Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X
IMPACT FACTOR: 6.017

IJCSMC, Vol. 8, Issue. 3, March 2019, pg.1 – 13

A Hybrid Communication System Using Pulse Position and Width Modulation

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Abstract: The digital revolution has emerged the need for storing, processing and communicating data in digital format. Accordingly, all-digital systems have become popular, where no analogue components are included in the circuitry. As the output of these systems is digital, pulse code modulation is employed to establish communications without the need for analogue components. A certain characteristic of the pulse, such as its width, position or amplitude, is adjusted based on the input value. The number of bits transmitted in the channel depends on the number of bits modulated per pulse and the number of pulses outputted from the system per second. However, these parameters are limited by the capabilities of the digital system and communication channel. In this study, a new hybrid communications technique is proposed to allow increasing the bandwidth of digital communication systems, without the need for significant modification to the system. The bits of the input data is split into two sets, one modulated using Pulse Width Modulation and the other is modulated using Pulse Position Modulation. The outputs from these modulators are encoded to the output signal, using one of two possible encoding techniques, amplitude or frequency, depending on the characteristics of the communications channel. The evaluation results show that the proposed method has been able to provide twice the bandwidth the digital system can establish using each of these techniques, solely.
Keywords: Digital Systems; Digital Communication; Pulse Amplitude Modulation; Pulse Width Modulation; Pulse Position Modulation.

1. Introduction

The employment of digital systems in different applications has increased the use of binary representations of the values, instead of analogs. The main difference between these types of values is that the binary representation has a discrete number of possible values in a range, while an analog value has an infinite number of values in any range [1]. To convert an analog signal to the digital form, the analog signal is sampled at a certain rate, i.e. quantized, and the nearest possible digital value is selected to represent the analog signal at that segment. Then, these digital values are used to store these signals or communicate them [2, 3].

Digital communication systems have higher resistance to noise, as the possible values that the incoming signal may have are known to the receiver. When a digital value is received, the receiver extracts the received value and quantize it to the nearest possible digital value as the received value. Such an approach is not possible in analog communication systems, as there is an infinite number of values that the incoming signal may have and it is impossible to predict the actual value transmitted by the transmitter. Thus, digital communication systems have been widely employed, as the data is already converted to digital form and these systems are more immune to noise [4, 5].

As the data being communicated and the systems that process these data are digital, all-digital systems are being widely used to establish communications, where no analogue components exist on these devices [6]. Mainly, these devices rely on Field Programmable Gate Array (FPGA) or microprocessors to process the digital inputs and establish communications. Thus, Pulse-Coded Modulation (PCM) has been widely employed in these systems, as outputting these pulses can be achieved digitally [7, 8]. The bandwidth of such system is measured by the number of transmitted bits per second (bps), which is calculated as the multiplication of the number of bits modulated per each pulse and the number of pulses transmitted per a second. To increase the bandwidth of the communications system, the number of bits being modulated per each pulse, the number of pulses per second or both are increased [9, 10]. However, there are some limitations imposed by the digital system or the communication channel to these parameters, so that, increasing the bandwidth require some significant modifications to them.

In this study, a new hybrid communication method is proposed, which relies on the Pulse Width Modulation (PWM) and Pulse Position Modulation (PPM) to increase the bandwidth of a digital communications system, with no or minimal modifications to the existing system. The proposed method uses two separate digital modulators and encodes their outputs to the output of the system, transmitted through the channel. To allow the application of the proposed method in different channels, two encoding techniques are used, amplitude and frequency encodings. The remainder of this paper is organized as follows: Section 2 reviews the literature related to digital communications. Section 3 describes the proposed hybrid communication method and encoding techniques. Section 4 shows the experiments conducted to evaluate the proposed method to illustrate the increment in the bandwidth it can achieve. Section 5 summarizes the conclusions from this work.

2. Literature Review

The use of digital communications has allowed the introduction of new signals modulation techniques that use pulses, instead of continuous signals, as carriers to modulate the data. As digital signals have discrete values, unlike analog ones, the existence of the carrier signal in places where the digital value may not appear is not required. Such modulation can reduce the power required to transmit the data, by reducing the amount of energy required to transmit the unnecessary modulation signals. However, the frequency of the carrier wave must be high enough to allow the detection of any change in the transmitted value at the receiving end [11, 12].

