Faculty of Engineering & Technology Electrical & Computer Engineering Department

Communication Lab - ENEE4113

Experiment 5: Phase Modulation
Report #2

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Date: 15-8-2023

Abstract

The main goal of this experiment is to put theoretical understanding of the phase modulation (PM) approach into practice. In addition to that, this experiment will show the phase modulation scheme, and the results will be shown in the time and frequency domains. Additionally, how to perform the Phase modulation and demodulation method, and to know the phase modulation sensitivity(k_P).Moreover, to be familiar with signals basics like characteristics of a low pass filter that we can have. Finally, all of the findings will be examined and compared to theoretic predictions.

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Acronyms and Abbreviations

PM	Phase Modulation
K_p	Phase Modulation Sensitivity
m(t)	Message signal or Modulating Signal
S(t)	Modulated Signal
CASSY	Measurement Device

Theory
Phase Modulation

Angle modulation, which includes phase modulation, modifies the carrier signal's whole phase angle in response to the amplitude of the message signal. PM is another name for phase modulation. Phase modulation follows a similar procedure to frequency modulation. The frequency of the signal changes whenever there is a change in the carrier signal's phase. [1]

While the amplitude of the carrier signal stays maintained during phase modulation, the phase is changed. [1]

Figure 1 shows the phase modulation. The first figure shows a low-frequency modulating signal, often known as a message signal, that contains the necessary data. The second figure shows a high-frequency carrier wave without any of any helpful information, and the last figure shows the resulting phase-modulated signal.[1]

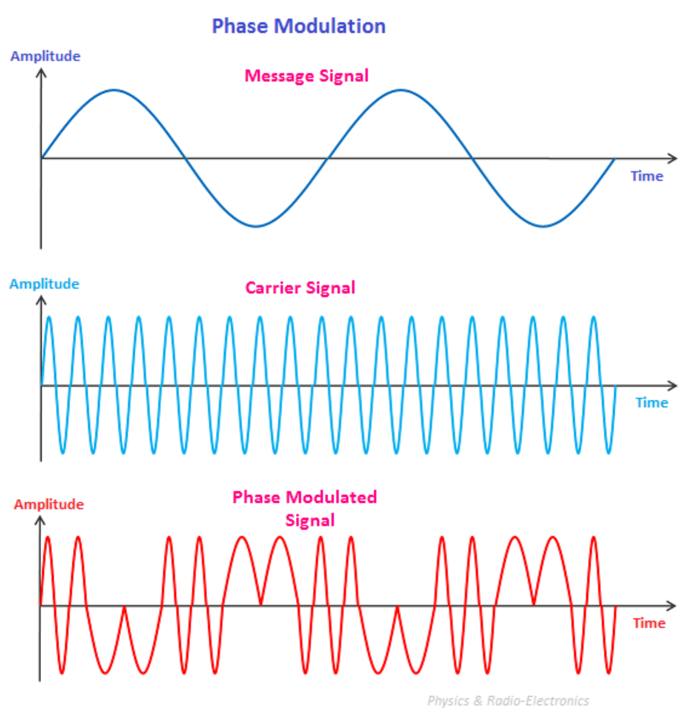


Figure 1: The Phase Modulation [1]

The third picture from figure 1 shows how the modulating signal's amplitude-dependent amplitude changes affect the carrier signal's phase for both the positive and negative half cycles. The carrier signal phase moves in one way during the positive half cycle while shifting in the other direction during the negative half cycle. In phase modulation, the phase deviation is directly proportional to the amplitude of message signal.[1]

Mathematical Formula for Phase Modulation

$$s(t) = A_C\, cos\,(2\pi f_C t + k_p\; m(t))$$

Equation 1 :Phase Modulation

Where:

- A_C is the carrier signal amplitude.
- f_C is the carrier frequency.
- m(t) is the message signal.
- k_p is the phase sensitivity

Phase Demodulation

The action of removing the original data, or signal, from the modulated carrier. when it comes to amplitude modulation or frequency modulation, a device known as a demodulator or detector is used. this device generates a signal that corresponds to the momentary changes in amplitude or frequency, respectively. the original modulating signal is the same as this signal. [3]

The demodulation of FM and the demodulation of PM are related. Let y(t) be the FM demodulator's output. The FM demodulator's output is exactly proportional to the modulated signal.[4]

$$m(t) \propto y(t)$$

Were: m(t) is the modulated signal

The message is proportional to the modulating system's phase angle. It is necessary for a phase-modulated signal.

$$m(t) \propto \theta(t)$$

$$y(t) \propto d\theta(t)/dt$$

$$y(t) = kd\theta(t)/dt$$

A constant is always substituted in place of the proportionality symbol.
Where: K is the proportionality constant.

By inserting the integrators after the frequency discriminator or frequency demodulators in FM, we are able to retrieve the message signal from the phase-modulated input.[4]

Procedure, Data analysis and Discussion

Part 1: PM Modulation

Displaying the FM Signal in the Time and Frequency Domain

Time Domain

At first, the components were connected as shown in figure 2.

