Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ENEE4113

COMMUNICATION LABORATORY

Pulse Amplitude Modulation (Sampling)

Report No.2

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Section: 5.

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Abstract

This experiment aims to transform the theoretical knowledge of the pulse train characteristics into practical application. It focuses on the main concepts of pulse amplitude modulation (PAM) and demodulation, including, how to perform the pulse amplitude modulation on different types of input signals in time and frequency domains. Additionally, to study the characteristics of the pulse amplitude demodulation by displaying the original message and the demodulated signal, compare between them, and examine the effects of the duty cycle on the signal. Also, to understand the concepts of Nyquist rate, aliasing, and analyzing the effect of the sampling pulses on the communication system. Finally, it explores the concept of transmitting and receiving multiple signals across the channel by pulse amplitude modulation (PAM) multiplex.

Table of Contents

Table of Figures

List of Tables

Theory

1. Pulse Amplitude Modulation (PAM)

1.1 Pulse Amplitude Modulation Block Diagram

Communication techniques are a vital part of any type of transmitting and receiving information between sender and receiver. Further, the signals that are being transmitted are in continuous wave format, and here comes the use of pulse amplitude modulation (PAM). Pulse Amplitude Modulation or PAM acts as a signal converter that helps in encoding the amplitude of the pulse and converts analog signal transmission into a digital version [2]. The block diagram of the pulse amplitude modulation is shown in the following figure. A low pass filter (LPF), a modulator, a pulse reshaping circuit (PRC), and the pulse generator are the main components of the PAM generator [3].

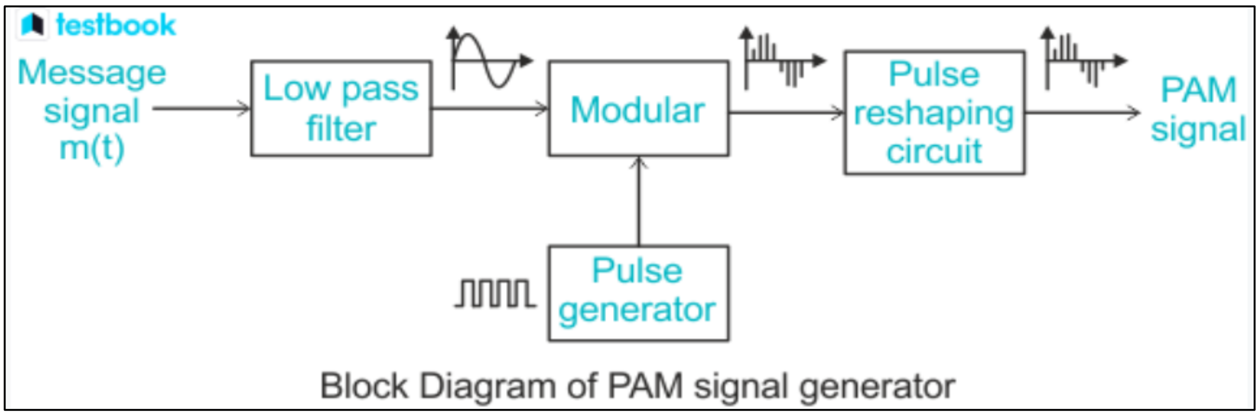

Figure 1 Pulse Amplitude Modulation (PAM) block diagram.

Pulse amplitude modulation is used in many applications such as graphic cards for high-speed networking, and LED drivers for efficiency in the energy of the lighting [4].

1.2 Sampling Theorem

A continuous time signal can be represented in its samples and can be recovered uniquely back when **sampling frequency fs** is greater than or equal to twice the highest frequency component of the original signal, and this is what it called **Nyquist rate [5].**

Equation 1 Nyquist Rate equation.

$$Ts = \frac{1}{2 * W}, equivalentely\ fs \geq\ 2 * W.$$

1.3 Signals Sampling Techniques

There are three types of sampling techniques, impulse sampling, natural sampling, and flat top sampling. In **Impulse Sampling** (known as ideal sampling), the message signal x(t) is multiplied by an impulse train with period (T). The amplitude of the output signal y(t) changes with respect of the input signal x(t). The output sampler is given by:

Equation 2 Impulse Sampling output equation.

$$y(t) = \sum_{n=-\infty}^{\infty} x(nt)\,\delta(t-nT)$$

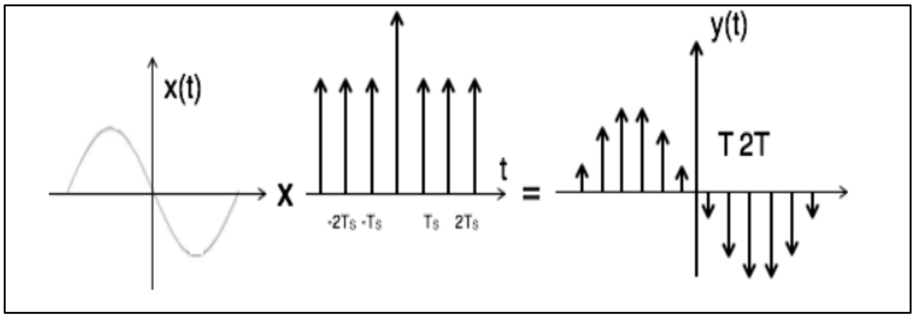

Figure 2 Impulse sampling.

The **Natural Sampling** is the similar as the impulse sampling but the input message signal multiplied by pulse train instead of impulse train.

Equation 3 Natural Sampling output equation.

$$y(t) = x(t) \sum_{n=-\infty}^{\infty} P(t-nT)$$

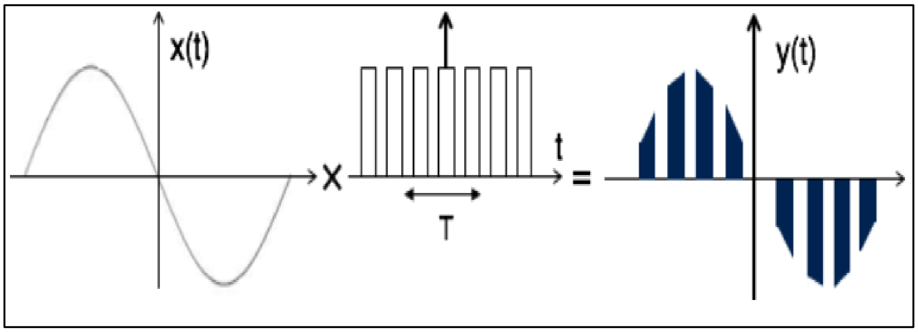

Figure 3 Natural sampling.

In **Flat-Top Sampling,** the sampling pulse has a flat-top shape, with constant amplitude. During transmission, noise is introduced at top of the transmission pulse which can be easily removed if the pulse is in the form of flat top. Theoretically, the sampled signal can be obtained by convolution of rectangular pulse p(t) with ideally sampled signal as shown [6].

Equation 4 Flat-Top Sampling output equation.

$$y(t) = p(t) * y\delta(t)$$

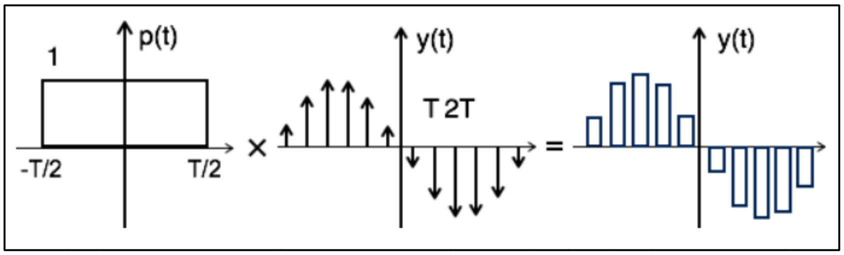

Figure 4 Flat-Top Sampling.

2. Pulse Amplitude Demodulation

For pulse amplitude modulated (PAM) signals, the demodulation is done using a holding circuit. This zero-order Holding circuit considers only the previous sample to decide the value between the two pulses [8]. The low pass filter eliminates the high-frequency ripples and generates the demodulated signal [9].

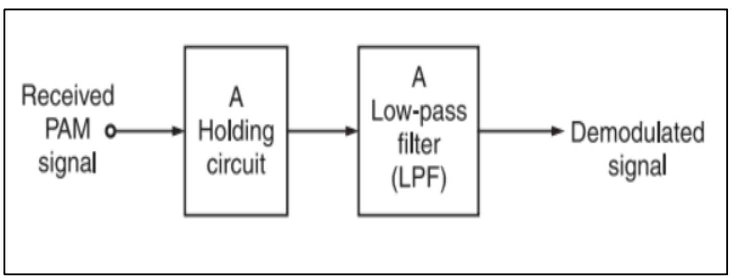

Figure 6 Pulse Amplitude Demodulation Block Diagram.

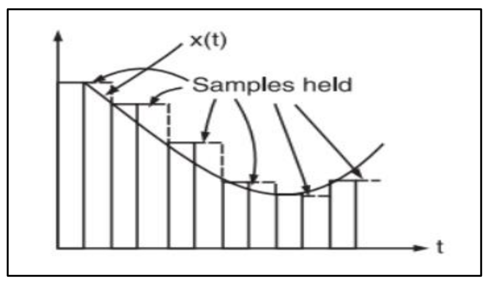

Figure 5 The output of the holding circuit.

3. Aliasing

When the sampling frequency (fs) is less than the **Nyquist rate,** a distortion type of noise called aliasing happened. In this case, the message signal cannot be recovered from the sampled signal without distortion. To avoid aliasing, the sampling rate must be at least twice the highest frequency component of the analog signal being sampled [1].

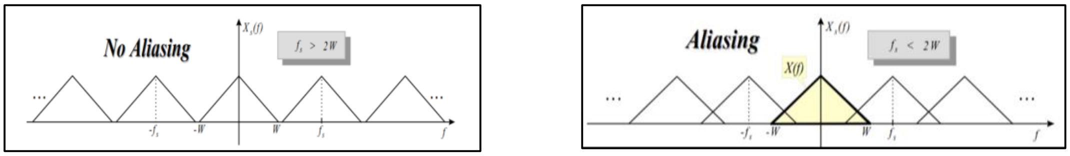

Figure 7 Aliasing effect on signal spectrum.

4. Time Division Multiplexing

Multiplexing is a technique used when the transmission medium has more bandwidth than the signals being sent. It enables multiple signals to be combined into a single signal and transmitted over the high-bandwidth link. **Time Division Multiplexing (TDM)** happens when the data transmission rate of media is greater than that of the source, and each signal is allotted a definite amount of time. These slots are so small that all transmissions appear to be parallel [12].

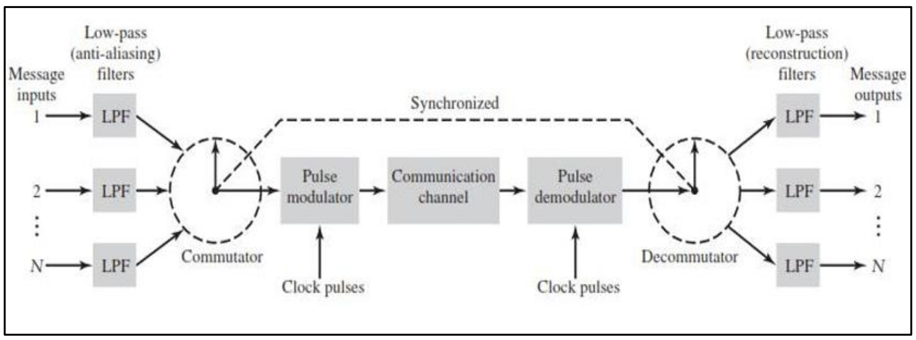

Figure 8 Time Division Multiplexing block diagram.

5. Crosstalk in Pulse Amplitude Modulation (PAM)

Crosstalk in pulse modulation refers to interference between two signals transmitted in the same channel, where the information from one source overlaps with the time slot of another source. It can lead to signal distortion, interference, and affecting the quality of communication.

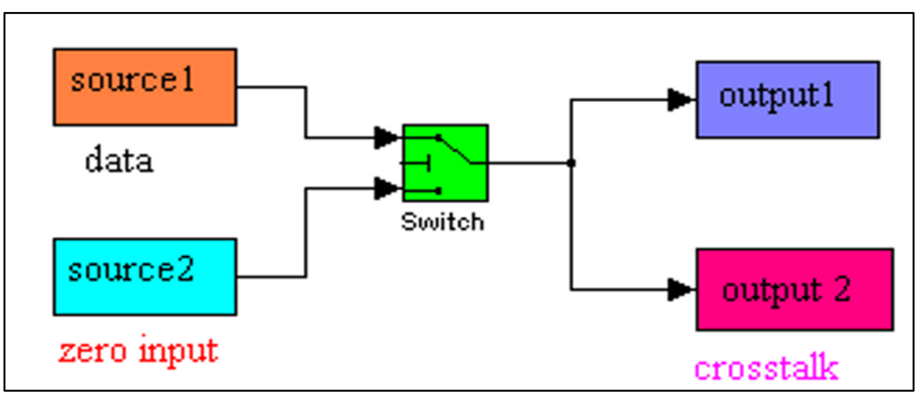

Figure 9 Crosstalk in pulse amplitude modulation (PAM) block diagram.

Procedure and Data Analysis

Part 1: Time and Frequency Characteristics of pulse train

The objective of this part is to study the characteristics of the pulse train in both frequency and time domains when changing the value of duty cycle and keeping the values of the frequency and the amplitude of the signal. Also, to find the zero crossings in the envelope of the pulse train spectrum for different duty cycles.

Firstly, the pulse train signal with frequency equals to $\mathbf{1\ kHz}$, amplitude $\boldsymbol{Vss = 10\ Volts}$, and $\boldsymbol{duty\ cycle\ = 10\%}$ was generated using the function generator. The circuit of generating the pulse train signal was connected as shown in the following figure.

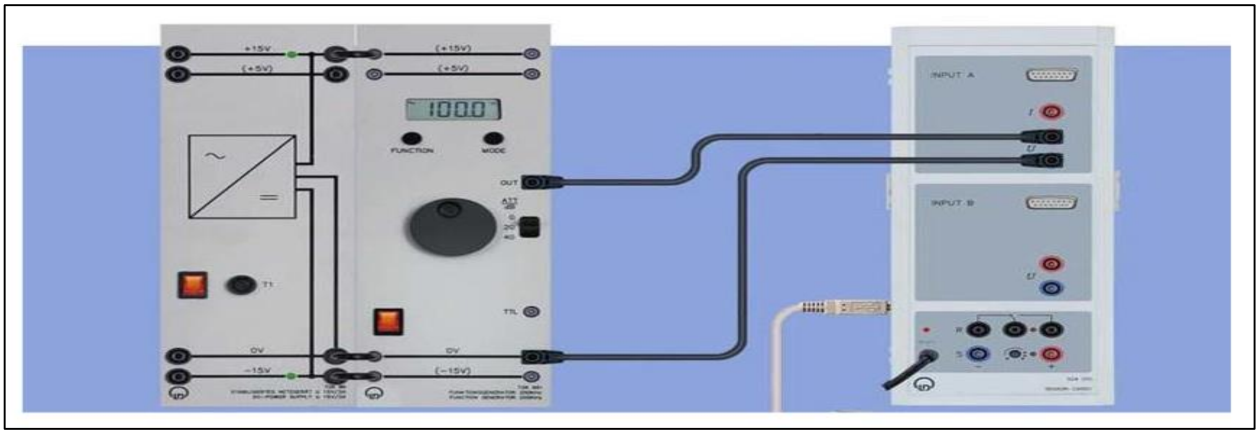

Figure 10 Pulse train signal circuit.

