 us süresince iletir. Modülasyon ve demodülasyon süreçlerinin gözlemlenmesi için yöntemler ayrıca Alanda Programlanabilir Kapı Dizileri (FPGA) derleyicisi Quartus'ta tasarlanmıştır. Çalışmada özellikle, uygulanabilir demodülatör mimarileri elde edilmiştir.

Anahtar kelimeler: *Çok seviyeli PPM (MPPM), Örtüşen PPM (OPPM), Görünür ışık haberleşmesi (GIH), Sarılı OPPM (W-OPPM)*

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1. Introduction

In recently, the Optical Wireless Communication (OWC) has become popular communication system. Hence, the optical communication systems have taken very attention from many researchers during the decades (Mao et al., 2017; Ray et al., 2015). Especially, the visible light communication system is one of the most significant candidates for optical transmission at the moment. Compared with the other optical systems, the VLC systems provide both (Light Emitted Diode) LED lighting and data transmission at the same time. To ensure the efficient data transmission, the VLC systems support the short-range wireless communication contrast to Radio Frequency (RF) communication. It is one of the most important disadvantages of VLC systems.

The modified transmission schemes have been required for VLC since it is topical communication system. The Pulse Position Modulation scheme is one of the most preferred techniques hence, various PPM schemes are improved for optical communication systems (Mohammed and Badawi, 2018). Recently, the variable pulse position modulation (VPPM) was proposed to provide the dimming level of LED (Lee and Park, 2011). The scheme was improved to provide multilevel data transmission hence it is referred as M-ary VPPM (Yoo et al., 2015). The providing of dimming level is very significant for visible light communication systems due to energy efficient. Therefore, a dimming method, which is named as Variable On-Off Keying, is improved for OOK modulation scheme which is one of the most basic transmission schemes (Lee and Park, 2011). In order to provide higher bandwidth efficiency compared to the traditional PPM, the Multilevel PPM scheme is proposed (Ghassemlooy et al., 2012). For instance, $\binom{5}{2}$MPPM scheme has two filled slots among the five slots hence, the ten conditions can be defined by $\binom{5}{2}$MPPM. In M-ary PPM, the M can be expressed as 2^n compared with Multilevel PPM. The n indicates bits number into one symbol. Additionally, M-ary PPM uses only one filled slot of which position is determined by symbol value.

The Overlapping PPM (OPPM) method is proposed to increase the filled slot number during one bit period (Ghorban Sabbagh and Molavi Kakhki, 2013). The method is improved to achieve higher throughput compared to traditional OPPM. The advanced Overlapping PPM is presented as differential OPPM (Ohtsuki et al., 1994). In order to reduce symbol error rate compared to to OOK and PPM, Wrapped OPPM (W-OPMM) technique advanced for optical wireless systems (Sabbagh and Kakhki, 2014). Recently, the Variable OPPM is proposed to ensure dimming level of OPPM for VLC systems (Chizari et al., 2017). Moreover, many papers were proposed to digital architectures for VLC systems (Jeong et al., 2014; Shi et al., 2020; Sönmez, 2017, 2018a).

In this paper, we give a performance comparison of OPPM, W-OPPM and MPPM techniques. In simulation environment, the OPPM, W-OPPM and MPPM schemes are compared in terms of BER performance. The BER performance is obtained in terms of transmission distance. Form simulation results, it is shown that the $\binom{5}{2}$ MPPM technique has better BER performance compared to W-OPPM and OPPM. Therefore, $\binom{5}{2}$ MPPM technique increases the distance between the transmitter and receiver. Three methods are achieved in FPGA complier Quartus. The demodulator architectures have complex structures due to providing synchronization while the transmitter structure is simply obtained.

The paper is organized as follows: First, in section 2 it is given theoretical foundation of modulation techniques. Then, the section 3 gives simulation results. Finally, Section 4 is devoted to conclusions.

2. The theoretical analysis of OPPM and multilevel PPM

In this section, the theoretical expressions are given for OPPM and $\binom{5}{2}$ MPPM scheme. The OPPM scheme can be obtained by using several filled slot while $\binom{5}{2}$ MPPM scheme uses two filled slots among five slots. The Table-1 shows the codewords of OPPM and $\binom{5}{2}$ MPPM techniques in terms of data bits.