Pulse Amplitude Modulation (PAM) is one of the pulse-based modulation techniques, where the amplitude of the pulses in the carrier is decided based on the input value of the digital signal being modulated. The power required to transmit a modulated signal using PAM is proportional to the input signal being modulated, as transmitting signals with high amplitudes requires more energy [13]. Moreover, PAM is one of the highly noise-sensitive pulse modulation techniques, among other pulse-based modulation techniques, as the noise mainly affects the amplitude of the signals. However, the use of digital systems can reduce such effect as the received value is adjusted based on the possible values expected at the receiver, so that, only higher noise that can affect the value selection from one to another can produce an error in the receiver [14, 15]. Figure 2.1 shows a sample PAM system.

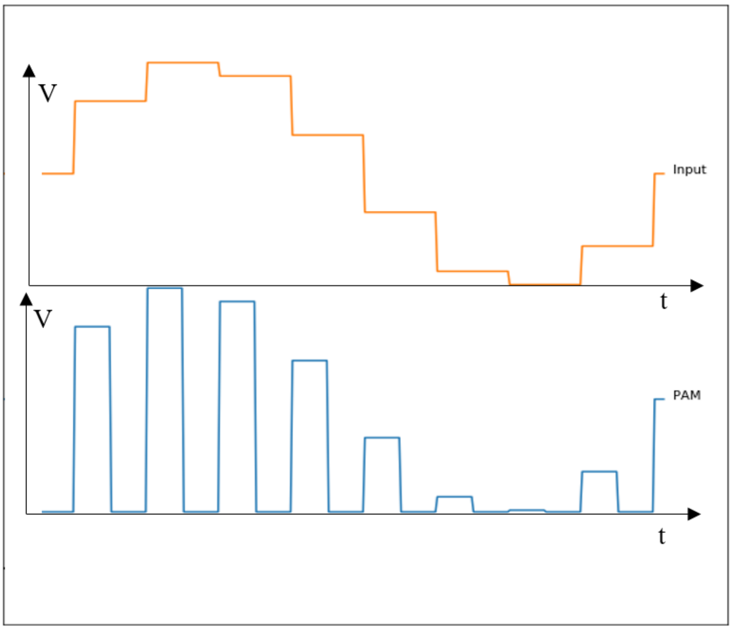

Figure 2.1: Input and output of a sample PAM.

Another popular pulse-based modulation technique is the Pulse Width Modulation (PWM), where the duty cycle of the modulated signal is adjusted based on the value of the input signal. As shown in Figure 2.2, the energy required to transmit a certain segment of the carrier pulses, depending on the input value, is also relational on the value of the input at that time segment. Higher input values require more pulses to be outputted, which requires more energy. However, this type of modulation is less sensitive to noise, as the amplitudes of the received pulses do not affect the received value [16, 17].

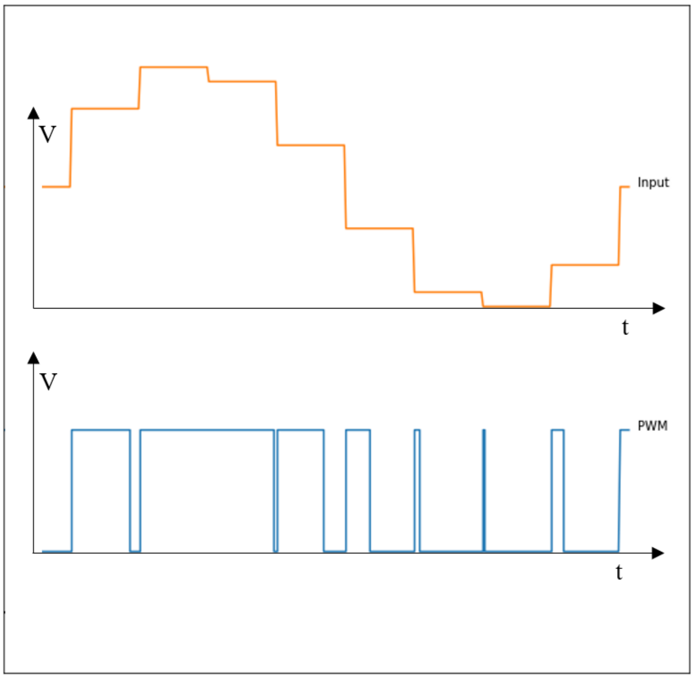

Figure 2.2: Input and output of a sample PWM.