And after starting the measurements, the pulse train signal in time and frequency domains are as the following:

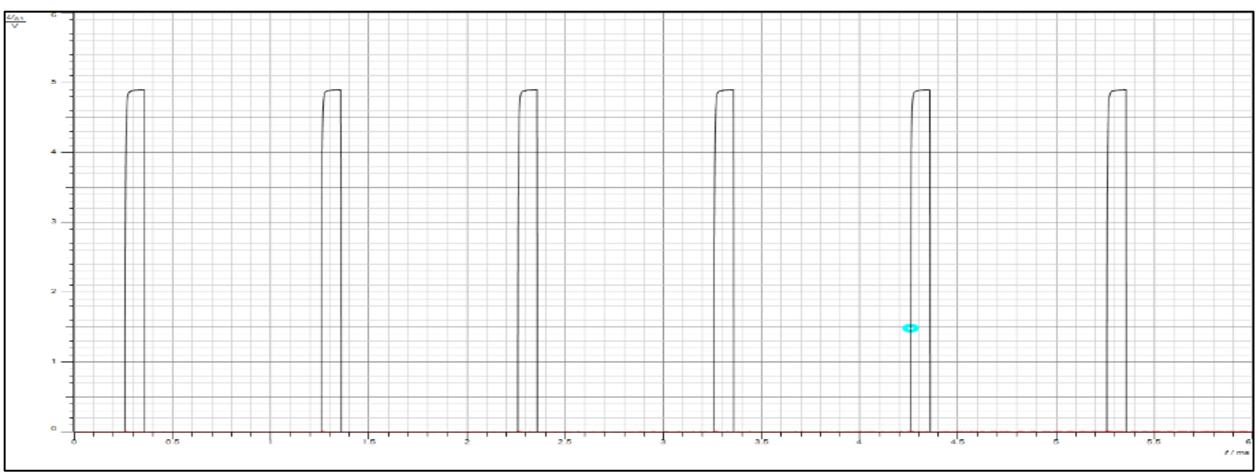

Figure 11 Pulse train signal in time domain when f=1 kHz, and Vss=10 Volt.

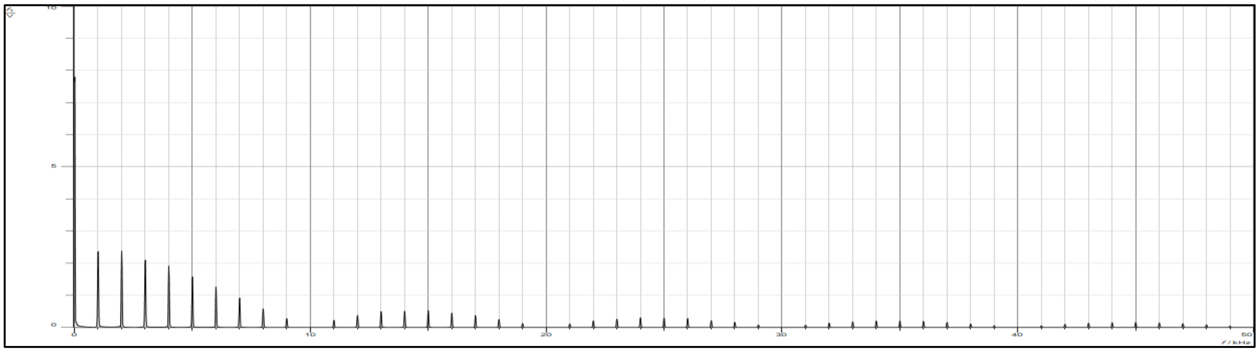

Figure 12 Pulse train signal in frequency domain when f = 1 kHz, and Vss=10 Volt.

In the previous case, when the duty cycle is 10%, it means that 10% of the pulse signal is ON for the total period, and 90% of the signal is inactive OFF. In other words, the pulse signal is being transmitted actively over the channel for a short time (10% of the total period), and the remaining percentage (90%) means that the signal is inactive (OFF), and not being transmitted. Also, the zero crossing is when the signal crosses the zero x-axis, which refers to the signal changing its polarity. From figure 14, when the duty **cycle = $\mathbf{10\%}$,** the first **zero crossing** of the pulse train signal in kHz will be at **10 kHz**. Zero crossing can be also calculated according to the following equation:

Equation 5 Zero crossing equation.

$$\boldsymbol{Zero\ Crossing = \frac{frequency}{duty\ cycle}}$$

After that, the same measurements will be repeated for different duty cycles 20%, 30%, 40%, 50% and 90% respectively. The following figures shows when changing the value of the duty cycle to 40%, but keeping the values of the frequency $\mathbf{1}\ \boldsymbol{kHz}$ and the amplitude $\boldsymbol{Vss} = \mathbf{10}\ \boldsymbol{Volts}$. The generated signal in time and frequency domains is as the following:

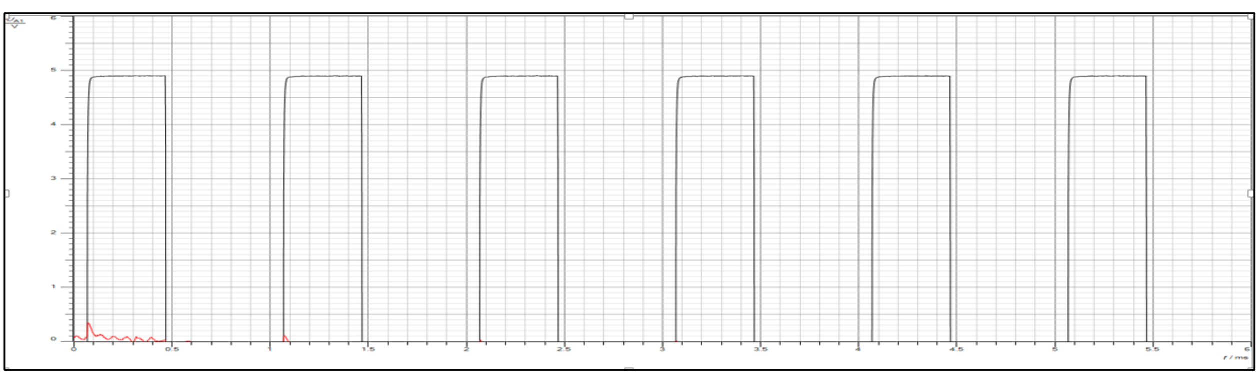

Figure 13 Pulse train signal when changing the duty cycle to 40% in time domain.

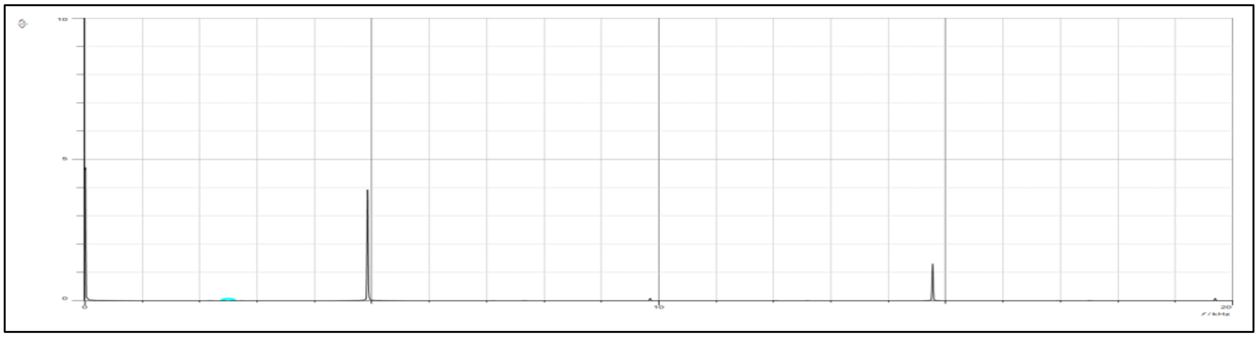

Figure 14 Pulse train signal when changing the duty cycle to 40% in frequency domain.

And the following table shows the zero crossing frequency for different duty cycles in kHz:

Table 1 The zero crossing frequency of different duty cycle.

Duty Cycle (%)	20	30	40	50	90
Zero Crossing(kHz)	5	3.333	2.49	2	1.11

From the previous results and plots, when the duty cycle is only **10%**, it is noticed that the pulse train signal has a small active (ON) period, while it has a large inactive period (OFF) of 90% of the period. And, when increasing the value of the duty cycle to **40%**, the inactive period was decreased, and the active (ON) was increased.

Pulse trains require large transmission bandwidths because the signal changes rapidly, and to avoid any kind of noise or distortion and to meet the requirements of the **Nyquist rate;** the large bandwidths is necessary. In other words, the larger bandwidth ensures that the higher frequency content of the pulse train is correctly preserved during transmission. Insufficient bandwidth can result in having a distorted pulse edges, leading to loss of signal quality and increase errors. In addition, the structure of the spectrum of the pulse train signal is as a **sink** function.

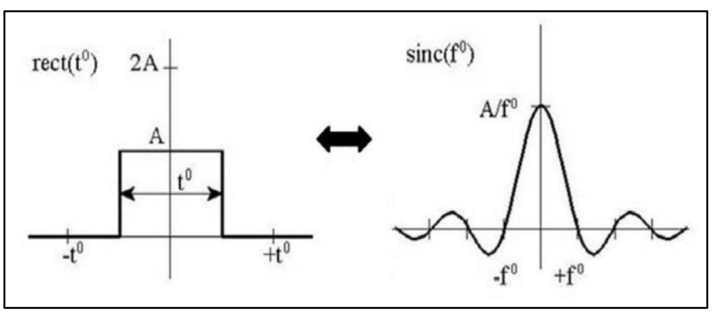

Figure 15 Pulse signal in time and frequency domains.

Part 2: Characteristics of Pulse Amplitude Modulation (PAM)

Now, this part aims to study and simulate the characteristics of pulse amplitude modulation (PAM). The pulse wave signal was generated using the function generator to sample the input message signal. Both sampling frequency (fp) knob and duty cycle (τ/TP) knob were adjusted to their maximum value. Finally, the Cassy UA1 was connected to the Clock generator output (G). The following figure shows the circuit connection:

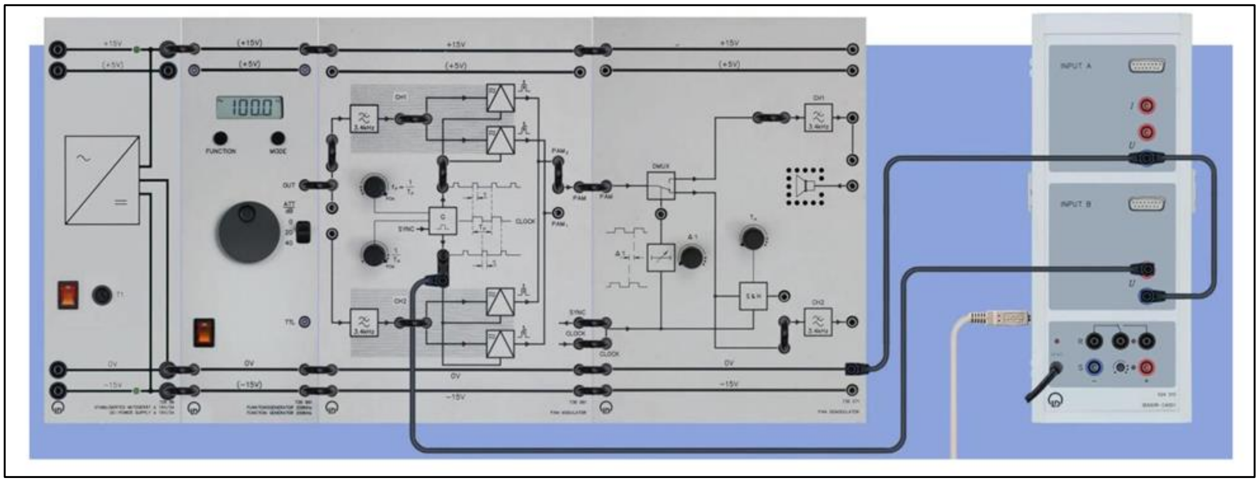

Figure 16 Pulse Amplitude Modulation Circuit.

In addition, the sampling frequency was adjusted to (fo=5000 Hz). The following figures shows the pulse wave signal, and the adjusted sampling frequency. It is noticed that the sampling frequency approximately at 5000 Hz, and the second pulse at 15000 Hz (3f) :

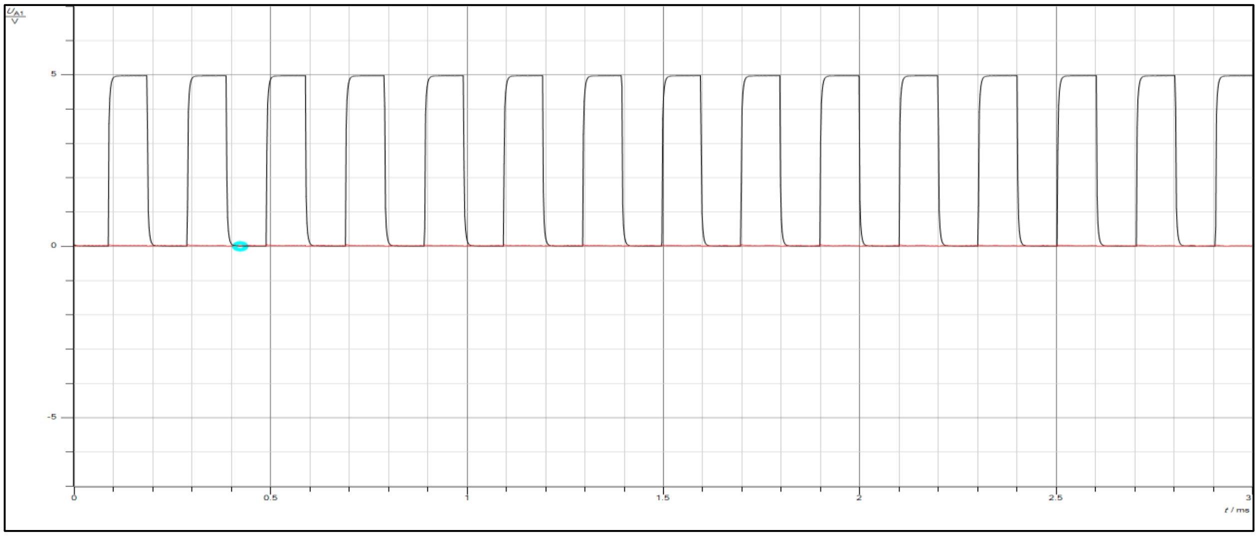

Figure 17 Pulse signal wave in time domain.