The OPPM uses three filled slots according to table while the multilevel PPM utilizes two filled slots among the five slots. Both OPPM and Multilevel PPM rotates their conditions over one slot. Compared with standard PPM, the MPPM consists of 5 slots for this condition. They transmit three bits per symbol. However, the MPPM has better advantage in terms of bandwidth efficiency (Ghassemlooy et al., 2012).

Table 1. Codewords for Modulation Techniques

Data Bits	Standard PPM (8-PPM)	Standard OPPM	Wrapped OPPM	$\binom{5}{2}$MPPM
000	10000000	1110000000	11100000	11000
001	01000000	0111000000	01110000	10100
010	00100000	0011100000	00111000	10010
011	00010000	0001110000	00011100	10001
100	00001000	0000111000	00001110	01100
101	00000100	0000011100	00000111	01010
110	00000010	0000001110	10000011	01001
111	00000001	0000000111	11000001	00110

Considering filled and empty slots for standard OPPM, the number of codeword can be written by,

$$Q = n - w + 1 \tag{1}$$

where, Q, n and w indicate the number of valid codeword, total slot number and filled slot number, respectively (Gancarz et al., 2015). The Q, n and w are equal to 10, 5 and 2 for $\binom{5}{2}$ MPPM while they get 8, 10 and 3. The OPPM and MPPM signals are demodulated by estimating filled slots at the receiver side hence, the integration process is utilized to compare to slots. The demodulation process may be better simple compared with MPPM since filled slots are serially placed in OPPM scheme. The received signals can be expressed by,

$$S_{OPPM}(t) = m_{OPPM}(t) + n(t) \tag{2}$$

$$S_{MPPM}(t) = m_{MPPM}(t) + n(t) \tag{3}$$

where, $S_{OPPM}(t)$ and $S_{MPPM}(t)$ are defined as received OPPM and MPPM signal, respectively. The signals are given by adding n(t) noise signal to modulated signals which are given as $m_{OPPM}(t)$, $m_{MPPM}(t)$ in Eq. (2) and (3). In demodulation process, received signals must be passed through an integrator. The integration process of MPPM signal can be given as follows

$$I_{MPPM}(i;j) = \int_{(i-1)T_S}^{iT_S} S_{MPPM}(t)d(t) + \int_{(j+1)T_S}^{(j+2)T_S} S_{MPPM}(t)d(t) \tag{4}$$

where, $I_{MPPM}(i;j)$, and T_s are presented as integral value and slot time. The slot time T_s can be determined as dividing bit period TB by slot number. The i and j, which get the values of 1, 2 and 3, can be used to indicate first and second filled slots, respectively. For instance, 01100 MPPM signal can be integrated by using i=2 and j=1. The data bits are determined in terms of maximum integral value which is calculated among 8 integral values. Similarly, the integration process of OPPM signal can be written by,

$$I_{OPPM}(k) = \int_{kT_S}^{(k+3)T_S} S_{OPPM}(t)d(t) \tag{5}$$

where, $I_{OPPM}(k)$ and k present the output of integrator and slot indicator, respectively. According to Table-1, the OPPM signal has three filled slots hence, the filled slots must be detected by using boundary of integrator. The number of total and filled slot are ten and three, respectively. Therefore, the integration of three slots are used to determine the data symbols.

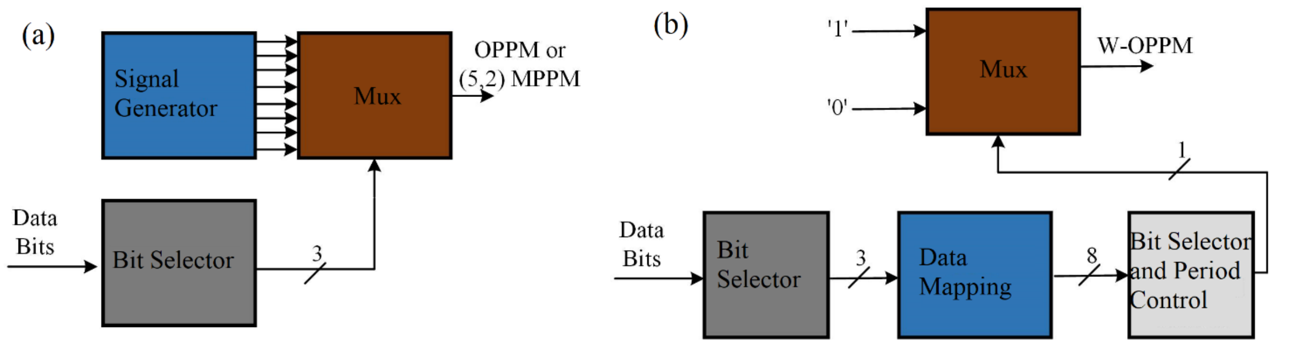

Figure 1. (a) The standard modulator architecture for OPPM and $\binom{5}{2}$ MPPM schemes **(b)** Serial block based architecture for W-OPPM (Sönmez, 2018b)