Pulse Position Modulation (PPM) is another pulse-based modulation technique, where the position of the pulse in a predefined interval is adjusted depending on the value of the input signal at that time instance [18]. As the width and amplitude of the output of this modulation technique are always constant, regardless of the value being modulated, the power required to transmit a modulated value is irrelevant to the value of the input signal and is always constant. This technique has also high immunity against noise, as the amplitude of the signal is not considered during the retrieval of the received value [19]. Figure 2.3 shows an example of the output of PPM for a sample input signal.

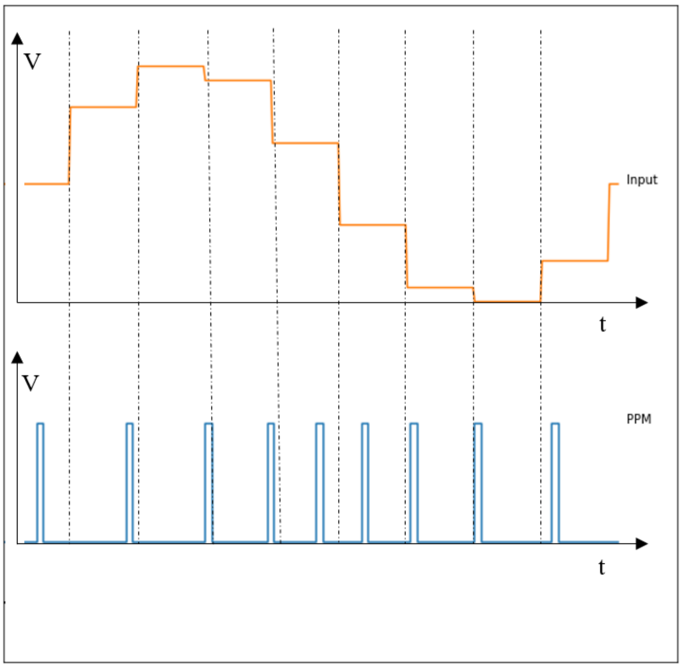

Figure 2.3: Input and output of a sample PPM.

3. The Proposed Method

In this study, a hybrid communication method based on PWM and PPM modulation techniques is proposed. By this combination, the proposed method is going to be able to modulate more data over the same communication channel. Instead of modulating a single value per an interval, it is possible to modulate two, one using PWM and the other using PPM, or splitting larger values and transmit them simultaneously, instead of using two separate intervals. In both cases, the bitrate of the transmission is going to be increased, so that, more data is transferred using the same channel, without the need to increase the capacity of the channel.

Per each interval, there are four possible states of the transmitted signal. The first state is when the PWM signal is transmitted while the PPM signal is not. The second state is when the PPM signal is transmitted and the PWM is not. The third state is when both signals are transmitted while the fourth state is when no signals are transmitted. These states must be distinguishable by the receiver, so that, both values can be retrieved and combined, in case these values are coming from a single larger value. When no carrier signal is detected, it is easy for the receiver to assume that both signals are not being transmitted. However, distinguishing the other three states from each other required encoding them at the transmitter, as shown in Figure 3.1.

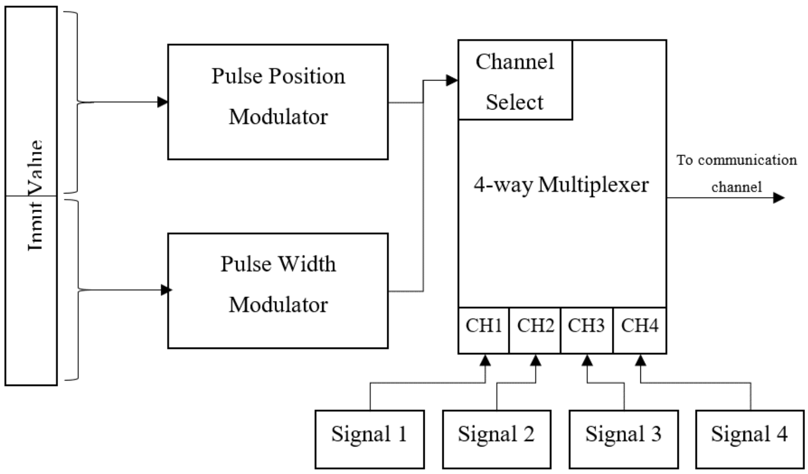

Figure 3.1: Encoding the output of the modulators in the proposed hybrid method.