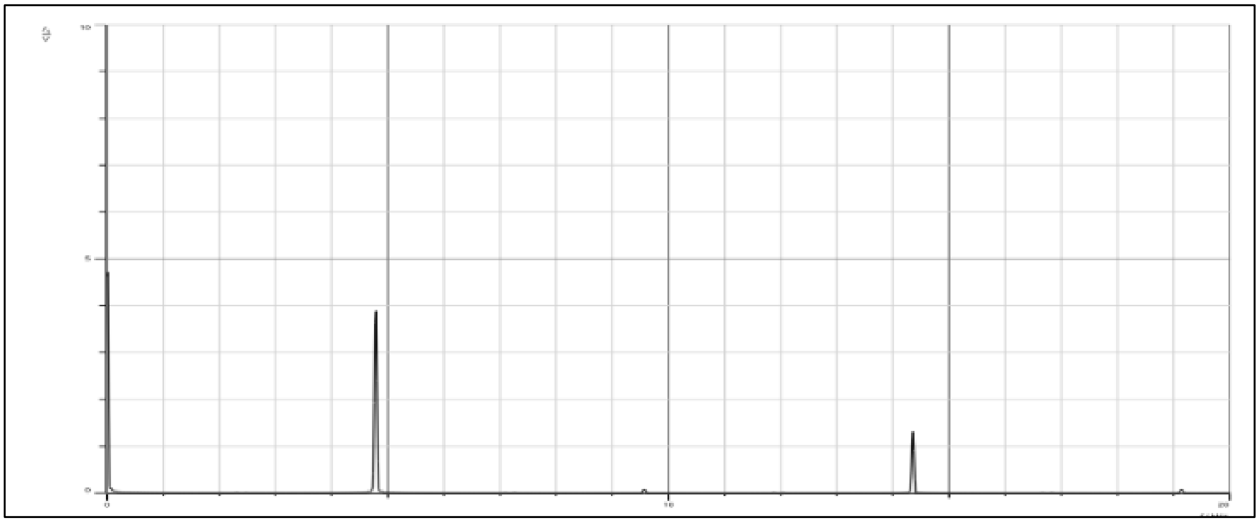

Figure 18 The adjusted sampling frequency.

2.1 The effect of the channel filter (CH1)

Firstly, in this part, the effect of the channel filter (CH 1) will be studied. To achieve that, an input signal with specified amplitude and frequency is passed through this channel filter. And finally, finding the effect of the channel according the difference between the input and the output signal.

To achieve this objective; a sine wave signal with frequency = 500 Hz, and voltage = 10V was generated form the function generator. Both Cassy UA1 and Cassy UB1to were connected to the input message signal and the output signal of the channel filter (CH1) respectively. The following figure shows the result:

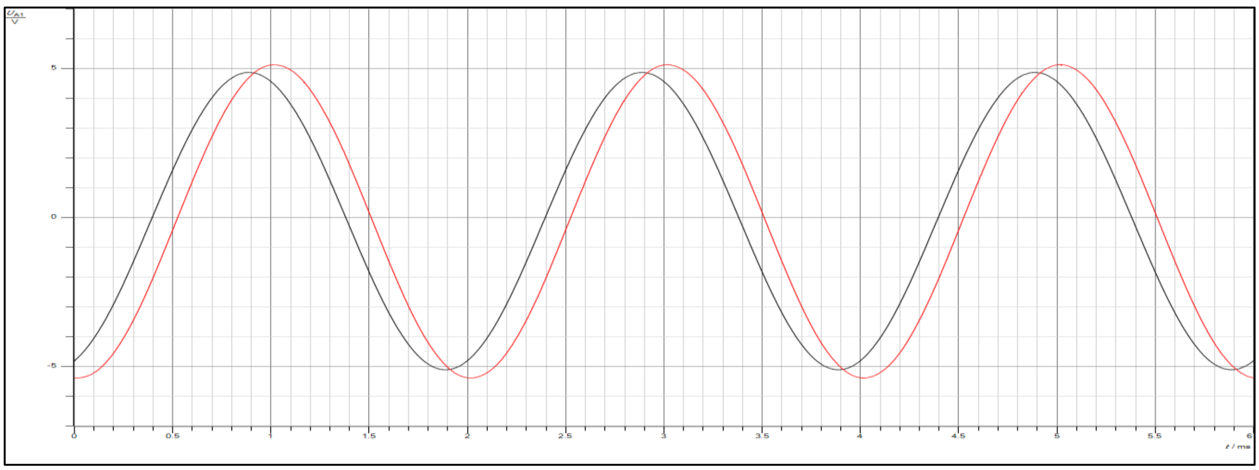

Figure 19 The input and output message signal of the channel filter.

It is noticed that the effect of the channel filter is that the filter shifts the input message signal by 90 degree. Also, the amplitude of the output signal of the filter was increased and the gain of the filter can be calculated as the ration of the amplitude of the output signal compared to the input signal as the following:

Equation 6 The gain of the channel filter (CH1) equation.

$$Gain = \frac{A_{output}}{A_{input}} = \frac{5.2}{4.8} = 1.08333\, Volts.$$

2.2 Displaying the Pulse Amplitude Modulated signal s(t) of PAM1 in the time domain

Now, it was required to simulate and display the modulated signal s(t) that has been passed through channel filter (CH1). The sine wave signal with frequency equals to 500 Hz, and voltage Vss = 10 Volts was generated using the function generator. Finally, the Cassy sensor UA1 to the output signal of the CH1 filter, and Cassy sensor UB1 to the PAM1 output signal. The following figures shows the pulse modulated signal in time and frequency domain.

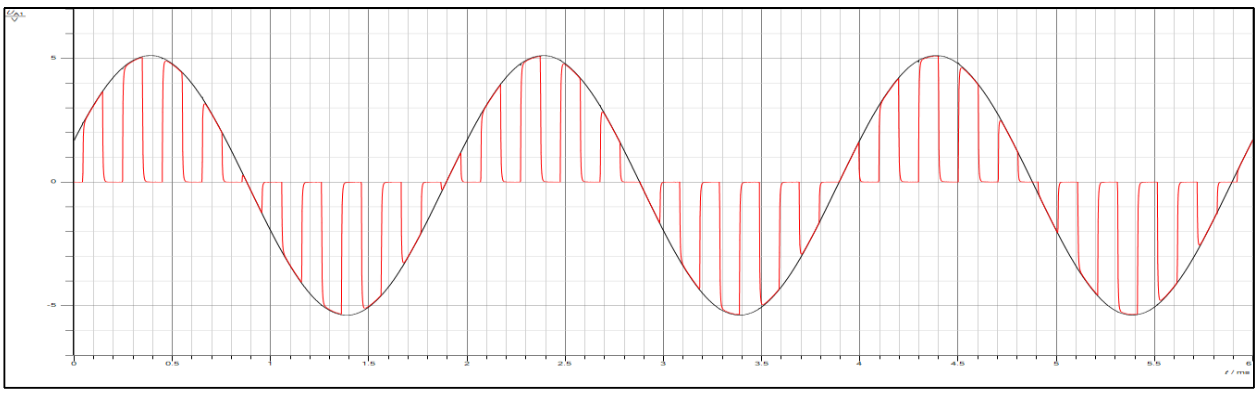

Figure 21 Pulse amplitude modulated signal in time domain.

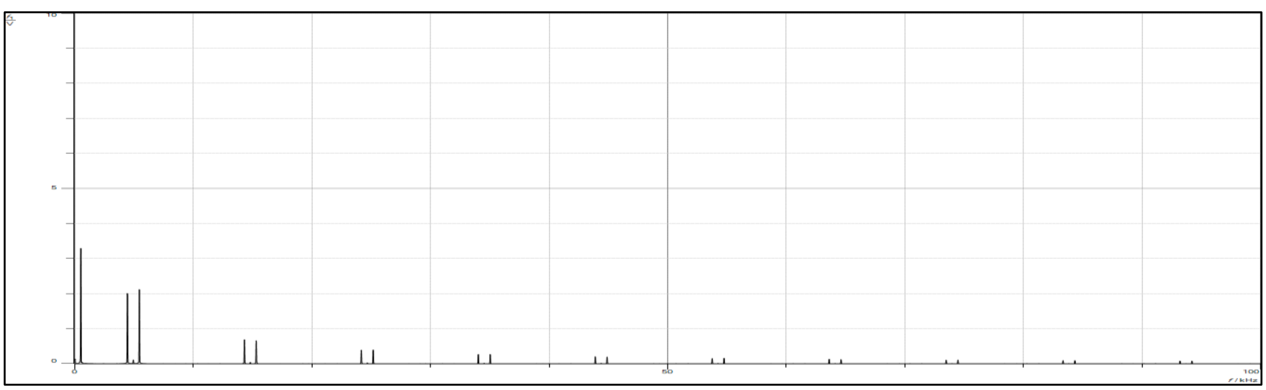

Figure 20 Pulse amplitude modulated signal spectrum.

It is noticed from the time domain modulated signal that the sampling is **natural sampling** and the duty cycle was it maximum value. Additionally, from the pulse signal frequency domain, the pulse appears as the message signal $\mp 500\ Hz$ which is the input signal frequency, and the next pulse equals 15000 Hz $\mp 500\ Hz$ which gives us the **odd multiple** of the sampling frequency **(1f0, 3f0, 5f0 , etc.).**

And to determine the effect of the duty cycle on the pulse amplitude modulation in time domain, the duty cycle was reduced to the min value. The following figure shows the output signal in time domain and frequency domain:

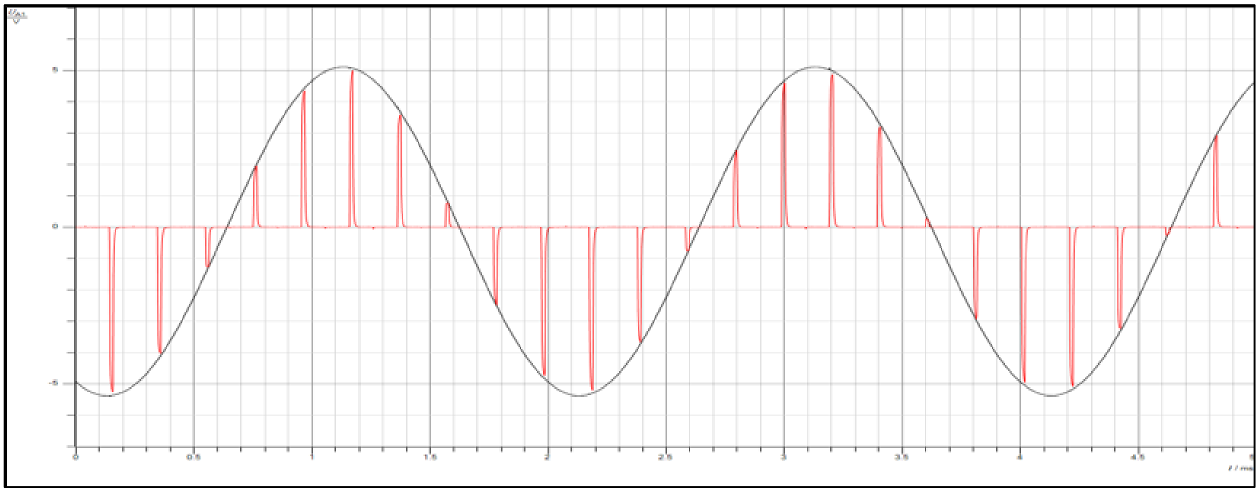

Figure 23 Pulse amplitude modulation when changing the duty cycle to min in time domain.

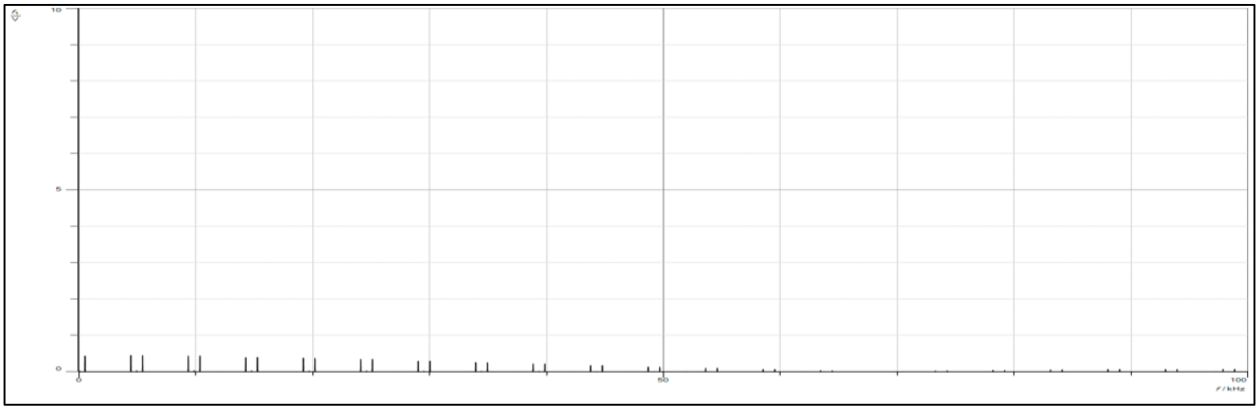

Figure 22 Pulse amplitude modulation when changing the duty cycle to min in frequency domain.

From the previous results which represent the output pulse modulated signal when reducing the duty cycle, it is noticed that when decreasing the value of the duty cycle the active (ON) duration of the pulse amplitude modulation was reduced, and the inactive (OFF) duration was increased resulting in a lower average signal amplitude which leads to having smaller power consumption compared when the duty cycle is at its max value. In addition, when the duty cycle is reduced, the quality of the modulated signal will be reduced compared to when the duty cycle is at its max.

2.3 Displaying the Pulse Amplitude Modulated signal s(t) of PAM1 in the Frequency domain

The spectrum of the pulse amplitude modulated signal of the CH1 filter was discussed deeply in the previous part. In this part, the effect of changing the message frequency **fm** on the modulated signal will be discussed. In addition, the effect of the duty cycle on the pulse amplitude modulation (PAM) will be specified and determined clearly.

- ✓ ***Determining the effect of the message frequency on the PAM in the Freq domain***

In this part, the input message signal will be modulated in two different frequencies **(1 kHz and 2 kHz)** in order to determine its effect. The following figures shows the pulse modulated signal of CH1 in time and frequency domains for both frequency values.