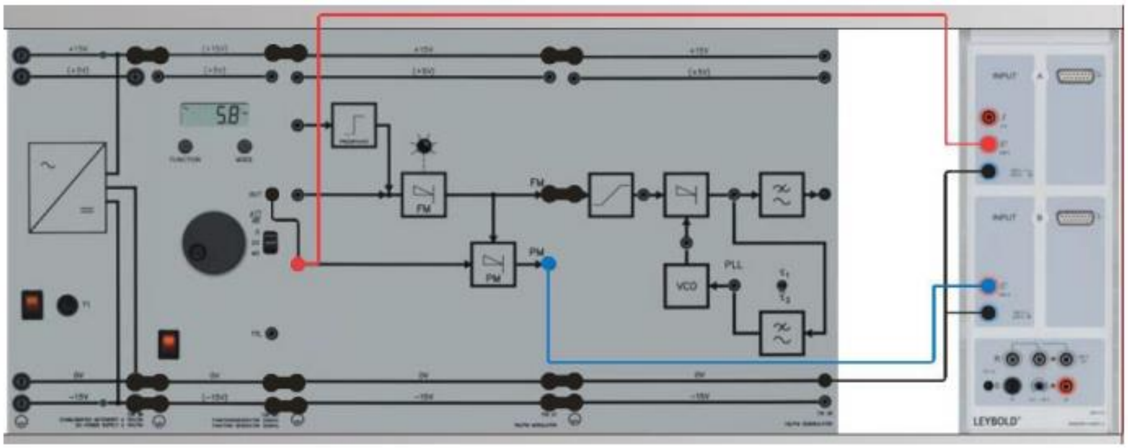


Figure 2: Components Connection for PM Modulation [5]

The function generator was be configured for the generation of a sinusoidal message signal with a v_{ss} of 2V and an f_m of 1kHz. The carrier knob should be adjusted to approximately 20kHz, figure 3 show the value of carrier frequency f_c which is equal 19.84 kHz, so it is very close to approximately value which is 20kHz.[5]

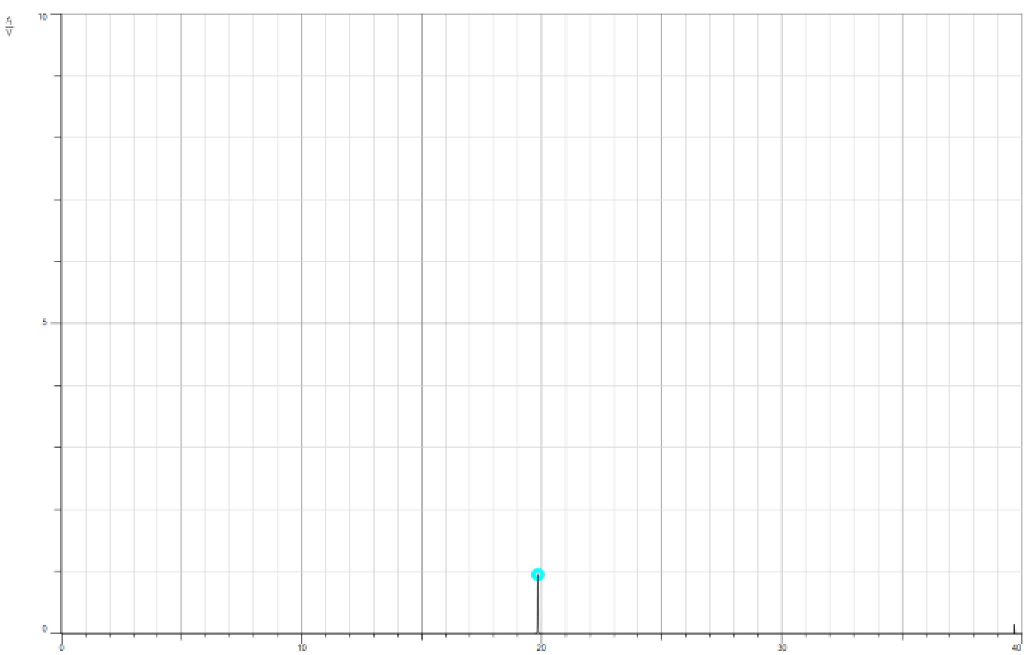


Figure 3:Value of Carrier Frequency f_c

After that, we loaded the CASSY Lab 2 example, PM_TDscope.labx, and started the measurement. Figure 4 show the message signal $m(t)$ and modulated signal $s(t)$ in time domine.