Two encoding techniques are going to be implemented and evaluated during the study. The first technique uses frequency encoding, where three frequencies are used to encode these three different states. The other technique uses amplitude encoding, so that, three different levels of amplitudes are used to detect these states. Figure 3.2 shows the output of the proposed method in different states, using both techniques.

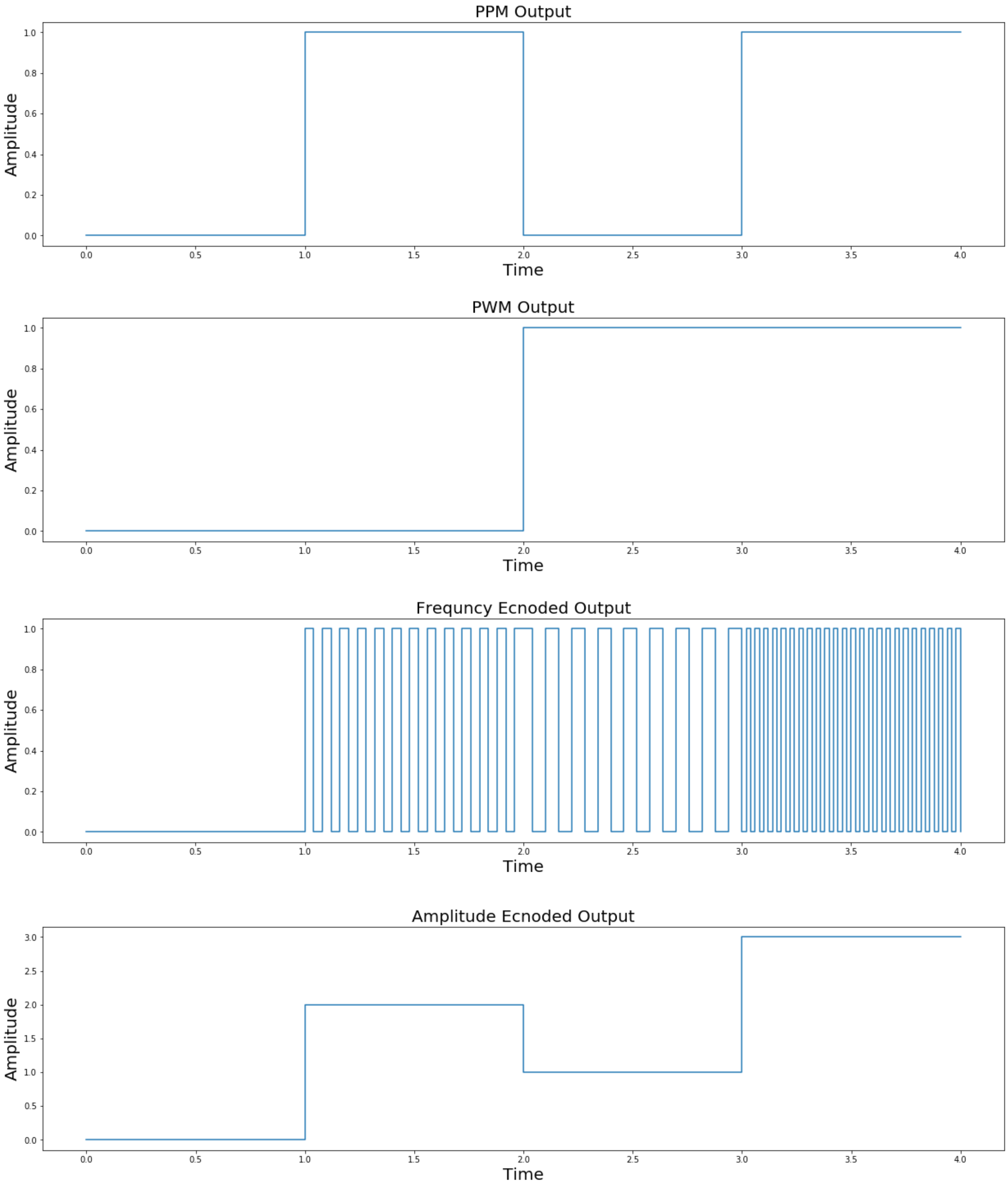

Figure 3.2: Outputs of the frequency and amplitude encoding techniques.