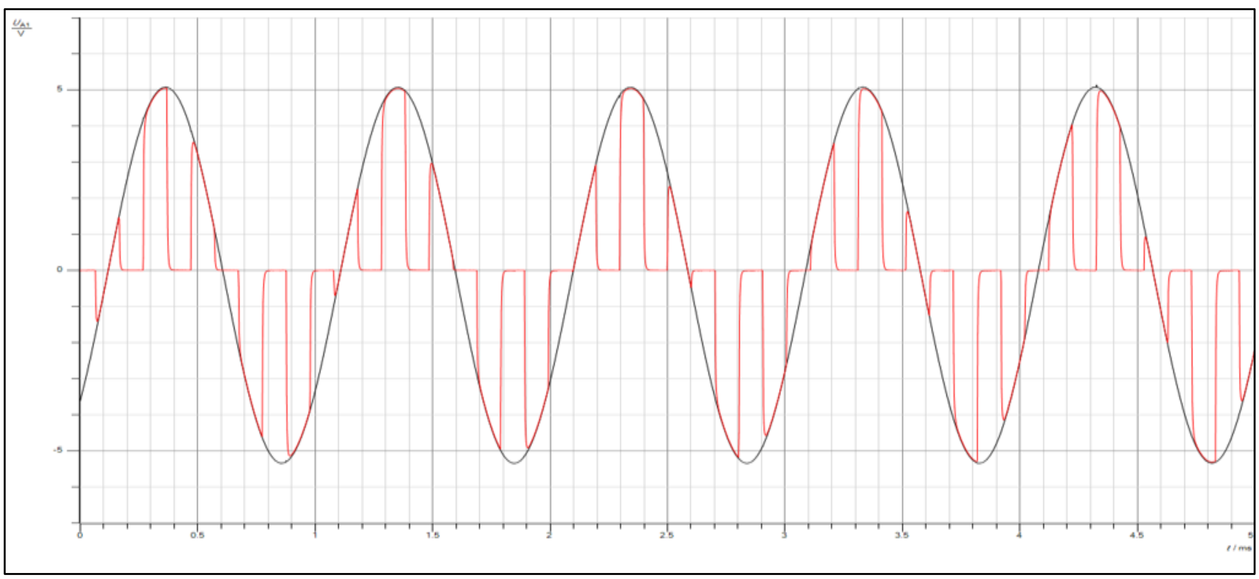

Figure 24 The natural sampling when the message frequency = 1 kHz in time domain.

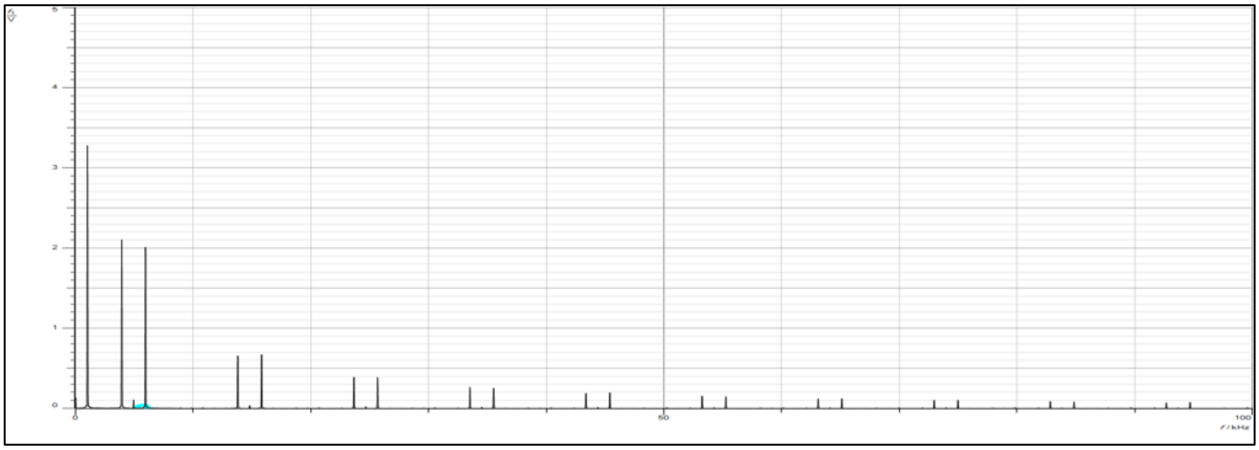

Figure 27 The natural sampling when the message frequency = 1 kHz in frequency domain.

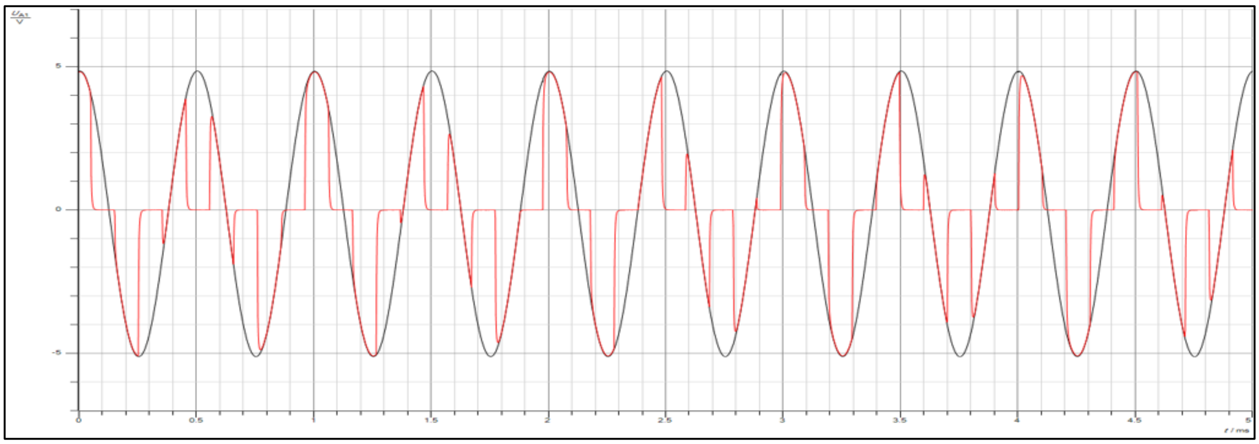

Figure 26 The natural sampling when the message frequency = 2 kHz in time domain.

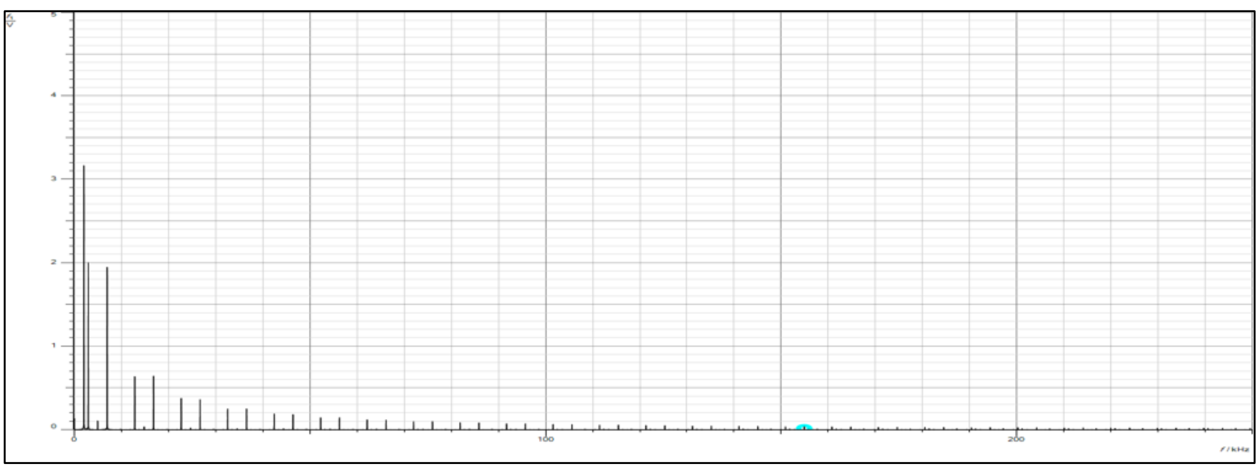

Figure 25 The natural sampling when the message frequency = 2 kHz in frequency domain.

From the previous results, it is noticed that when the frequency of the input message signal increased form 1 kHz to 2 kHz makes the transmission rate so rapid, and), and in terms of frequency domain, the space between the two pulses increases with the increase of the message signal frequency.

- ✓ ***Determining the effect of the duty cycle on the PAM in the Freq domain***

In this part, the effect of the duty cycle on the pulse amplitude modulation will be determined. The input message signal frequency was set to be 500 Hz, and the duty cycle of the clock generator will be 10% initially, and then to be changed to 10% and 30%.

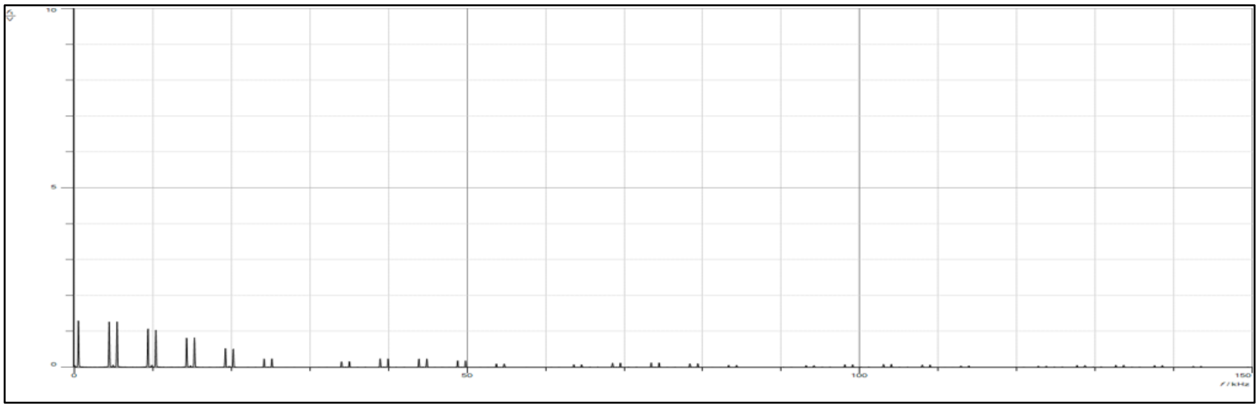

Figure 29 The pulse modulated spectrum when the duty cycle 10%.

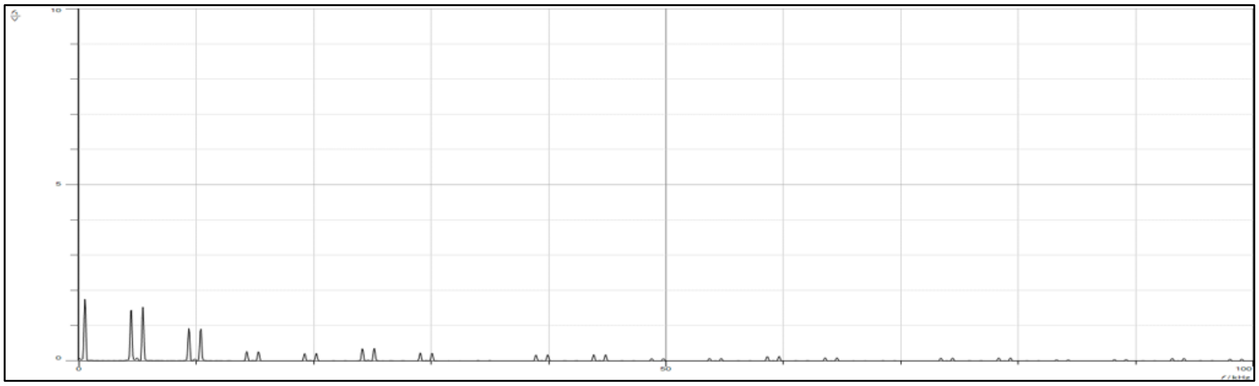

Figure 28 The pulse modulated spectrum when the duty cycle 30%.

From the previous results, it was noticed that when the duty cycle increased, the amplitude of each pulse increased within the same input message signal frequency.

2.4 Displaying the Pulse Amplitude Modulated signal s(t) of PAM2 in the time domain

The objective of this part is to display the pulse amplitude modulated signal of the PAM2 in time domain. To achieve that, the message signal with frequency equals to 500 Hz, and amplitude equals to 10 Volts. Finally, the Cassy UA1 to the output signal of the CH1 filter, and Cassy UB1 to the PAM2 output. The following figure shows the output of the modulation when the duty at it max (duty cycle = 30%) in time and frequency domain:

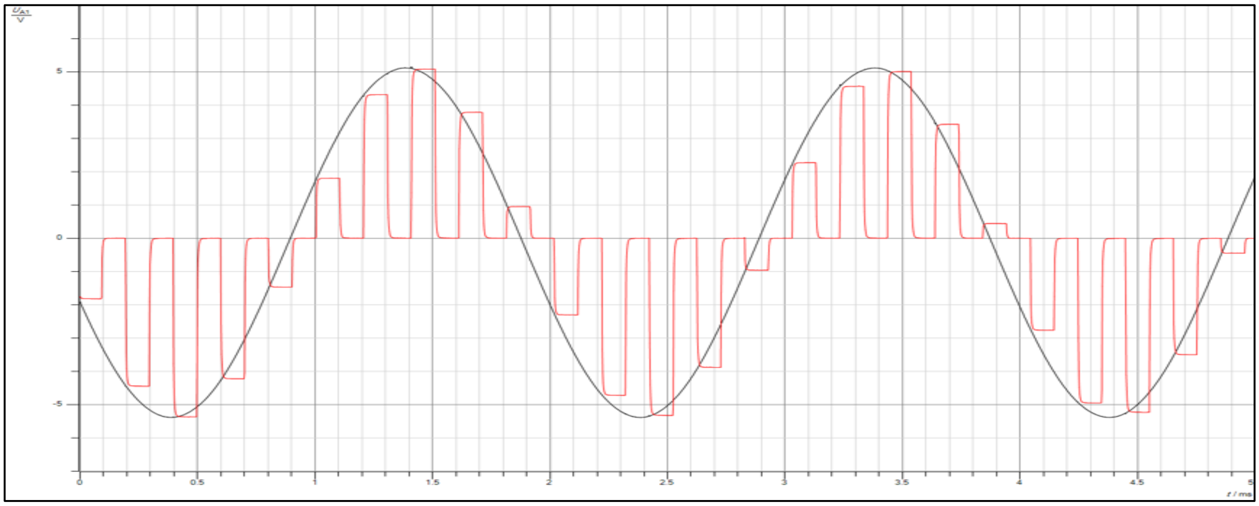

Figure 30 Flat-top Sampling with fm=500Hz and max duty cycle.