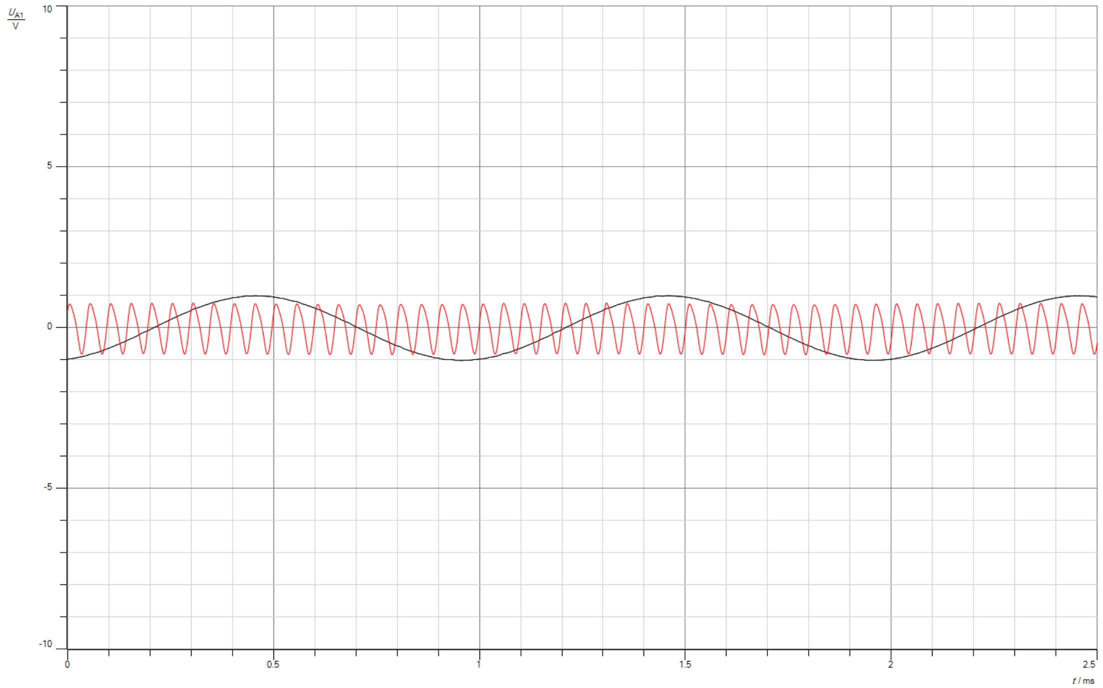


Figure 4: m(t) and s(t) in Time Domain

The red signal indicates to the message signal m(t), and the black signal indicates to modulated signal s(t).

The phase of the carrier signal changes with the signal variation (amplitude) of the message signal. The amplitude and frequency of the carrier signal remain constant, but if the amplitude of the message signal changes, the phase of the carrier changes.

To give an explanation for this in more detail, Phase Modulation (PM) is a form of angle modulation in which a baseband or modulating signal m(t) linearly modulates the phase angle ϕ with respect to an unmodulated phase angle. The phase angle of the carrier wave is given by:

$$\phi(t) = \phi_c + K_p m(t)$$

Where:

- ϕ_c : is the initial phase angle of the carrier wave.
- K_p : is a constant called the phase sensitivity.
- $m(t)$: is the message signal.
- $\varphi(t)$: is the phase angle of the modulated signal

The modulated signal's phase angle varies linearly along with the message signal's amplitude. This indicates that while the modulated signal's phase is continually changing, its frequency is remaining constant. As a result, a signal that shows the message signal's information has a varies phase but a constant amplitude.

In summary, Phase Modulation works by changing the angle of a signal to carry information. This change in angle is linked to how strong or weak the message is. This method is really useful when we need to change the angle of a signal exactly to send information. Then, on the receiving side, we can figure out the information by looking at these angle changes. It's like using different angles of a spinning top to send secret messages. Just like the spinning top's angles can be decoded to get the messages, we do something similar with Phase Modulation to get meaningful data.

Frequency Domain

- Message signal in Frequency domine:

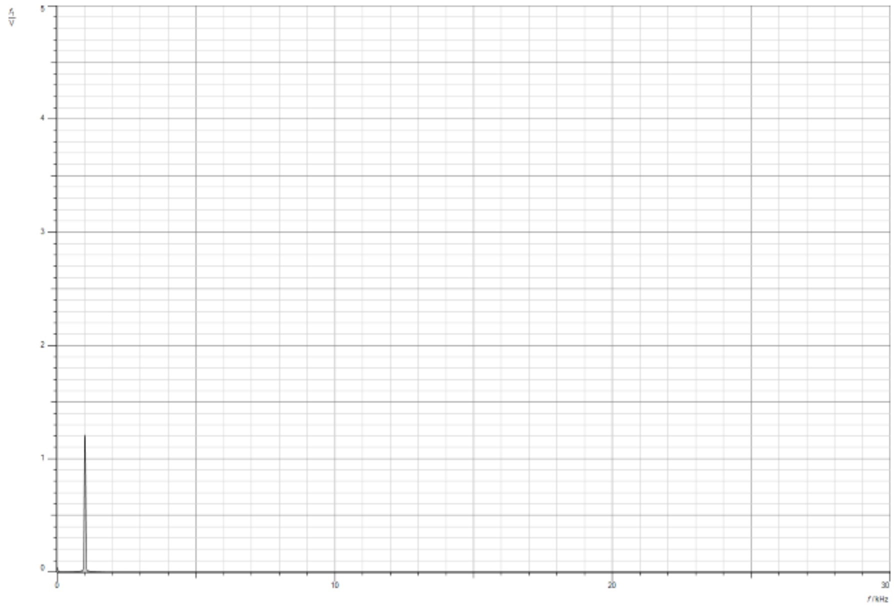


Figure 5: Message Signal in Frequency Domine

- Modulated signal in Frequency domine:

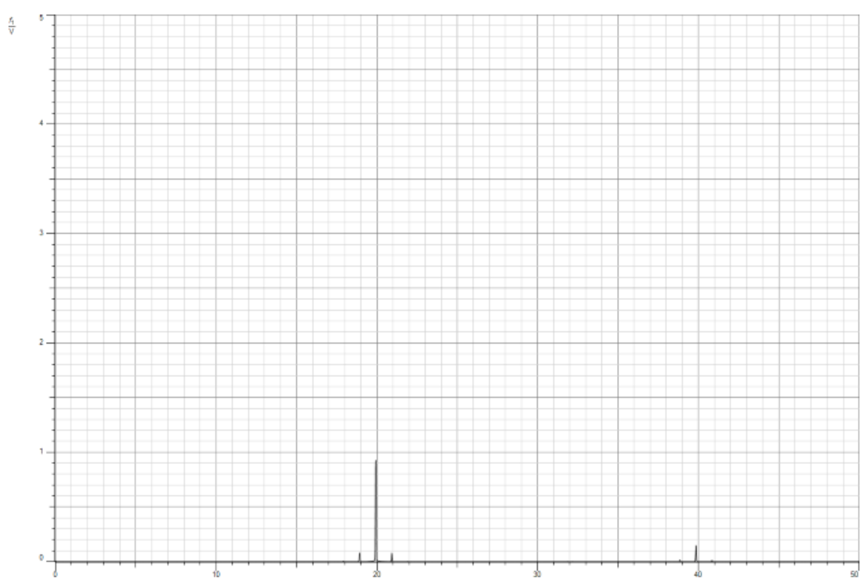


Figure 6: Modulated Signal in Frequency Domine

As shown in figure 6 the carrier frequency is shown by the impulse at 20 kHz. In PM, the amplitude changes of the message signal are used to modify the phase of the carrier signal. As a result, while the carrier frequency changes, its phase does not. Around the carrier frequency, sidebands are produced by these phase changes. The carrier frequency itself is represented by the impulse at 20 kHz.

The sidebands as shown in figure 6 produced by the phase modulation are seen in small impulses to the right and left of the carrier frequency (20 kHz). Due to the phase changes the message signal causes, these sidebands create symmetrically. The frequency of the message signal (1 kHz in this example) sets them away from the carrier frequency, where they occur. These little impulses' being indicates the frequency components that have been added to and removed from due to the message signal's inducing phase alterations.

2.1: The Characteristic of the FM Modulator

Establishing the modulator sensitivity constant kp in °/V is the goal of this section. The DC-signal message signal must be modulated with the 20 kHz carrier signal, starting at -1V. For this, the PM_TD.labx example from CASSY Lab 2 should be loaded.

The phase difference Δt (ms) between the carrier oscillations of the FM and PM output was also measured. The measurement of the carrier frequency was repeated while the DC voltage was increased in steps of 0.2V, complete the given table.

Table 1:table for determine kp

Message Voltage	Δt (µs)	$\Delta\theta$(degrees)
-1	-7	$-49.896°$
-0.8	-5	$-35.64°$
-0.6	-4	$-28.512°$
-0.4	3	$21.384°$
-0.2	1	$7.128°$
0	1	$7.128°°$
0.2	3	$21.384°$
0.4	5	$35.64°$
0.6	4	$28.512°$
0.8	6	$42.768°$
1	1	$7.128°$

The coefficient of the PM modulator K_p was be determined. The following equation was be used for this purpose:

$$\Delta\theta = (\,\Delta t\ /\ Tc\,)\ 360°$$
$$= (\Delta t)\ (fc)\ 360°$$

The equation above come from the concept of the angular frequency:

$$W = \Delta\theta\ /(\Delta t) = 2\,\pi\, fc$$

$$\Delta\theta = (\Delta t)(fc)360° \Rightarrow (1)$$

As we mentioned before the message signal is proportional with the carrier phase:

$$\phi = K_p m(t) \Rightarrow (2)$$

From the equation 2:

$$K_p = \Delta\theta / |m(t)| = \Delta\theta / \Delta A_m$$

$$= (\theta_2 - \theta_1) / (A_{m2} - A_{m1})$$

- To find θ_2:

$$\theta_2 = (\Delta t_2)(f_c)\ 360°$$
$$= (1\mu s)(19.8\ kHz)360°$$
$$= 7.128°$$

$$A_{m2} = 1\text{v}$$

- To find θ_1:

$$\theta_1 = (\Delta t_1)(f_c)\ 360°$$
$$= (-7\ \mu s)(19.8\ kHz)360°$$
$$= -49.896°$$

$$A_{m1} = -1\text{v}$$

- To find K_p:

$$K_p = (\theta_2 - \theta_1) / (A_{m2} - A_{m1})$$

$$= (7.128° - (-49.896°)) / (1 - (-1))$$

$$= 28.512\ °/v.$$

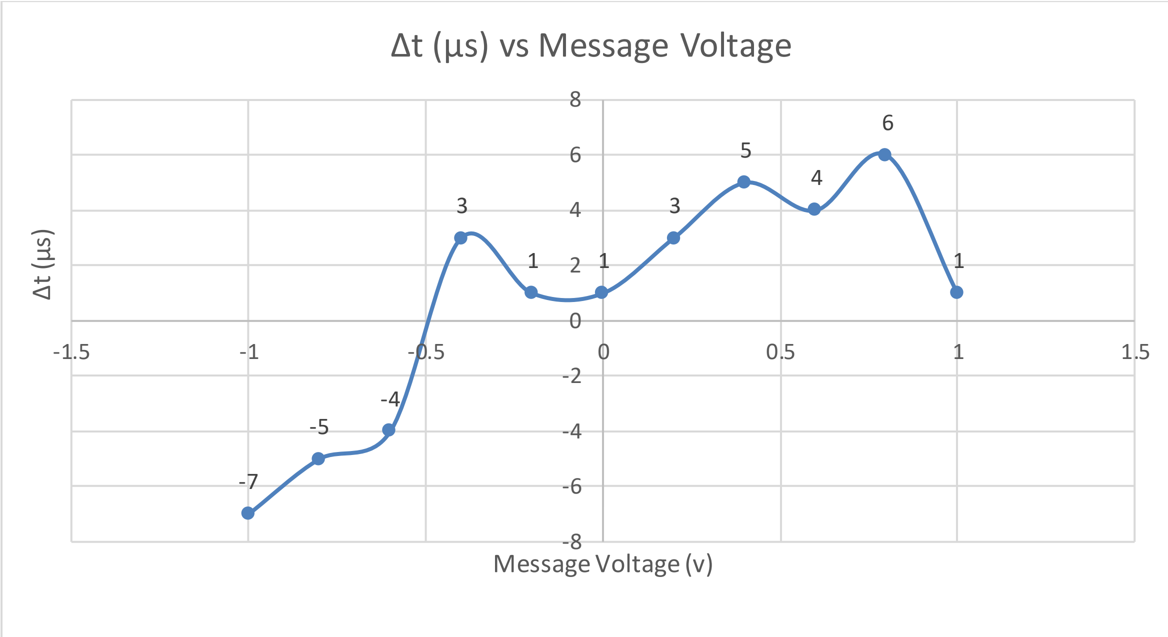


Figure 7: Δt (µs) vs Message Voltage

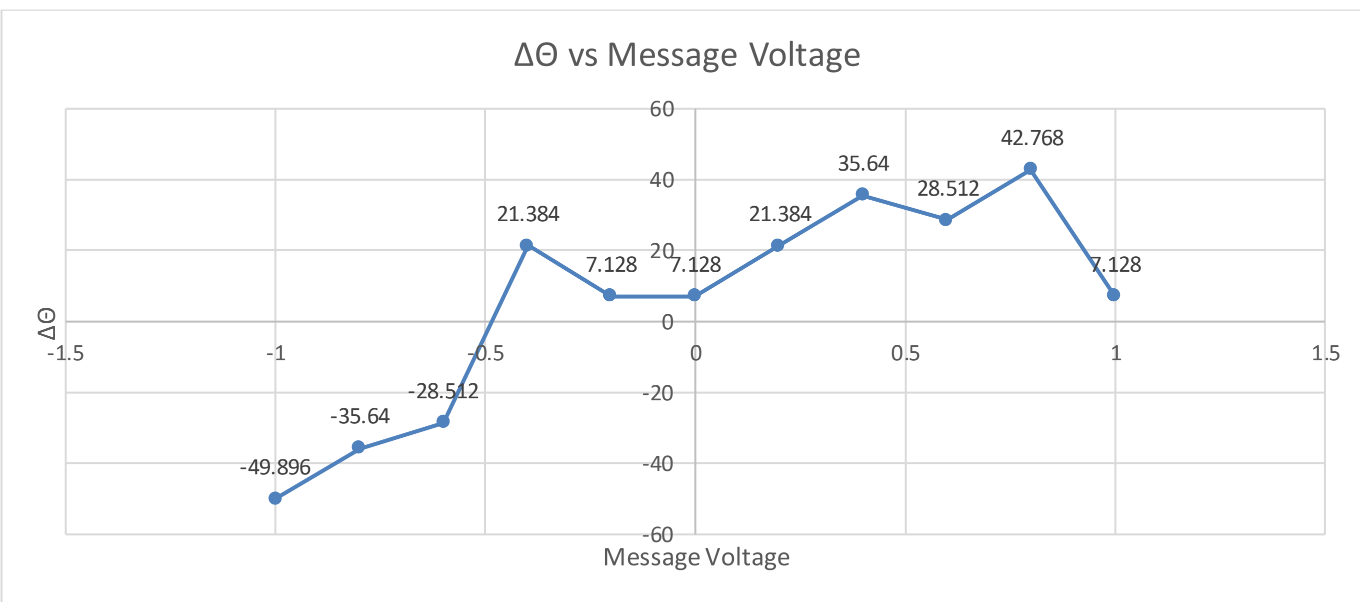


Figure 8: ΔΘ vs Message Voltage

2.2: Displaying the PM signal spectrum

With the same kit setup, a sinusoidal signal with v_{ss} = 2V and f_m = 3000Hz was be used as the message signal m(t). Then, the modulated signal spectrum was be plotted using Cassy Lab.