4. Evaluation

A simulation of the proposed method is implemented in Matlab's Simulink, where the entire system is implemented based on a 50MHz global clock, which represents the limitation of the digital system's capabilities. To illustrate the improvement in the communications bandwidth, using the same components, the use of PPM and PWM solely is evaluated using the same systems, using different number of bits being modulated per each pulse. The simulation is implemented and run using a Windows computer with Intel Core i7@2.8GHz processor frequency with 8GB memory.

The bandwidths achieved by the system, using the PWM and PPM separately are shown in Table 4.1 alongside with the Bit Error Rate (BER). Two different input seizes, 8 and 16, are evaluated using 9 different pulse rates. These results are summarized in Figure 4.1, which shows that PPM has been able to maintain lower BER up to 8Mbps, compared to the BER of the PWM. Thus, for the proposed method, the PPM is implemented for the part of the input data that contains the most significant bits, as they have higher weight on the calculated decimal value.

			Bit Error Rate	
Pulse Rate	**Input size (bits)**	**Transmission Rate (bps)**	**PWM**	**PPM**
1K	8	8K	0.831%	0.000%
1K	16	16K	0.963%	0.000%
5K	8	40K	0.834%	0.000%
5K	16	80K	0.839%	0.000%
10K	8	80K	0.000%	0.000%
10K	16	160K	1.731%	0.000%
50K	8	400K	0.838%	0.007%
50K	16	800K	1.467%	0.008%
100K	8	800K	0.841%	0.008%
100K	16	1.6M	3.382%	0.011%
500K	8	4M	0.326%	0.082%
500K	16	8M	2.107%	0.013%
1M	8	8M	0.715%	0.418%
1M	16	16M	2.613%	0.609%
5M	8	40M	8.041%	1.557%
5M	16	80M	10.287%	2.343%
10M	8	80M	7.942%	2.612%
10M	16	160M	11.826%	3.804%

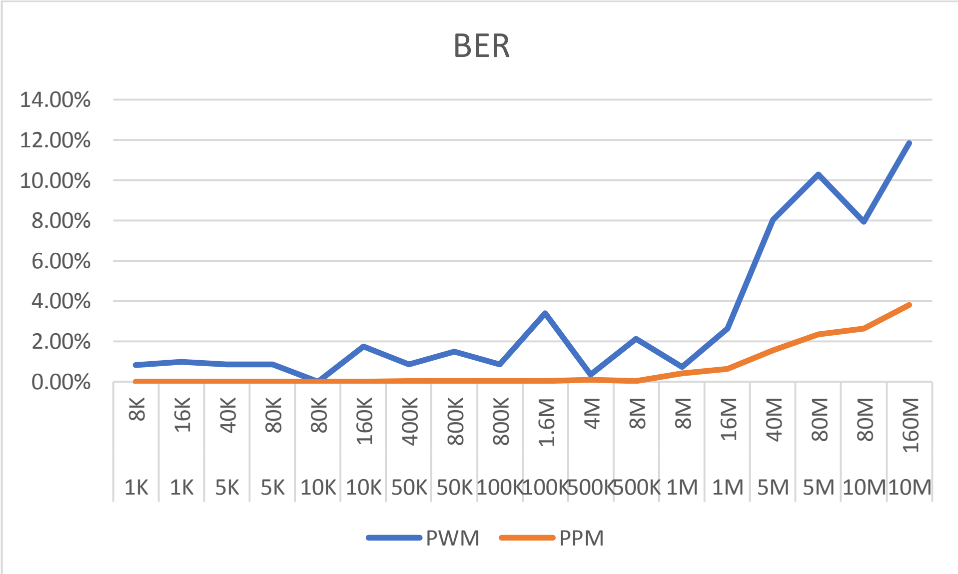

Figure 4.1: BER versus the pulse rate and bandwidth of the PWM and PPM modulations.

For the same parameters, the proposed hybrid method is implemented and evaluated, by measuring the bandwidth and BER for the received data. Table 4.2 summarizes these values for the parameters and the bandwidths they achieve as the BER per each scenario, for both encoding techniques. As summarized in Figure 4.2, the results show that the proposed method has been able to achieve twice the bandwidth achieved by the use of PPM or PWM separately, where the proposed method has been able to achieve up to 16Mbps with a BER less than 10^{-4}.