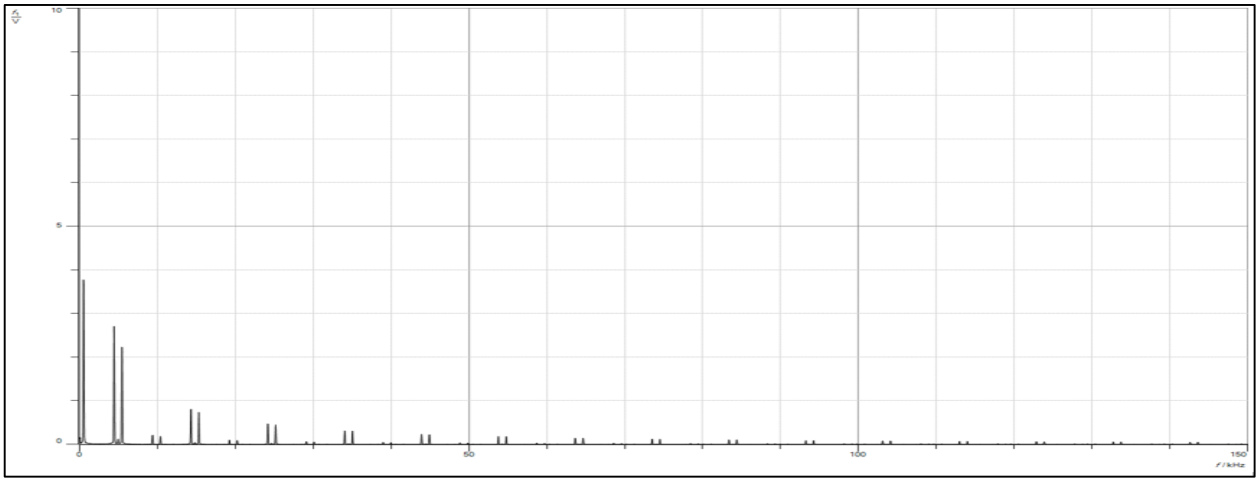

Figure 31 The spectrum of the Flat-top Sampling with fm=500 Hz and max duty cycle.

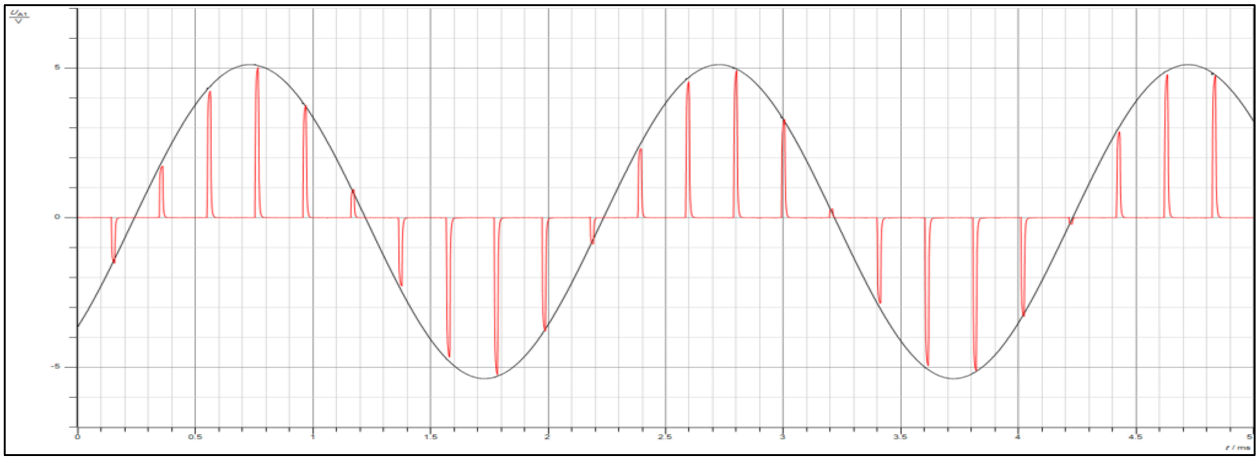

Figure 33 Flat-top Sampling with fm=500Hz and min duty cycle.

Figure 32 The spectrum of the Flat-top Sampling with fm=500 Hz and min duty cycle.

From the previous results, and after making the input message frequency constant for all cases and equals to 500 Hz, the effect of the duty cycle on PAM2 that when reducing the duty cycle to the minimum value, the power consumption of transmitting the signal will be reduced also compared when the duty cycle at its highest value. In addition, reducing the duty cycle in the flat-top sampling caused to reduce the active (ON) period of the signal compared with inactive period. In terms of the frequency domain, the signal with max duty cycle has a higher pulse value, so reducing the duty cycle will reduce the value of the pulses in the spectrum of the output signal.

2.5 Displaying the Pulse Amplitude Modulated signal s(t) of PAM2 in the freq domain

In the last part of this section, the same connection of the previous sections was used to display the pulse modulated signal s(t) in frequency domain of PAM2. The duty cycle was set again at it maximum value, the Cassy UA1 was connected to the clock generator output. The following figures represent the output signal in time and frequency domain:

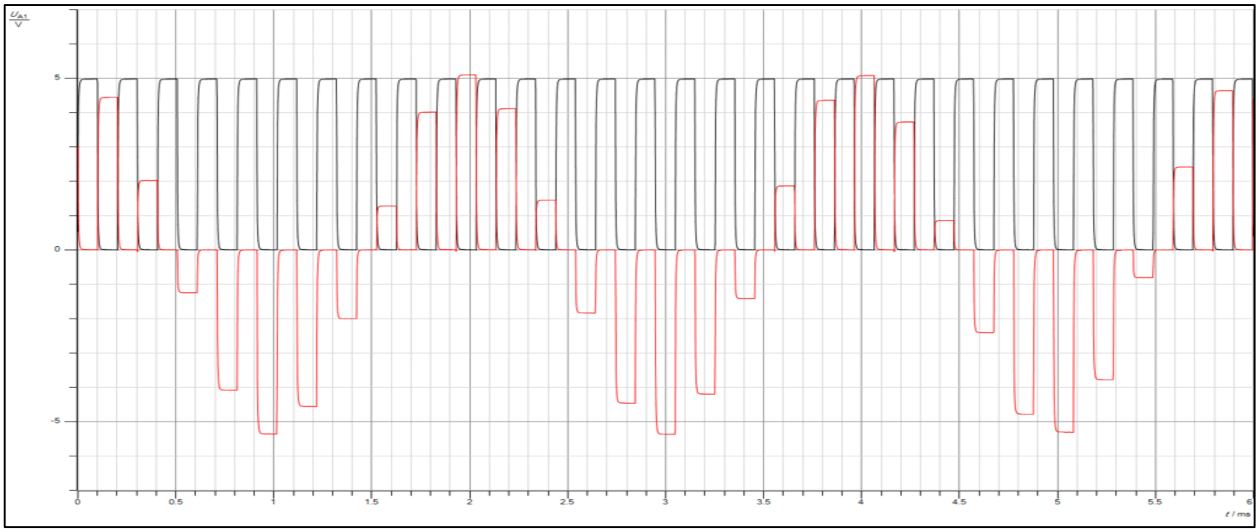

Figure 34 Pulse amplitude modulated signal s(t) of PAM2 in time domain.

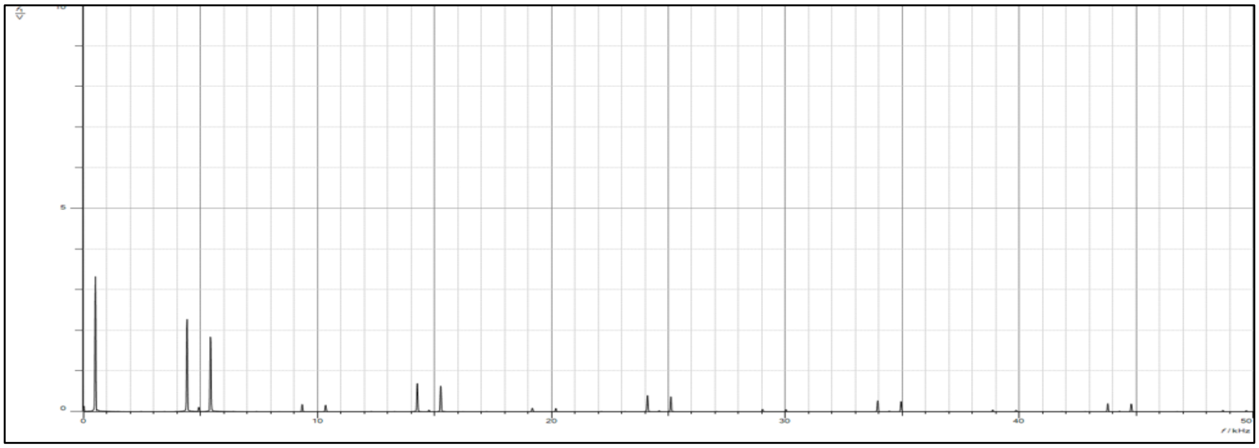

Figure 35 Pulse amplitude modulated signal s(t) of PAM2 in frequency domain.

- ✓ ***Determining the effect of the message frequency on the PAM in the Freq domain***

In this part, the effect of the message frequency will be studied. The message frequency was changed between 1 kHz, and 2 kHz to compare between them. The following figures represents the results in time and frequency domain:

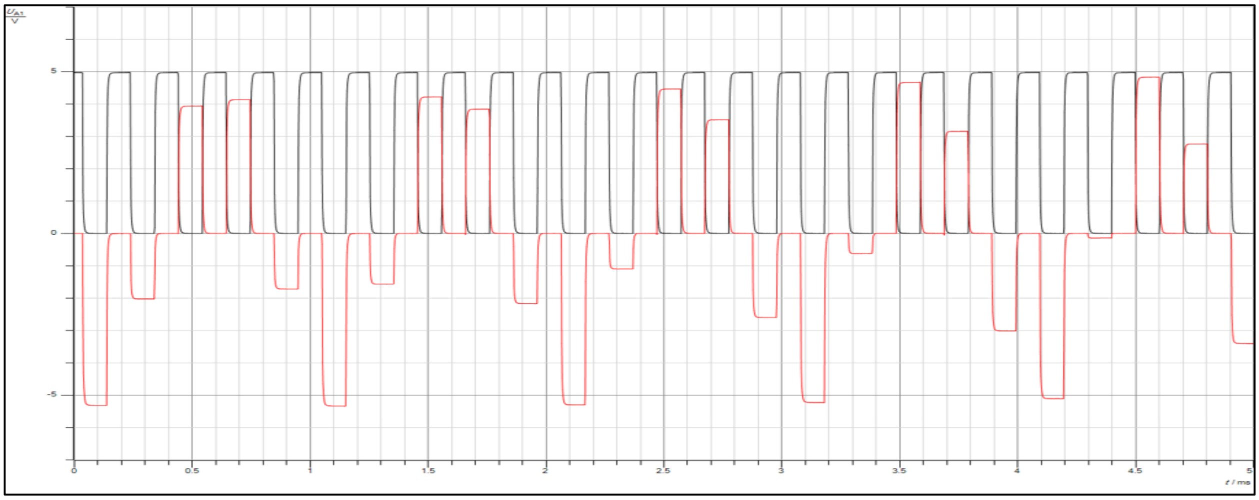

Figure 38 Pulse amplitude modulated signal when fm = 1 kHz in time domain.

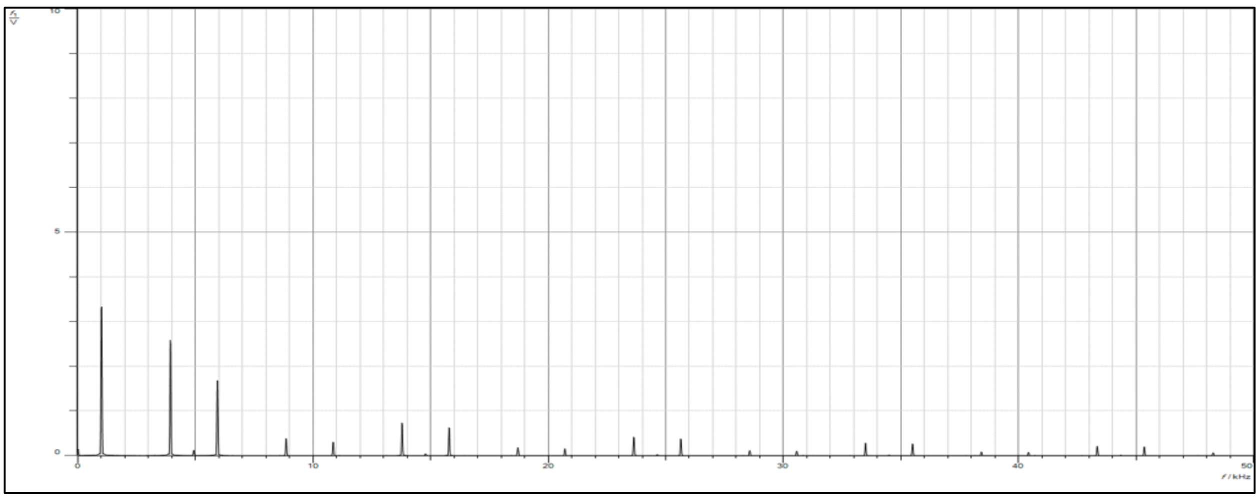

Figure 37 The spectrum of pulse amplitude modulated signal when fm = 1 kHz.

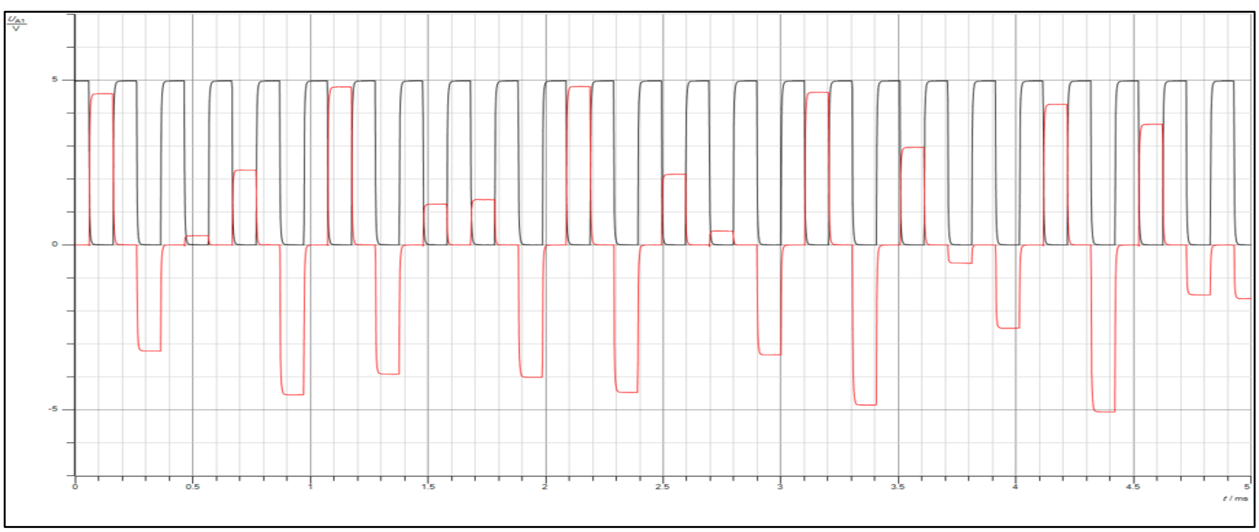

Figure 36 Pulse amplitude modulated signal when fm = 2 kHz in time domain.