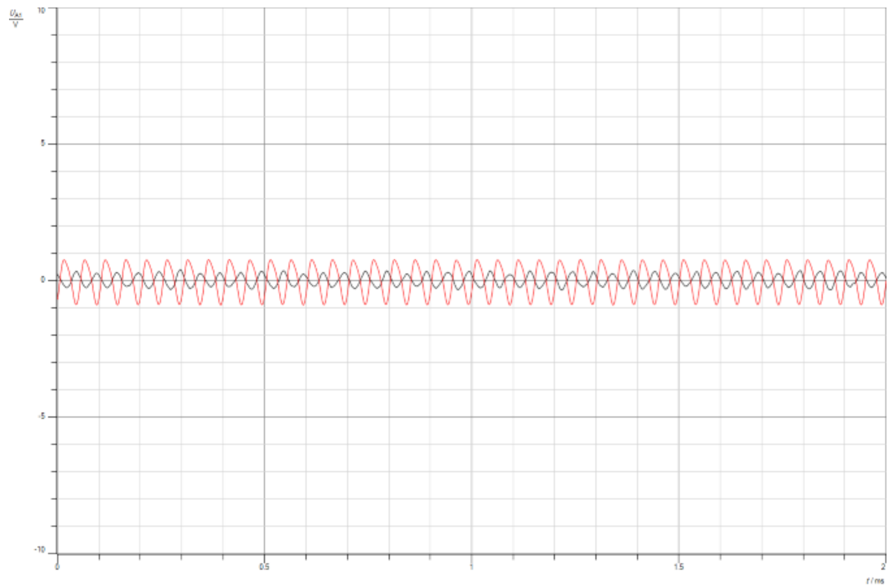


Figure 9:m(t) and s(t) in time domine when f_m=3000Hz

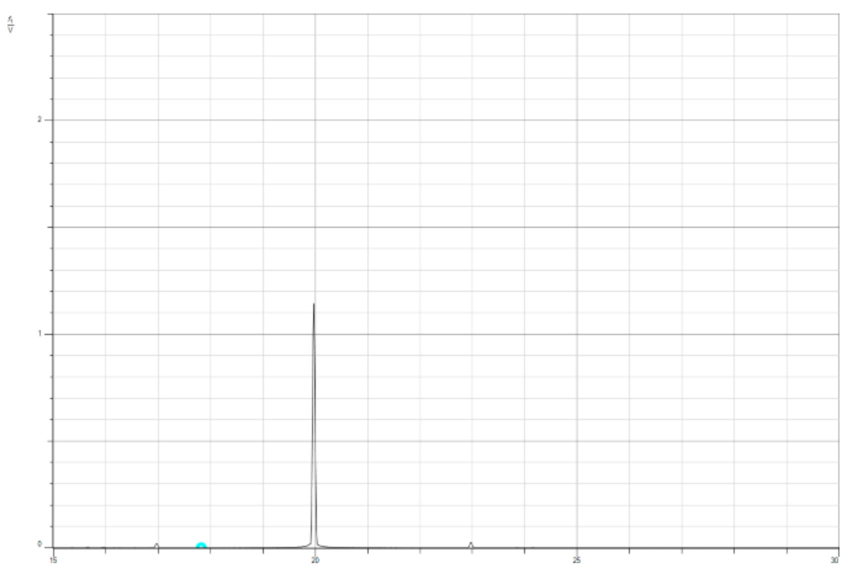


Figure 10: modulated signal s(t) in frequency domine when f_m=3000Hz

After that, we repeated the measurement for a message signal Vss = 2V and fm = 200Hz. Then, the modulated signal spectrum was be plotted using Cassy Lab.