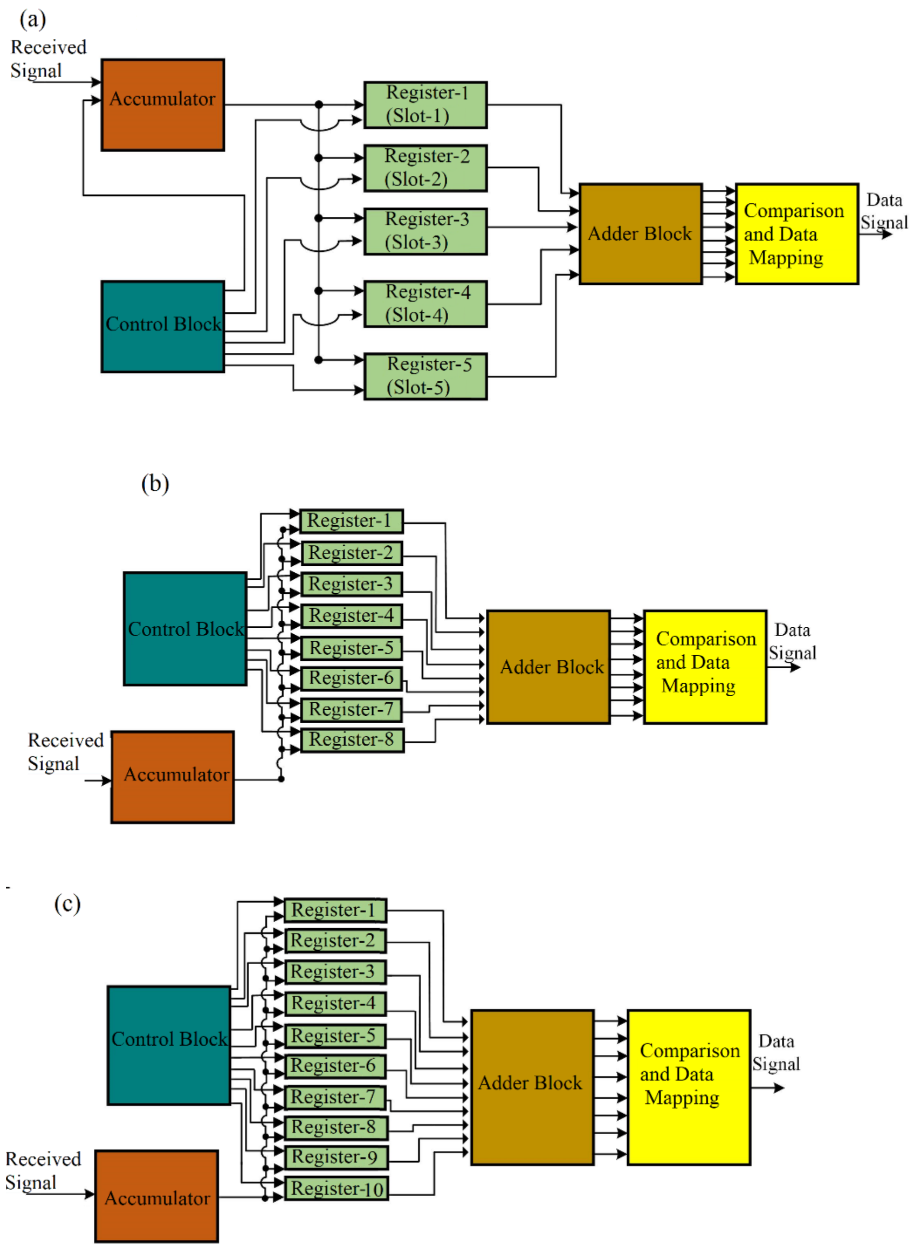

Figure 2. (a) The Demodulator Architecture of $\binom{5}{2}$MPPM **(b)** The Demodulator Architecture of WOPPM **(c)** The Demodulator Architecture of OPPM