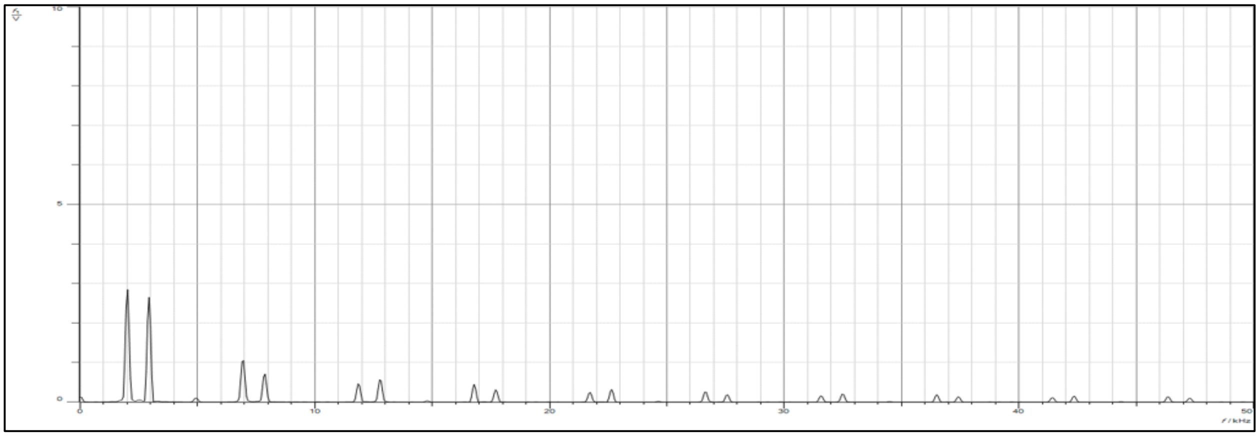

Figure 39 The spectrum of pulse amplitude modulated signal when fm = 2 kHz.

- ✓ ***Determining the effect of the duty cycle on the PAM in the Freq domain***

In this part, the effect of changing the duty cycle on the pulse modulated signal in the frequency domain will be determined and noticed according the simulation results. Firstly, the message frequency was set to 500 Hz, and the duty cycle was changed to 10%, and 30%. The following figures show the results.

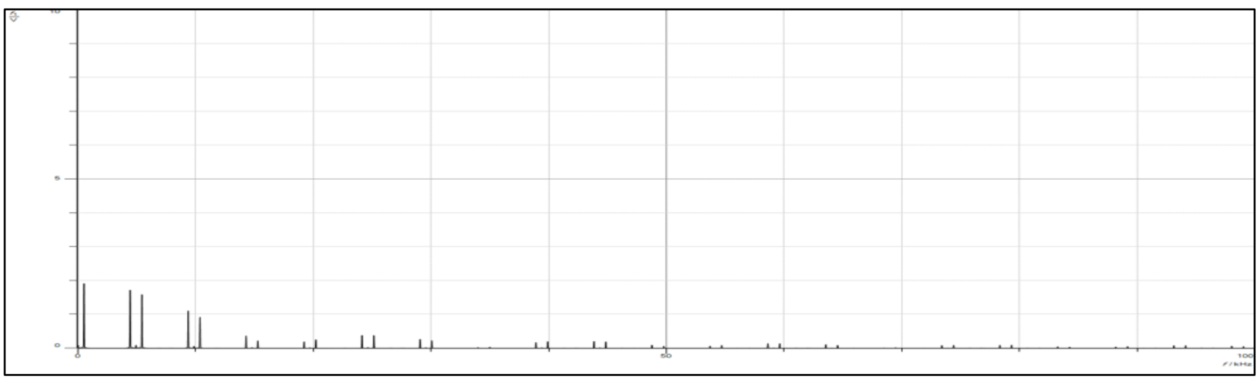

Figure 40 The output modulated signal when the duty cycle = 10%, and fm =500 Hz.

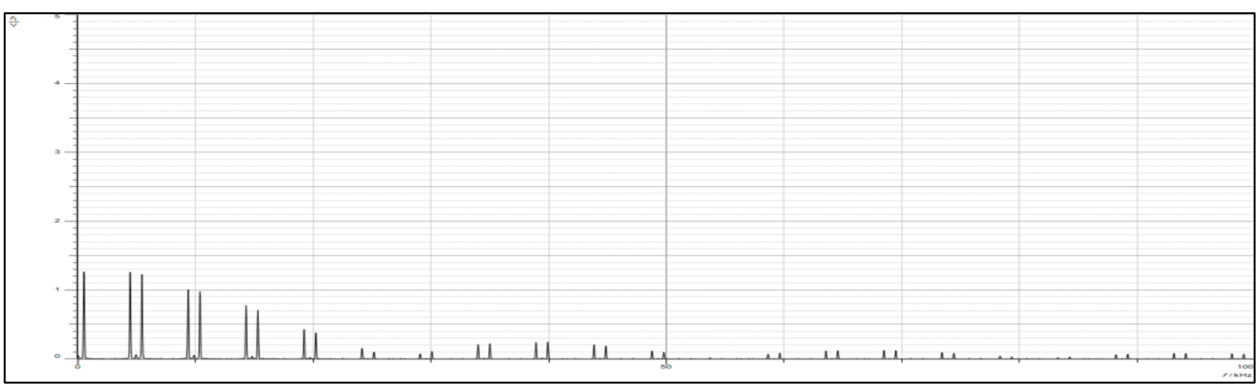

Figure 41 The output modulated signal when the duty cycle = 30%, and fm =500 Hz.

From the previous results, it is noticed that when increasing the value of the duty cycle, the amplitude of the of the pulse was increased compared with when decreasing the value if the duty cycle which leads to need more power to transmit the message signal through the channel.

Part 3: Characteristics of Pulse Demodulation

The aim of this part is to display the transmitted input signal, and the demodulated signal using PAM1, and to determine the effect of the duty cycle on the PAM in time domain.

3.1 Displaying the message signal and the demodulated signal using pam1

The clock function generator was set to its maximum value, and the input sine wave message signal with frequency 500 Hz, and amplitude equals to 10 Volts was generated by the function generator. Finally, the Cassy UA1 and Cassy UB1were connected to the input signal of the CH1 filter, and to the output of the demodulator filter of CH1 respectively.

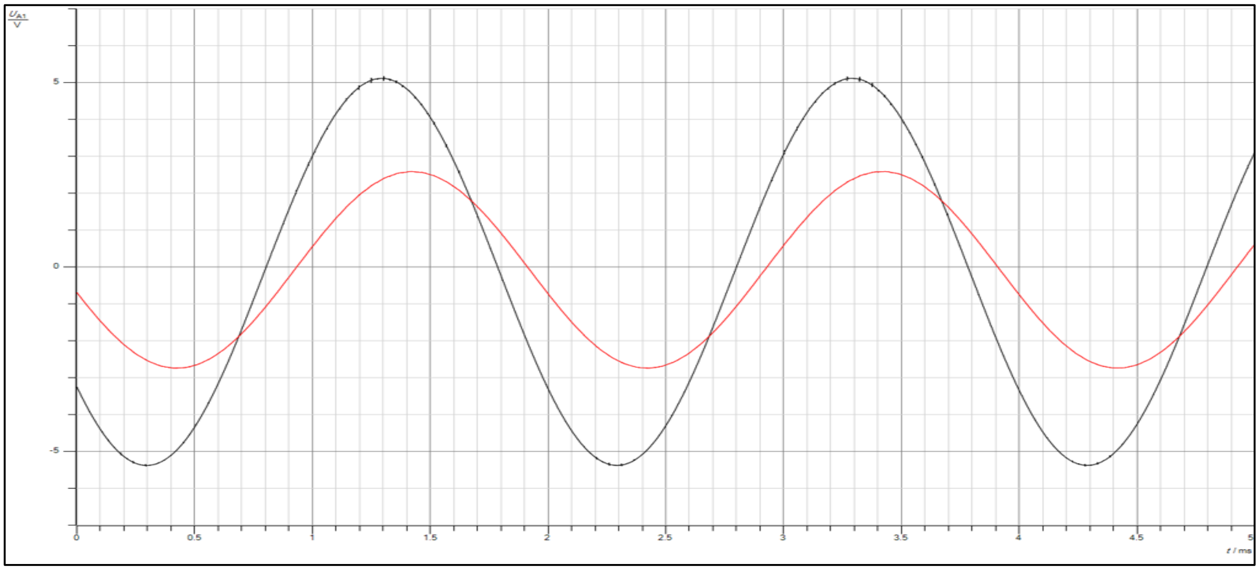

Figure 42 The original and demodulated signal using PAM1 in time domain.

From the above result, it is noticed that the original signal was demodulated successfully, but the demodulated signal has a smaller amplitude value and shifted for small amount of angle compared to the original one.

3.2 Determining the effect of the duty cycle on the PAM in the time domain

In this part, the duty cycle of the clock generator was changed to 10%, and 30% respectively. The following figures shows the results in time domain:

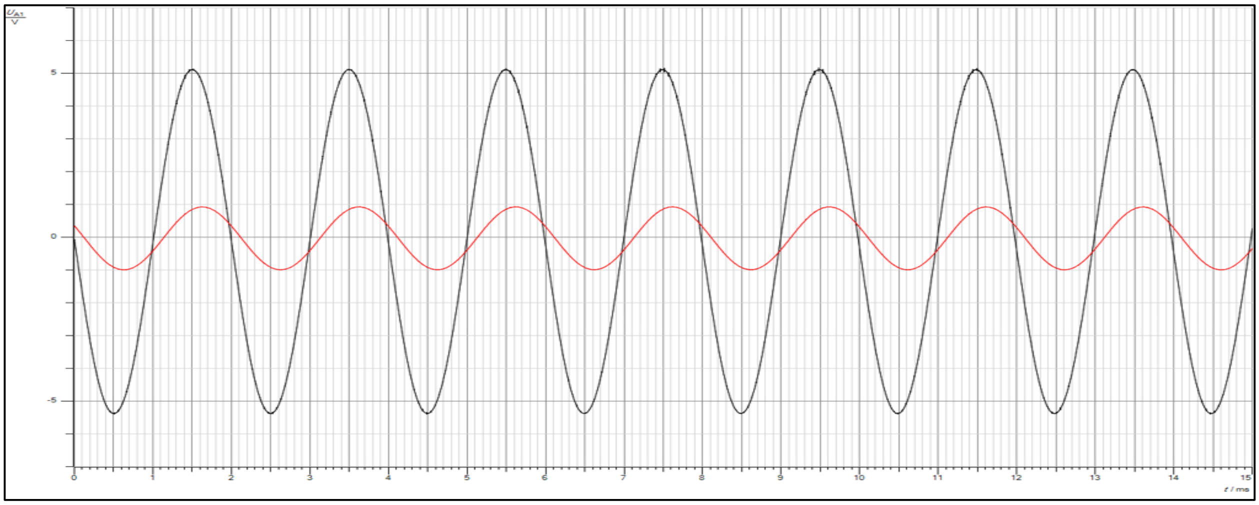

Figure 44 Pulse Amplitude Demodulation signal with fm=500Hz and 10% duty cycle In time domain.

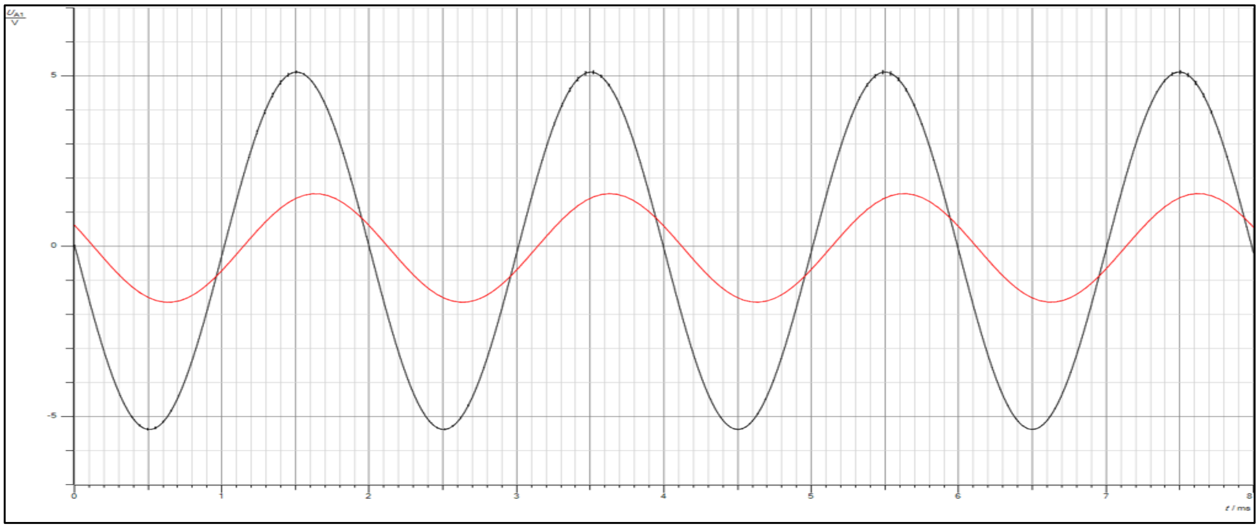

Figure 43 Pulse Amplitude Demodulation signal with fm=500Hz and 30% duty cycle In time domain.

It is noticed that when increasing the value of the duty cycle, the amplitude of the demodulated signal increasing to be closer to the original message signal. However, it didn't affect the amount of shifting which was the same in both cases.

Part 4: Aliasing in the Time and the Frequency Domains

The objective of this part is to display the aliasing on the modulated and the demodulated signal using PAM1 in time and frequency domain. Firstly, the clock generator frequency was set to 1000 Hz, and the duty cycle to 30%. The input signal with sine wave, frequency equals to 3000 Hz, and amplitude equals to 5 Volts. Finally, the Cassy sensor UA1 was connected to the output of the clock generator while Cassy sensor UB1 to the PAM1 modulator. The following results represents the modulating signal in time and frequency domain with **aliasing**.