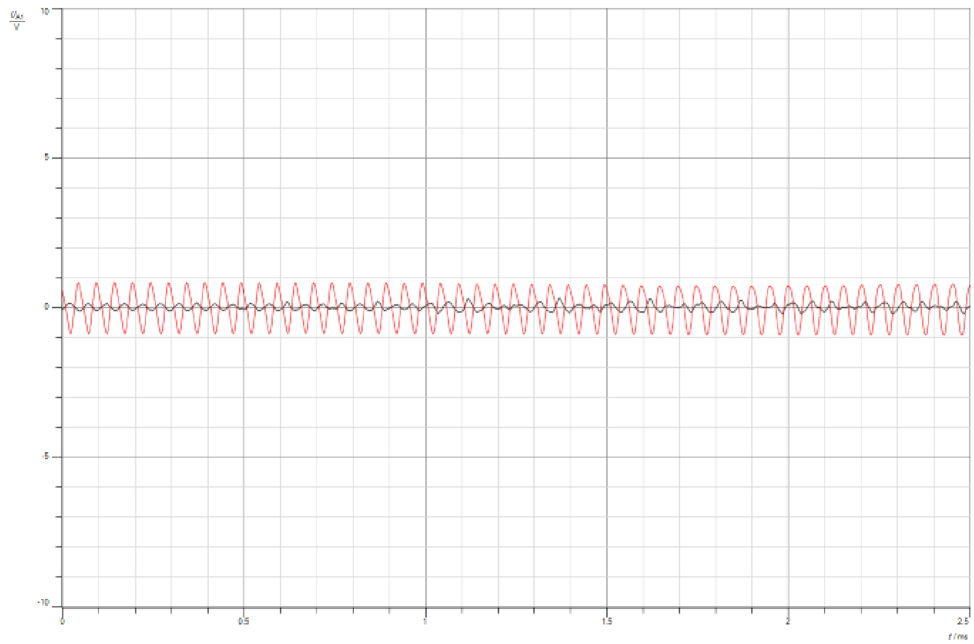


Figure 11: m(t) and s(t) in time domine when f_m=200Hz

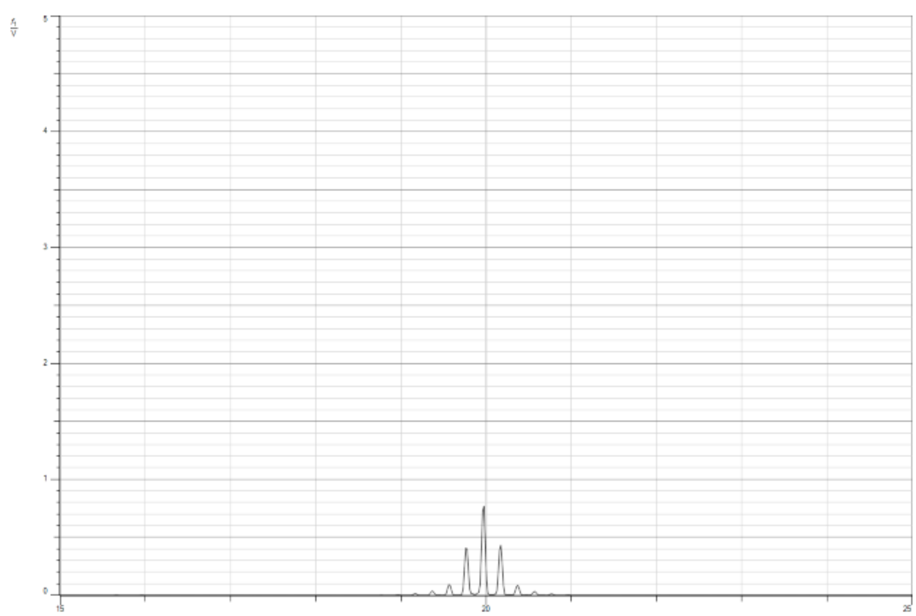


Figure 12: modulated signal s(t) in frequency domine when f_m=200Hz

The signal's spectrum clearly varies as the message signal's frequency (m(t)) is changed. The distribution of a signal's frequency components is shown by the signal's spectrum. The increasing importance of certain frequency components during the spectrum changes when the message signal's frequency is changed.

Higher frequencies in the message signal usually make the patterns in the signal's graph simpler. This happens because the different parts of the signal are closer together, as shown in figure 8. On the other hand, lower frequencies make the graph more complicated because the different parts of the signal are farther apart, as shown in figure 10. This complexity comes from lower frequencies including a wider range of signal changes.

The PM signal's spectrum is distinct from the FM (frequency modulation) signals. In FM, the amplitude of the message signal determines how much the carrier wave's frequency varies. As a result, there are spectral components at the carrier frequency as well as an unlimited number of sidebands at integral multiples of the modulating frequency. The frequency deviation, which is inversely proportional to the amplitude of the message signal, determines the FM sidebands' amplitude.

Different to PM, the FM signal's spectrum is determined by the frequency deviation rather than the message signal's amplitude. The maximum frequency deviation, which is defined by the message signal's amplitude and frequency, is inversely correlated with the FM signal's bandwidth. So, when the message signal amplitude grows, the FM signal spectrum widens, but the PM signal spectrum widens as the message signal frequency increases.

Part 2: PM Demodulation
Section 1: Time domain PM demodulated signal
Time Domine

The function generator was be configured for the generation of a sinusoidal message signal with a v_{ss} of 2V and an f_m of 500 Hz. Then, the loop filter of the PM demodulator was be set to τ2.

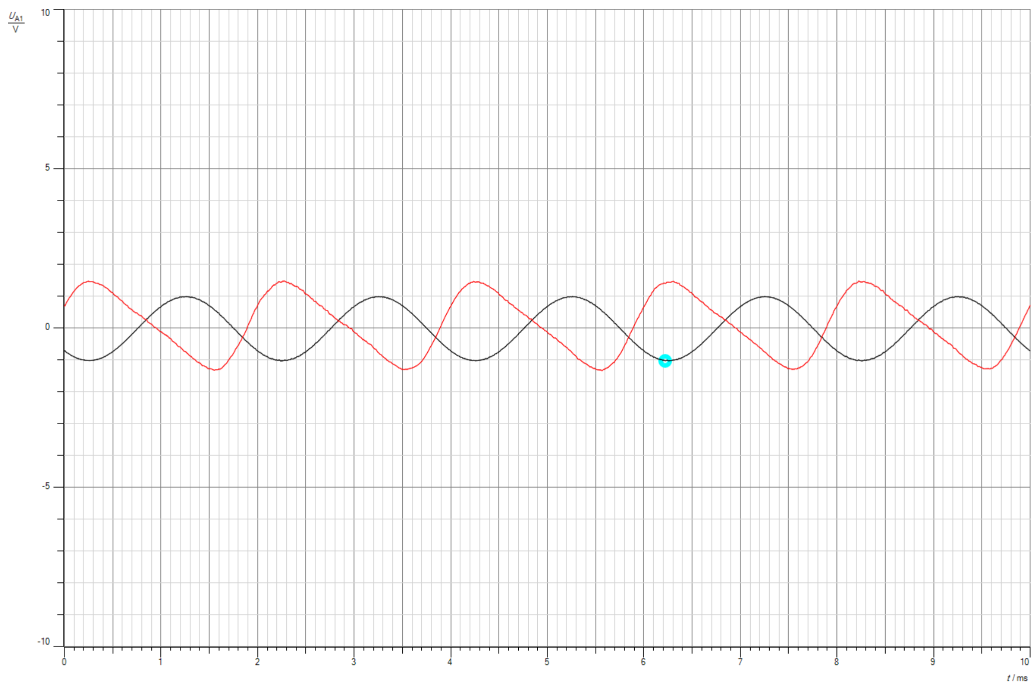


Figure 13: message and demodulated signals in Time Domine

The red signal indicates to the message signal m(t), and the black signal indicates to demodulated signal.