			Bit Error Rate	
Pulse Rate	**Input size (bits)**	**Transmission Rate (bps)**	**Amplitude Encoding**	**Frequency Encoding**
1K	8	8K	0.000%	0.000%
1K	16	16K	0.000%	0.000%
5K	8	40K	0.000%	0.000%
5K	16	80K	0.008%	0.009%
10K	8	80K	0.000%	0.000%
10K	16	160K	0.000%	0.000%
50K	8	400K	0.000%	0.000%
50K	16	800K	0.000%	0.000%
100K	8	800K	0.000%	0.006%
100K	16	1.6M	0.009%	0.012%
500K	8	4M	0.000%	0.000%
500K	16	8M	0.001%	0.007%
1M	8	8M	0.007%	0.012%
1M	16	16M	0.008%	0.010%
5M	8	40M	0.800%	1.312%
5M	16	80M	0.911%	1.687%
10M	8	80M	1.034%	2.509%
10M	16	160M	2.168%	3.813%

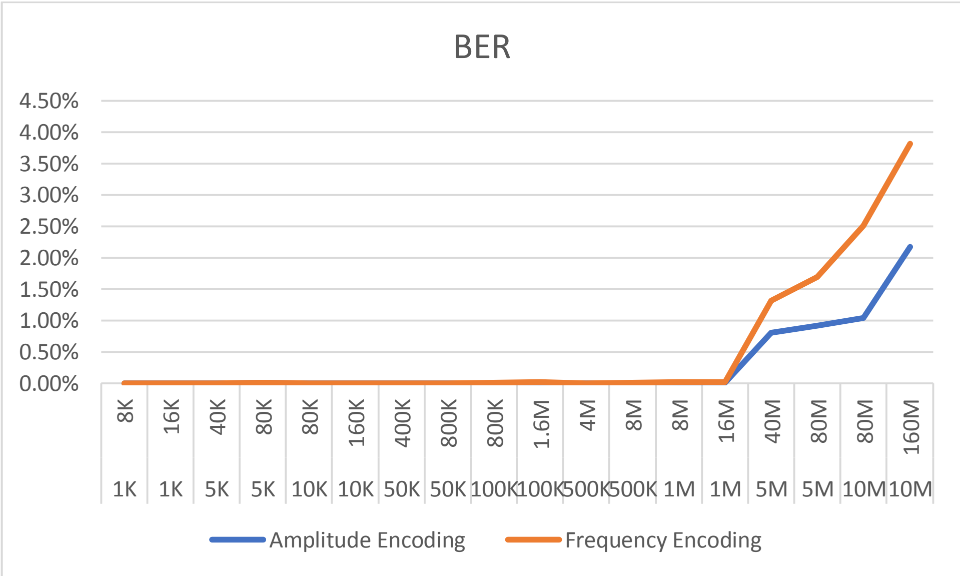

Figure 4.2: BER versus bandwidth for the proposed hybrid method using amplitude and frequency encoding.

Sample outputs of the frequency and amplitude encoded output, collected from the simulated model, as shown in Figure 4.3.