The modulator schemes can be obtained by using mux based architectures. In this section, we give both modulator and demodulator structures for OPPM and $\binom{5}{2}$ MPPM signals. In Figure 1, we give transmitter architectures for W-OPPM, OPPM and MPPM schemes. According to Figure 1, the data bits are selected by using bit selector block. The output of bit selector consists of three bits which are presented as data symbol. The modulated signal can be generated in terms of data symbol at output of mux. In Figure 1 (b), the data mapping is used to avoid eight signals. The Ts symbol period is determined by the period control block. The input of mux is logical '0' and logical '1'.

Figure 2 shows a demodulator architecture which is designed for $\binom{5}{2}$ MPPM signals. The demodulator architecture consists of accumulator, control, register, adder and comparison blocks. The accumulator block acts as an integrator (Sönmez, 2018a). The $\binom{5}{2}$ MPPM has five slots length according to Table 1 hence, the five register block is used to save the values of integral, all of which belong to separate slot. It is must be obtained eight integral results achieve the data signal. The results of integral are compared to each other in the last stage which is presented as comparison and data mapping block in the figure. For instance, the received signal has the characteristic of "10001" signal. In this case, the data signal must be determined as "011" without using gray coding. According to demodulation process, it is must be get integrals of all slots. The accumulator adds to received signal with its output value. Thanks to control block, the output of accumulator is deleted at each T_S period. Additionally, the control block activates one of the register blocks at each T_S period. Therefore, a summation value is stored in the register block. For "10001" signal, the biggest summation value must be stored in Register-1 and Register-5 if noise condition is neglected. Afterwards, the adder block adds to two values. The last stage decides data signal by comparing the outputs of adder block.

In Figure 2 (b) and (c), it is shown the architectures of W-OPPM and standard OPPM schemes. Similarly, they uses register block to compare the integration values of slots. The number of register is determined by slot number. Therefore, the W-OPPM and standard OPPM use eight and ten registers, respectively. The functions of other blocks are mentioned in previous paragraph.

3. The simulation results

In this section, we give simulation results of modulation schemes. The simulations are obtained by relating the architectures as mentioned in previous section. Each modulation scheme is lengthily analyzed to observe the variety among architectures. Moreover, the methods are compared them to each other in terms of bit error rate performance.

Figure 3 (a) shows the simulation results for $\binom{5}{2}$ MPPM in FPGA complier Quartus. The *t_data_signal*, *e_bit*, *r_data_signal*, *clear_sig*, *MPPM* and *Slot-(1-5)* indicate transmitted data signal, encoded bits, estimated data signal, clear signal of accumulator, MPPM and output of registers, respectively. A mux based structure is used to generate the $\binom{5}{2}$MPPM signal. The *e_bit*, can be considered as selector input of mux block. The input of mux block consists of eight signals which are depicted as 000-111 in simulation, since there are eight conditions. According to selector input of mux block, the MPPM signal is generated by using one of the eight signals. For example, first symbol consists of "010" bits. The MPPM signal must be coded as 10010 according to codeword table which is given in Table-1. This condition is shown in the Figure 3 (a). The slot-1 registers the integration value of first slot at receiver side while the slot-4 registers the integration value of fourth slot. The 48 samples are received over one slot. Due to considering the dimming system, one sample is coded 20 decimal value. The estimated symbol is "010" at the receiver side since the maximum value is obtained by adding slot-1 and slot-4. The Figure 3 (b) and (c) shows simulation results of W-OPPM and OPPM, respectively. We use 30 samples over one slot cycle for both simulations. According to Figure 3 (b), the W-OPPM signal is obtained by using first, second and last slots. Moreover, the *clear_sig* clears the accumulator at each slot period. The W-OPPM uses eight slots while standard OPPM signal is transmitted by using 10 slots. Thanks to data mapping, the standard W-OPPM signal is generated. Therefore, *e_bit* presents the output of bit selector. The selector input of mux consists of one bit for W-OPPM. In Figure 3, the slot (1-10) and slot (1-8) indicate the outputs of registers. For architectures, Figure 3 shows that the transmitted bits *t_data_signal* could be estimated as *r_data_signal* at the receiver side.