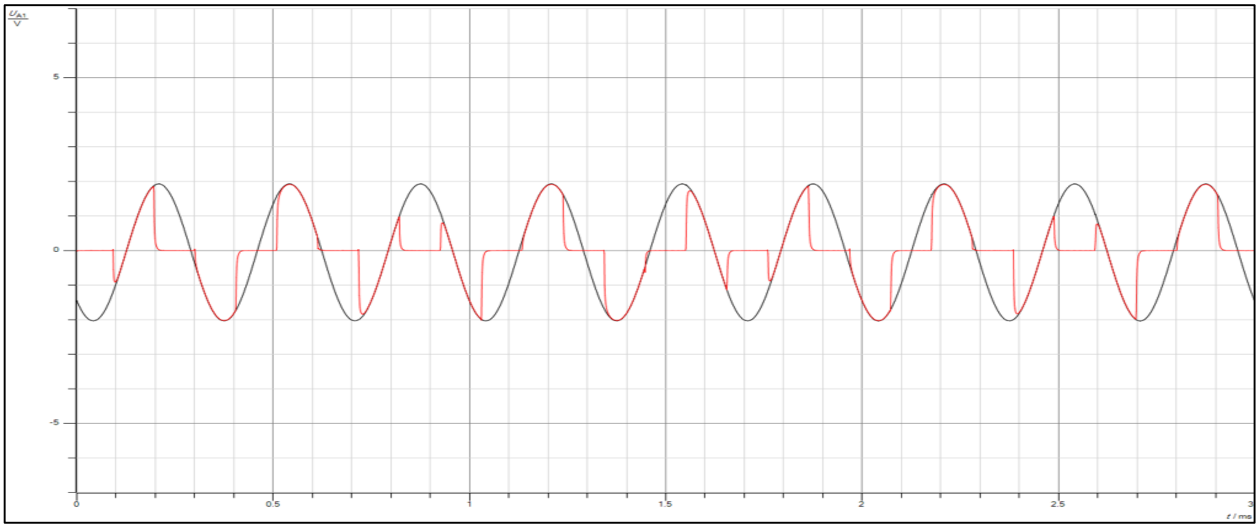

Figure 45 Pulse amplitude modulated signal with aliasing in time domain.

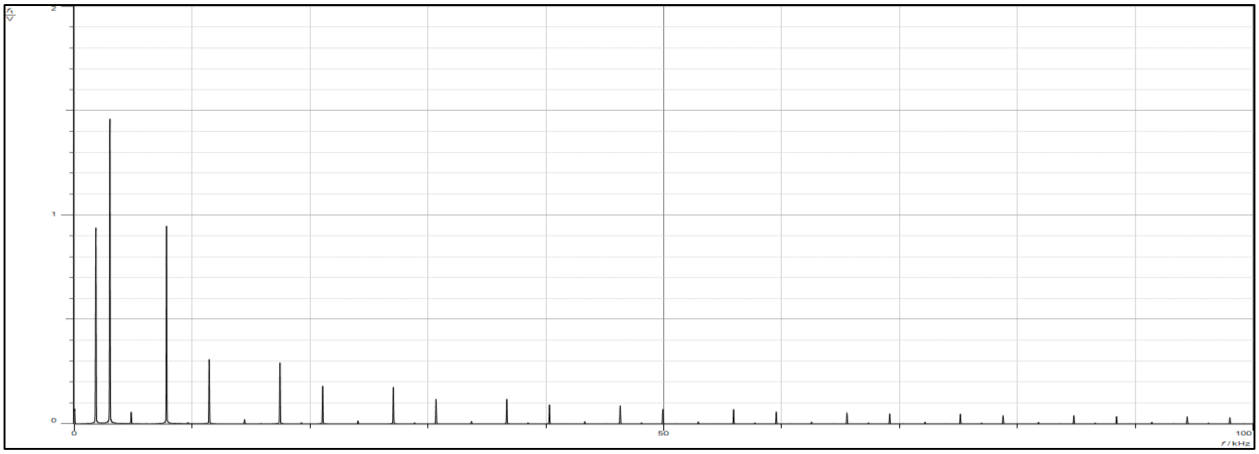

Figure 46 Pulse amplitude modulated signal with aliasing in frequency domain.

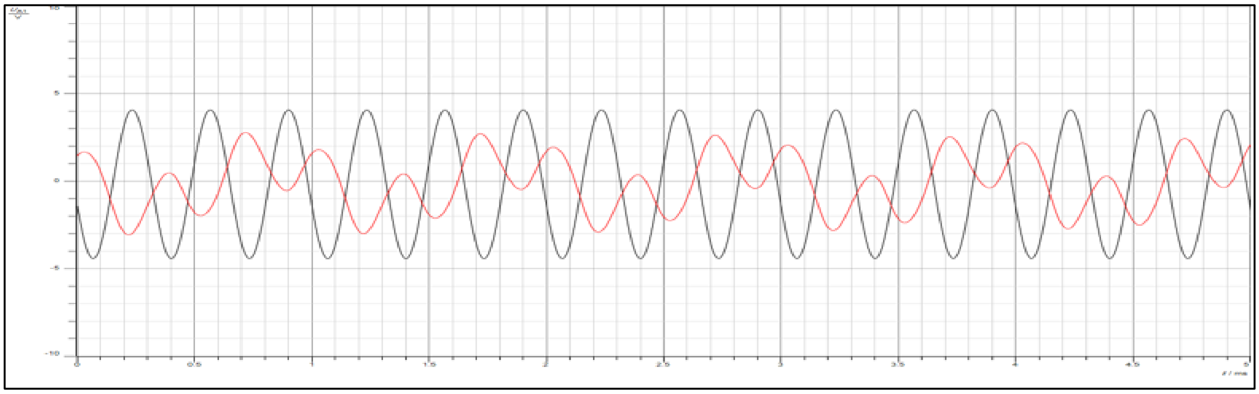

Figure 48 Pulse amplitude demodulated signal with aliasing in time domain.

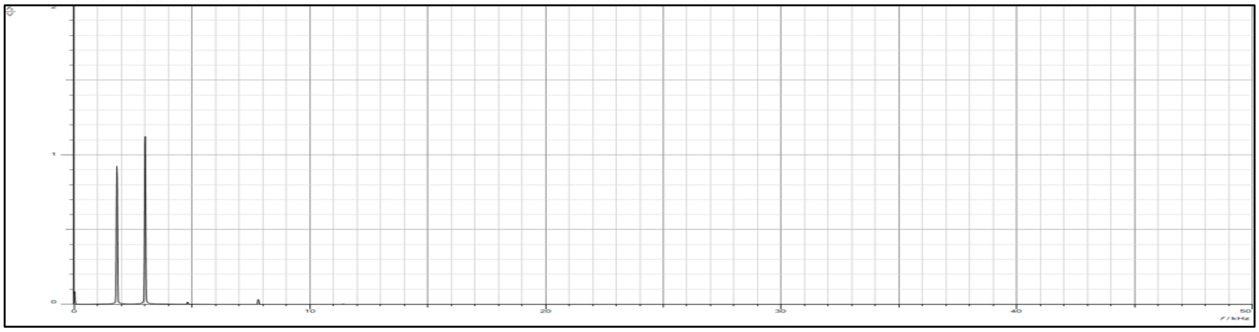

Figure 47 Pulse amplitude demodulated signal with aliasing in frequency domain.

From the above results, the aliasing appears with causing a distortion since the frequency of the pulse train is not high enough.

Part 5: PAM Time Multiplex

The objective of this part is to learn how to transmit and receive two signals over one common channel by using the concept of time division multiplexing. The circuit was connected as shown:

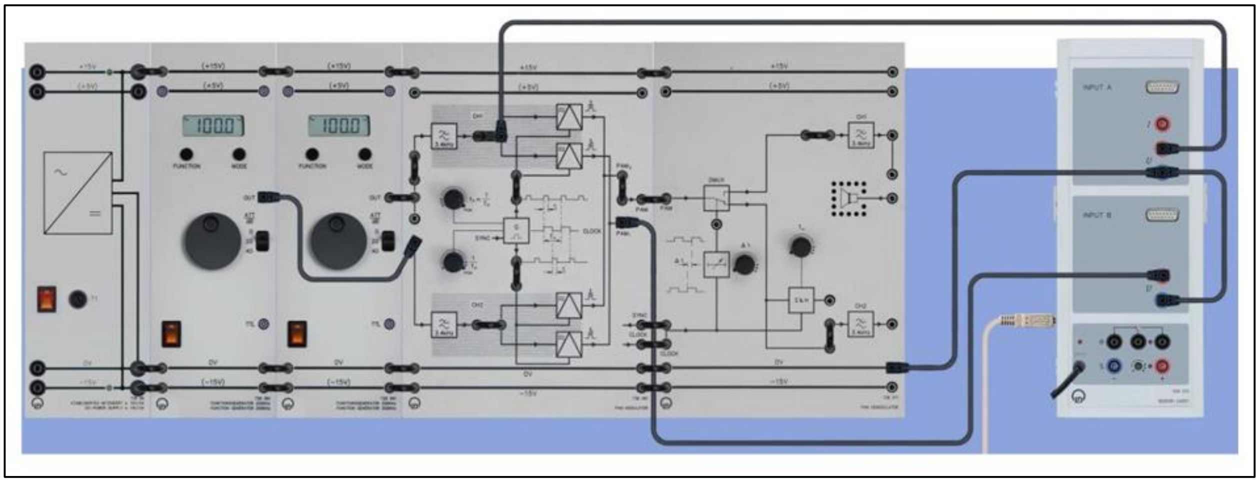

Figure 49 Pulse Amplitude Modulation time multiplex circuit connection.

5.1 Displaying the time characteristic of the time multiplex signal

The aim of this part is to transmit two signals at the same time. Firstly, both sampling frequency and the duty cycle were set to their maximum values. And the first function generator was set to generate the **triangle** wave with message frequency equals to 200 Hz, and amplitude equals to 5 Volts. While the second function generator was set to have a **sine** wave with message frequency equals to 300 Hz, and 10 Volts for amplitude.

Firstly, the input triangle wave, and the input sine wave was set as shown in the following figures:

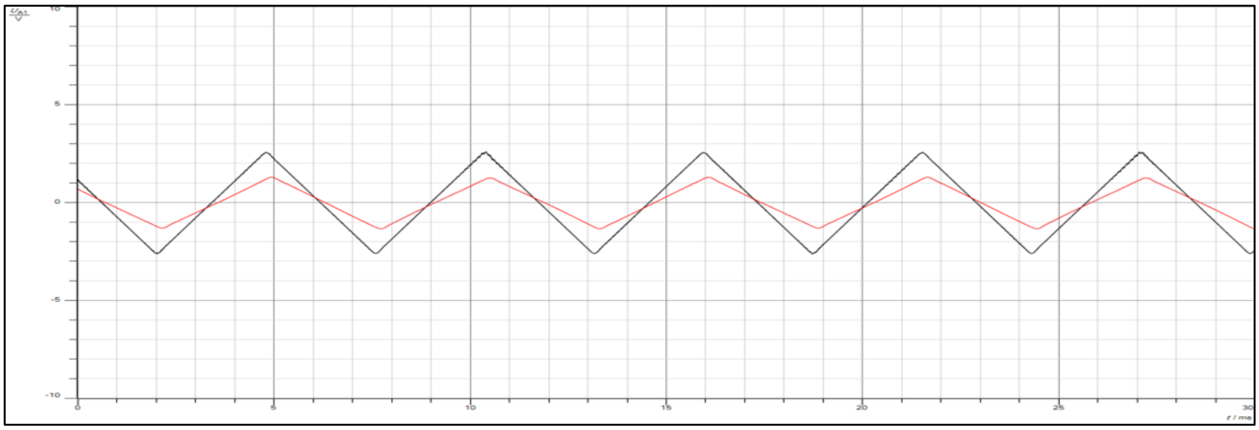

Figure 51 triangle input signal when f = 200 Hz and Vss = 5 in time domain.

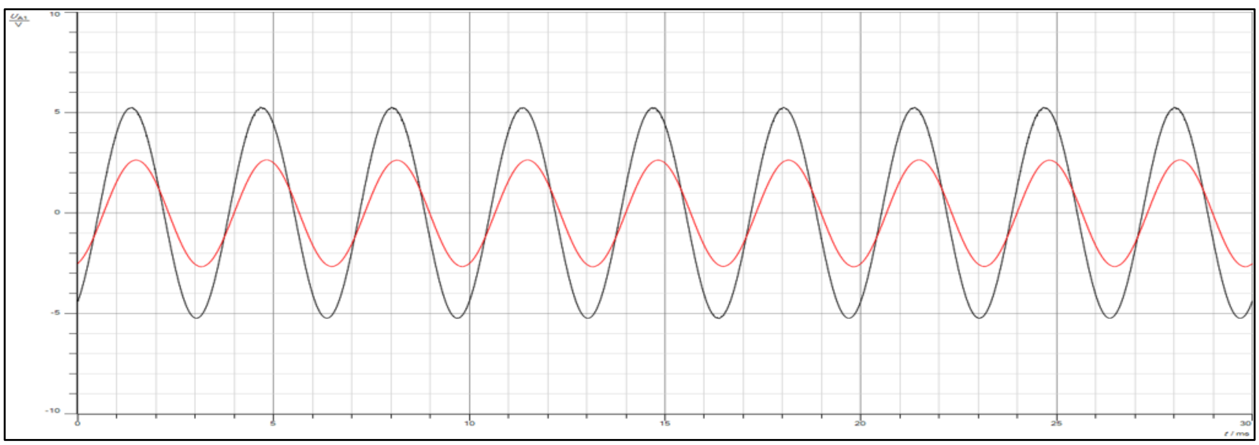

Figure 50 sine input signal when f = 300 Hz and Vss = 10 in time domain.

Now, the Cassy UA1 and Cassy UB1 were connected to the triangle message signal and the output of the pulse amplitude modulation (PAM) modulator PAM1 output. And then, the Cassy UA1 was changed to be connected to the sine message signal channel CH1. The following figures represent the results:

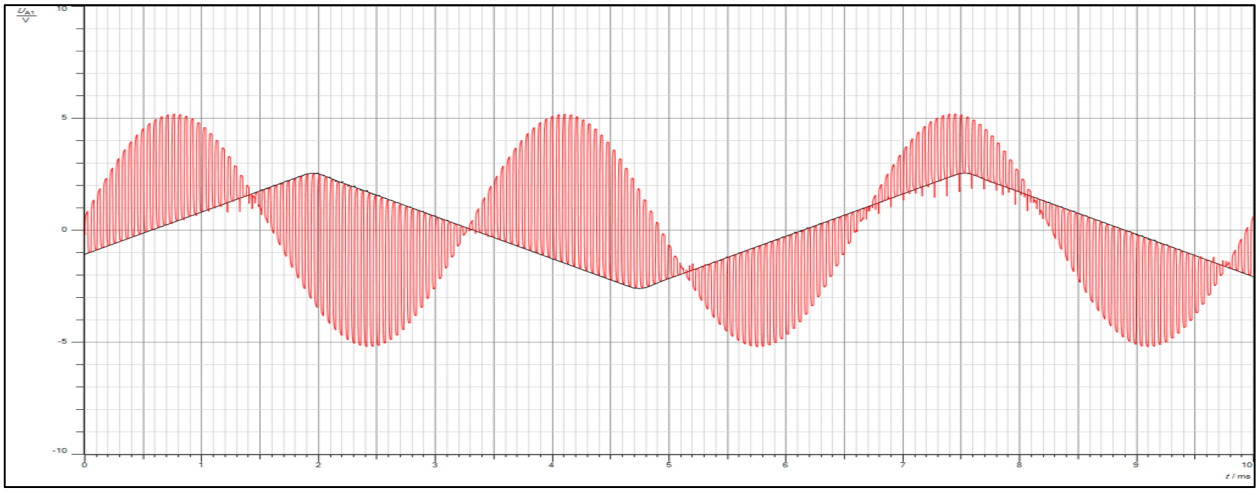

Figure 53 PAM multiplexing for triangle signal and the modulator output signal in time domain.