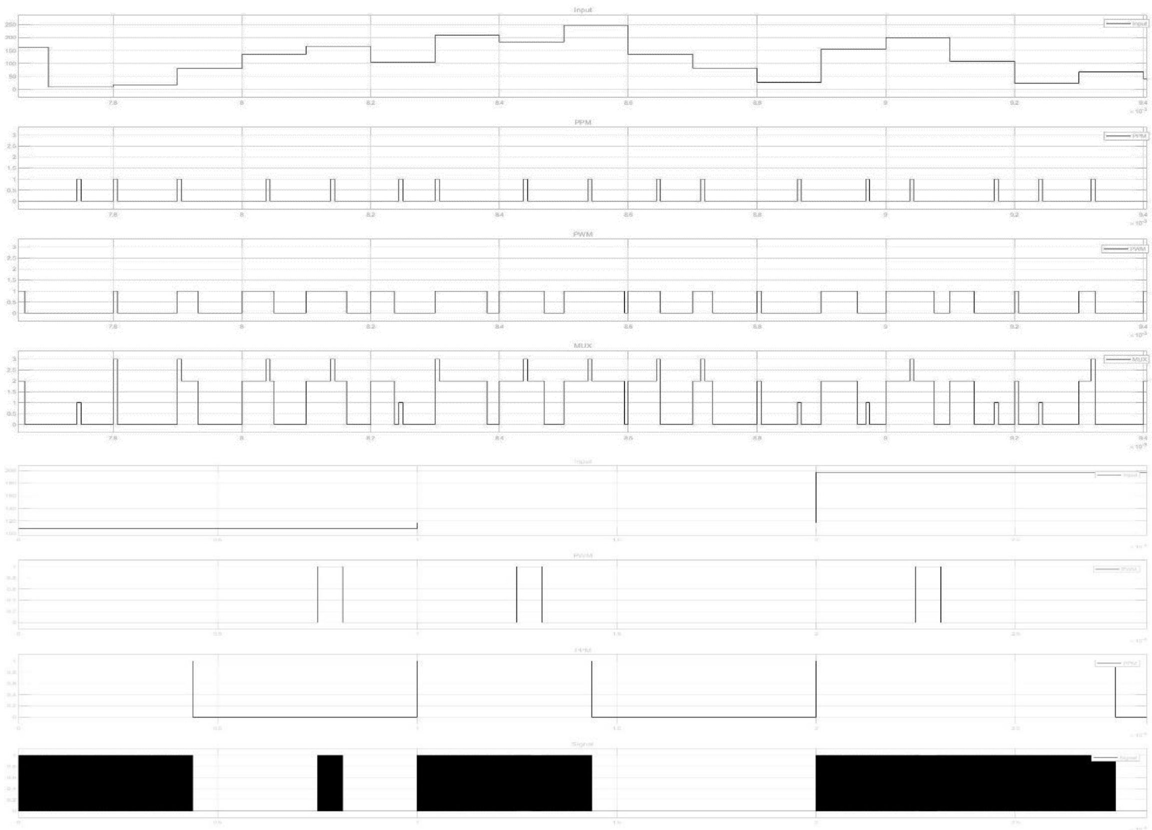

Figure 4.3: Sample outputs from the amplitude and frequency encoded signals.

The results also show that the proposed hybrid all-digital method has been able to achieve higher bandwidth, compared to other techniques implemented in earlier studies. The PWM communication system implemented by Pradana et al. [20] has a maximum bandwidth of 920bps, with BER of 10^{-4}, while the results in [21] have been able to reach up to 5Mbps using PPM. The comparison with the 16Mbps achieve by the proposed method using the same system that has only been able to achieve a maximum of 8Mbps with 10^{-4} BER, shows the significance of implementing this method to improve the bandwidth of the digital communication system without the need to impose significant modifications to the system. These changes can be implemented by changing the software of the controller of the digital system, such as the FPGA or the microprocessor.

5. Conclusion

Information is being collected and stored in digital formats in recent years, which has led to a huge emphasis on communicating it in the same format. Different communication systems are proposed to communicate these data, where the employment of pulses as data carriers has been allowed according to the discrete number of values that a digital variable can have. PPM and PWM are two of the widely used digital communication techniques, where certain characteristics of the output signal are manipulated, based on the value of the input signal at that time instance. In PPM, the position of the pulse of manipulated, while the duty-cycle of the signal is adjusted in PWM. Thus, these techniques are less affected by noise, as the noise mainly affects the amplitude of the signals.

In this study, a new hybrid communication method is proposed, which combines the PPM and PWM outputs over the same communications channel, in order to increase the communication speed. Using such approach, it is possible to send two values simultaneously, one over the PPM and the other over PWM, or be sending larger values by splitting their bits over these techniques, which increases the bitrate of the communications in both cases. The evaluation results have been able to prove this improvement in the bandwidth, as twice the bandwidth has been achieved using the same system. The implemented system, which has only been able to establish an 8Mbps communications using the PPM and PWM separately, has been able to achieve 16Mbps using the proposed system. As the proposed method can be implemented in the software of programmable digital devices, it can provide significant improvement in the communications. Depending on the characteristics of the communication channel, one of two encoding techniques, amplitude and frequency encodings, to employ the proposed hybrid method.

In future work, the employment of pulse amplitude modulation with the pulse position modulation is going to be evaluated. Despite the higher sensitivity of PAM to noise, the need for only four states to encode the states of the modulators can provide better resistance to noise, while significantly increasing the bandwidth, as the levels are used for encoding rather than modulation.

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