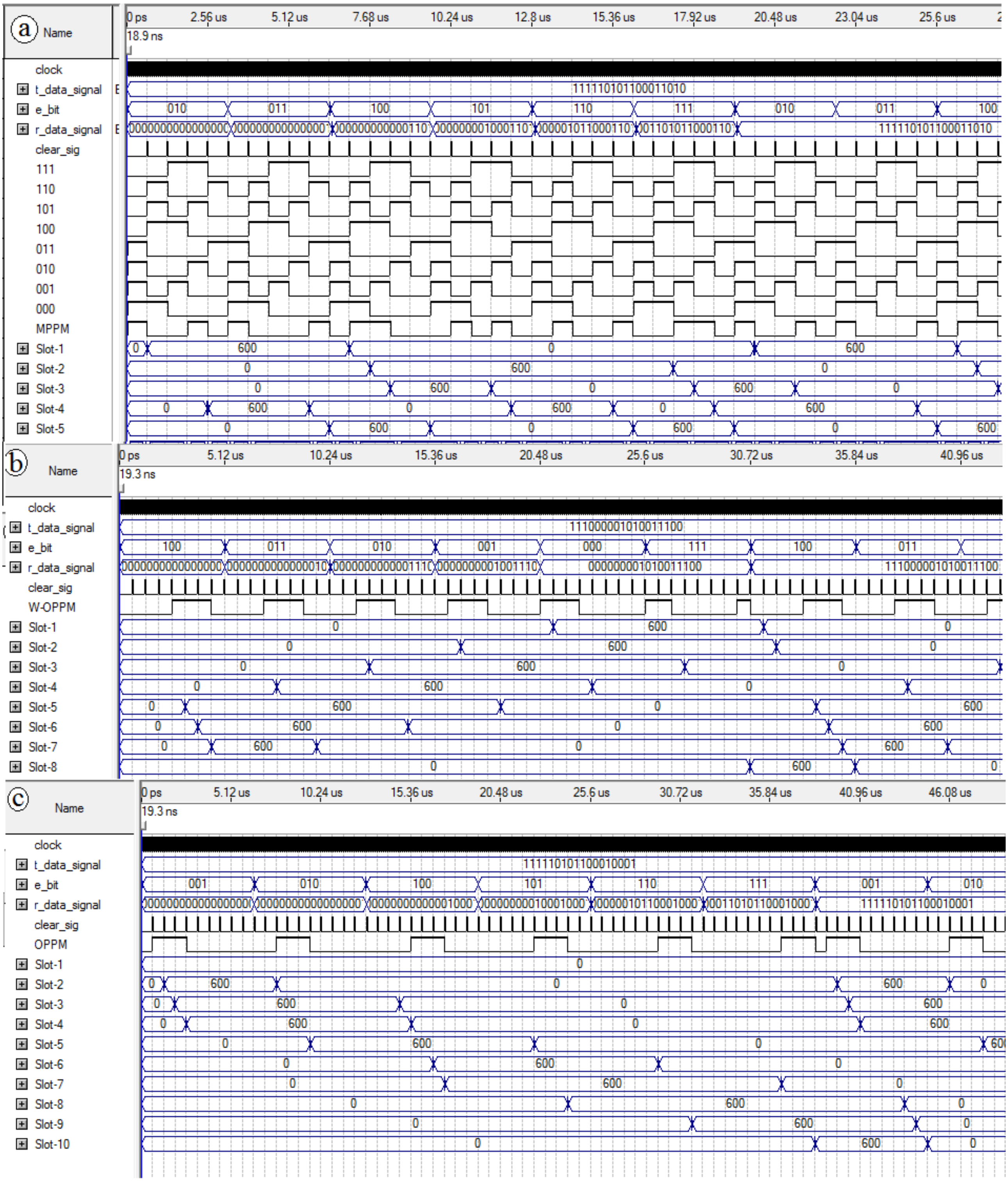

Figure 3. (a) The simulation result for $\binom{5}{2}$ MPPM **(b)** The simulation result of W-OPPM **(c)** The simulation result for OPPM

MPPM, W-OPPM and standard OPPM transmit a packet data during 19.29, 30.85 and 38.41us, respectively if the sample number per slot is taken as equal for modulation techniques. A power spectral density comparison is given in Figure 4.

According to results, standard OPPM has better spectral efficiency compared to the $\binom{5}{2}$ MPPM and W-OPPM. The spectral analysis is obtained by taking same sample number per slot.