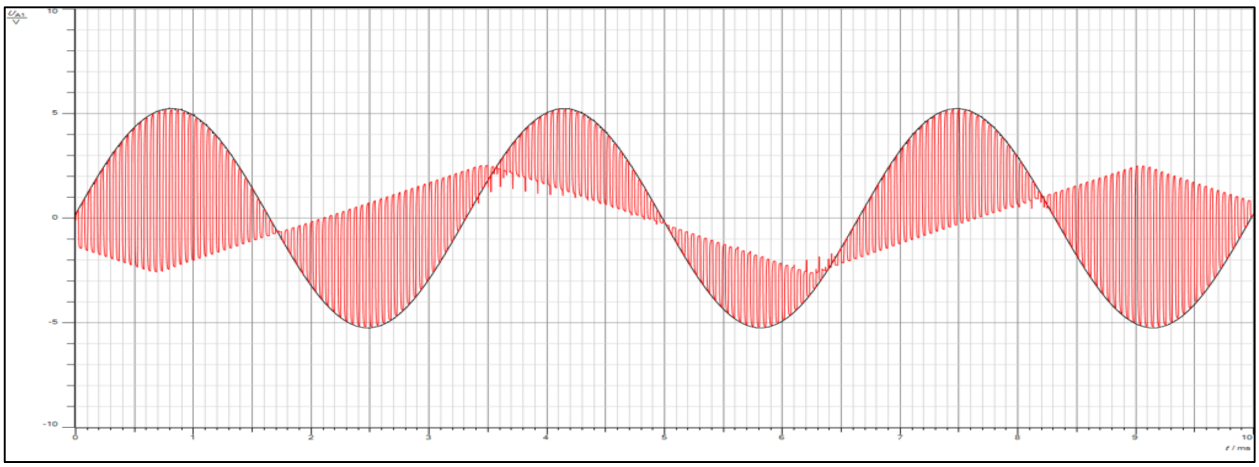

Figure 52 PAM multiplexing for sine signal and the modulator output signal in time domain.

From the above figures, it is clear that the output of the pulse amplitude multiplexing in time domain is a PAM signal that interleaved pulses that represent both the triangle and the sine wave signals, where the amplitude levels of the pulses correspond to the amplitudes of the triangle and sine signals at their respective time instances.

The next step was to represent the demodulated signals which are the triangle and the sine wave, and this was done by connecting the CASSY sensor UA1 to the demodulator filter CH1, and the CASSY sensor UB1 to the demodulator filter CH2. The following figure represents the result.

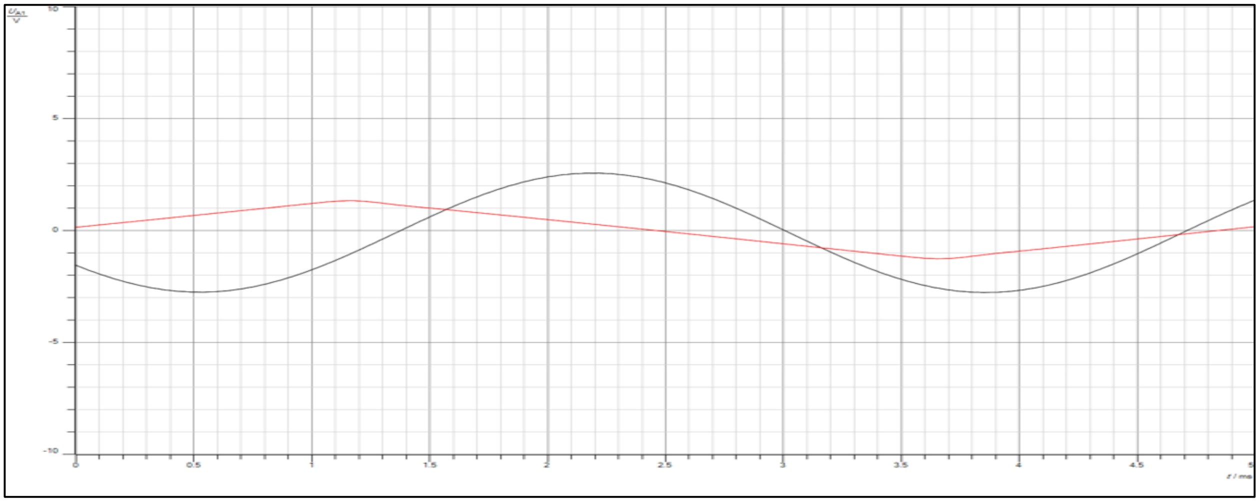

Figure 54 The demodulated triangle and sine signals in time domain.

5.2 Cross Talk (Δt) left/middle

In the last section, the concept of the cross talk will be discussed. The connection was kept the same, and the effect of cross talk was observed as a phase shift Δt that occurs in the time domain as shown in the following figure:

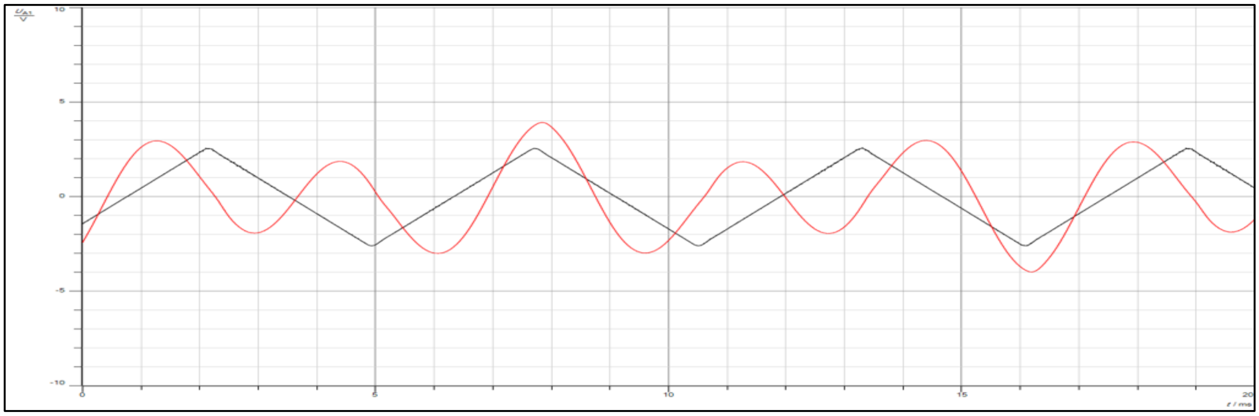

Figure 55 Cross talk on the triangle and sine input message signals.

And then, the first function generator was set to amplitude equals to 0, while the second generator of the sine signal was kept the same as it was. The following figure shows the cross talk of the sine wave signal.

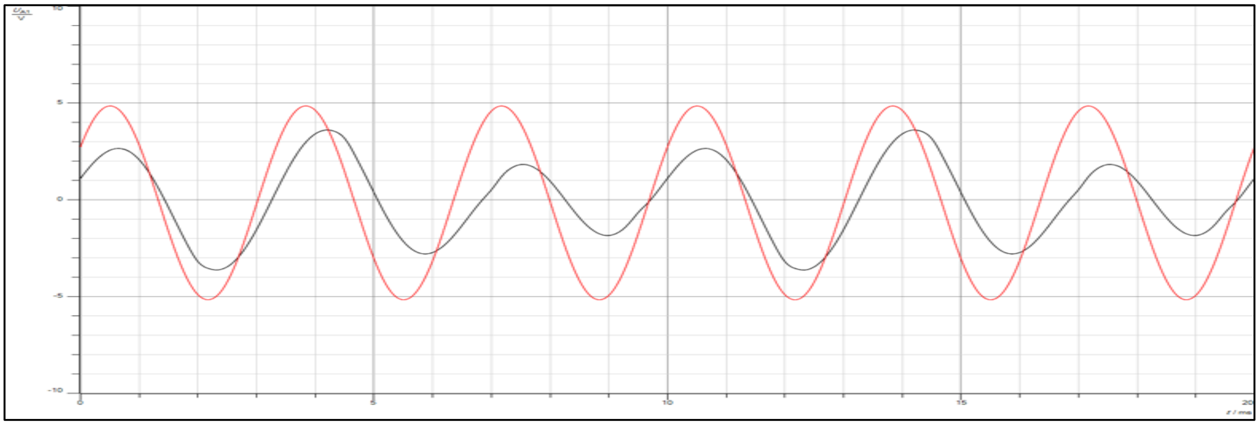

Figure 56 Sine signal cross talk.

Conclusion

In conclusion, the concepts of pulse amplitude modulation (PAM) in time and frequency domains were covered and discussed. It involved implementing pulse amplitude modulation (PAM) and demodulation techniques on various input signals. The process of pulse modulation and demodulation, comparing the original message signal with the demodulated signal, and studying the effects of the duty cycle on the modulated signal was examined clearly. Additionally, important concepts such as the Nyquist rate, aliasing, and the impact of sampling pulses on communication systems were explored. Finally, the concept of PAM multiplexing, examining how to transmit and receive multiple signals over a single channel effectively was discussed.

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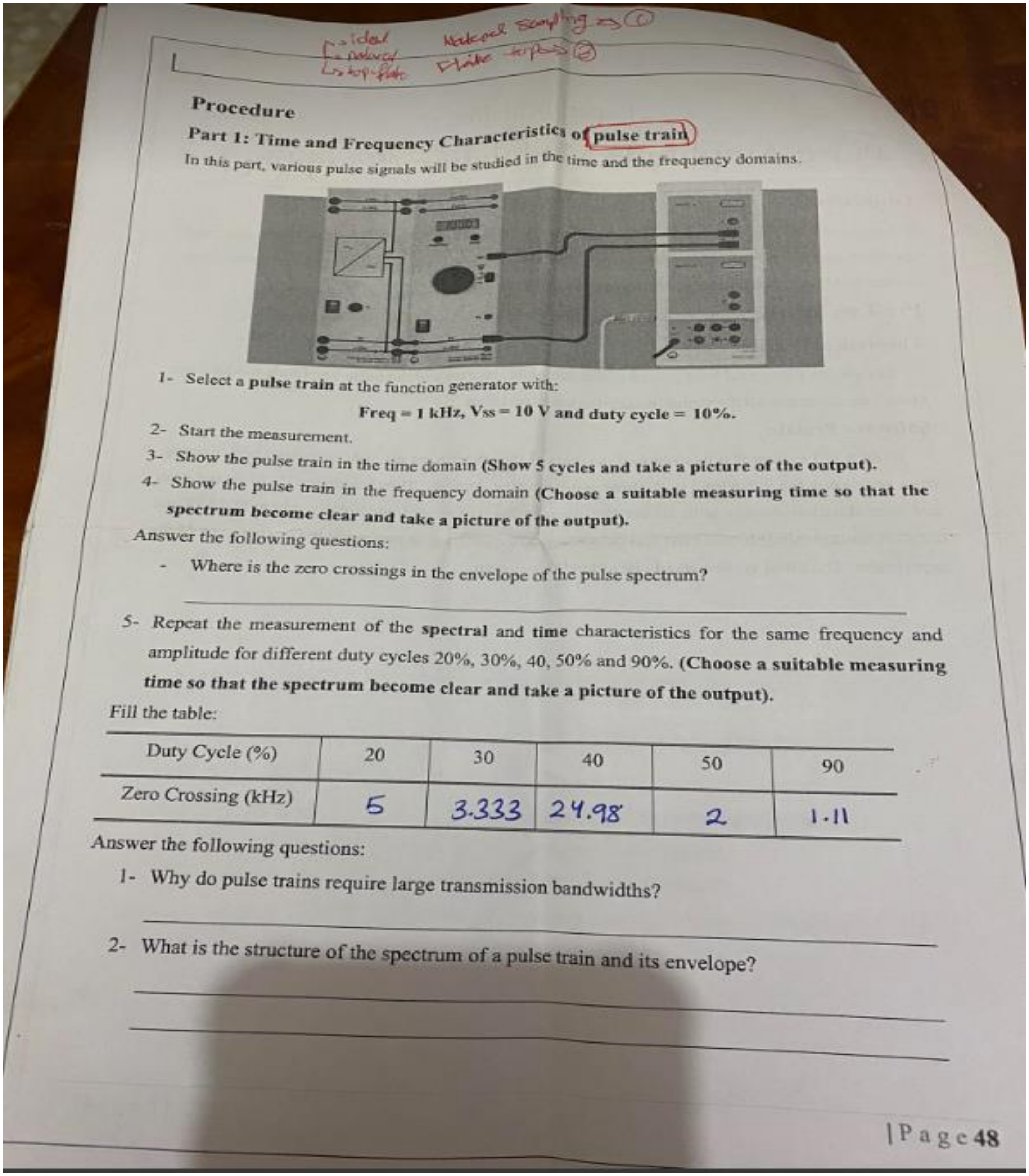
Appendixes



→ ideal
→ natural
→ top-flat
Natural sampling → (1)
Flat-top → (2)

Procedure

Part 1: Time and Frequency Characteristics of pulse train

In this part, various pulse signals will be studied in the time and the frequency domains.

1- Select a **pulse train** at the function generator with:

Freq = 1 kHz, Vss = 10 V and duty cycle = 10%.

2- Start the measurement.

3- Show the pulse train in the time domain **(Show 5 cycles and take a picture of the output).**

4- Show the pulse train in the frequency domain **(Choose a suitable measuring time so that the spectrum become clear and take a picture of the output).**

Answer the following questions:

- Where is the zero crossings in the envelope of the pulse spectrum?

5- Repeat the measurement of the **spectral** and **time** characteristics for the same frequency and amplitude for different duty cycles 20%, 30%, 40, 50% and 90%. **(Choose a suitable measuring time so that the spectrum become clear and take a picture of the output).**

Fill the table:

Duty Cycle (%)	20	30	40	50	90
Zero Crossing (kHz)	5	3.333	24.98	2	1.11

Answer the following questions:

1- Why do pulse trains require large transmission bandwidths?

2- What is the structure of the spectrum of a pulse train and its envelope?

| P a g e 48