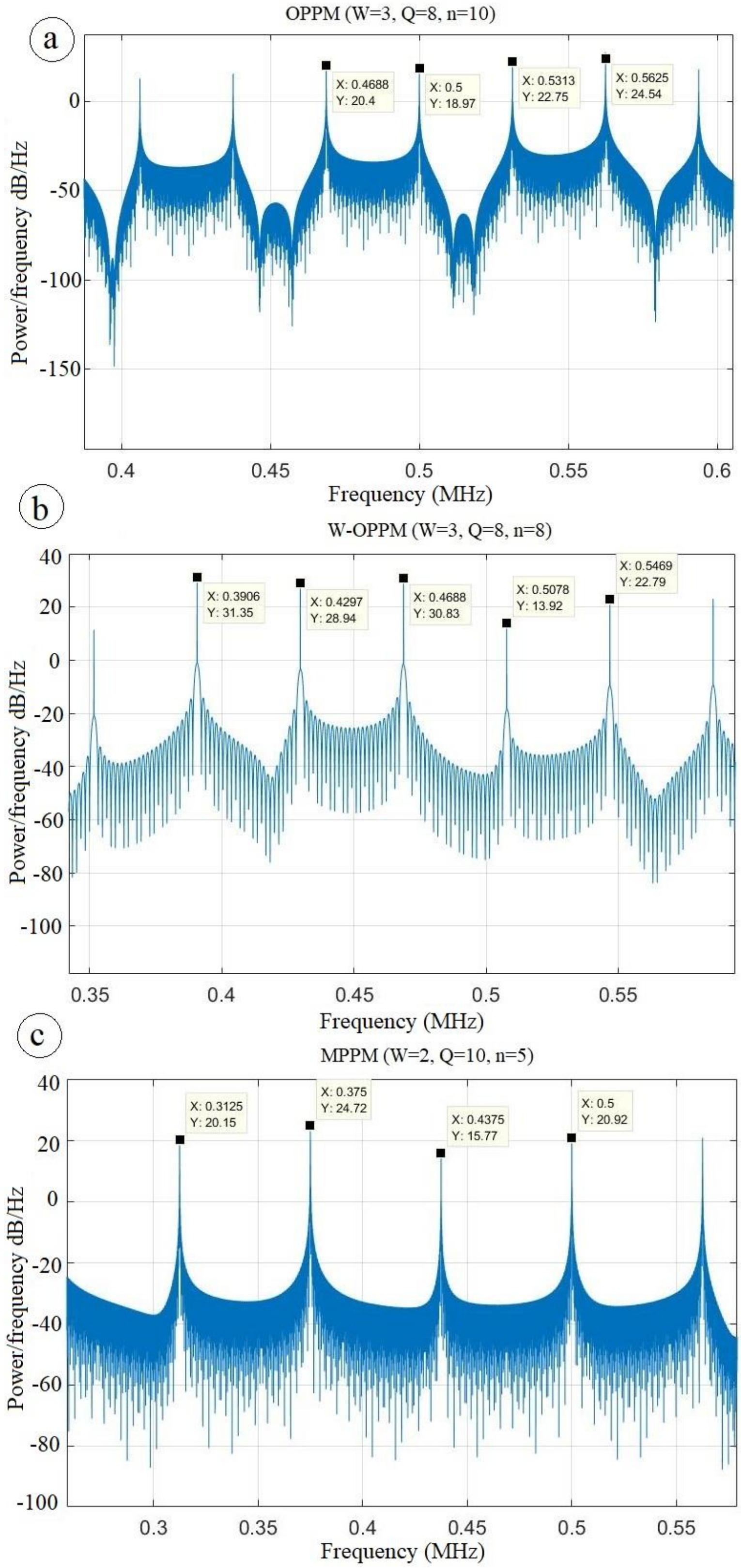

Figure 4. (a) Power Spectral Density of OPPM. (**b**) Power Spectral Density of W-OPPM. (**c**) Power Spectral Density of MPPM

4. Conclusions

In this paper, multiple-pulse modulation schemes are investigated in terms of bit error rate performance and FPGA based-design for visible light communication systems. Compared with MPPM and W-OPPM, the OPPM modulation scheme has better spectral efficiency. Moreover, the transmission schemes are designed in FPGA complier Quartus. Specifically, the demodulator architectures of systems are very complex compared to their modulator schemes. In future works, it may be improved the demodulator schemes of OPPM and MPPM.

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