Frequency Domine

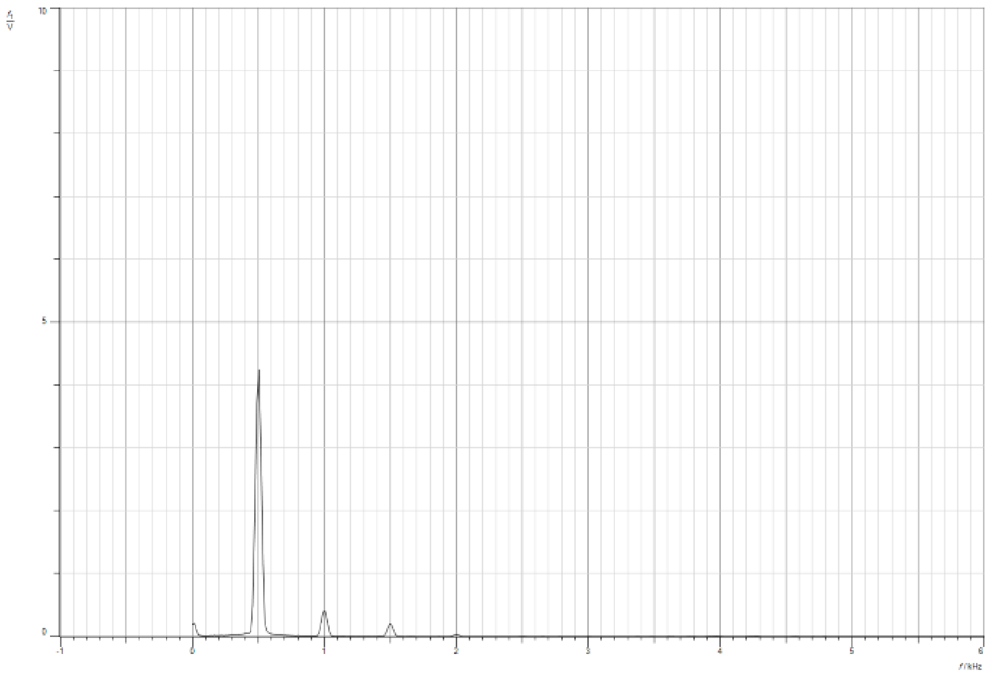


Figure 14: Demodulated signal in Frequency Domine

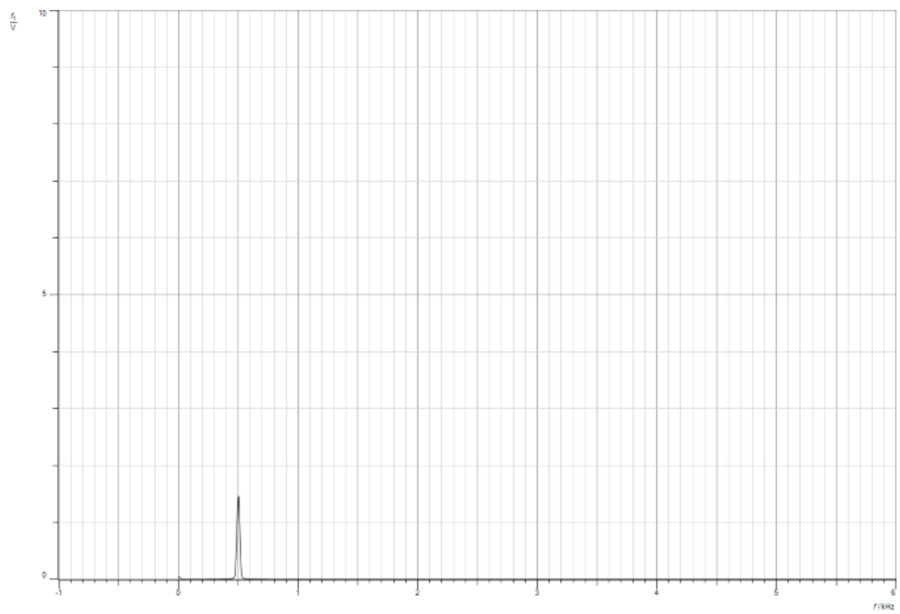


Figure 15: Message signal in Frequency Domine

We should compare the frequency and phase characteristics of the input message signal and the output demodulated signal to see if the Phase-Locked Loop (PLL) demodulator is correctly operating for the PM signal. The frequency and phase of the demodulated signal should match those of the message signal in the ideal situation.

We noticed a phase shift between the message signal and the demodulated signal in the figures above; this might be an indication that the loop filter or Phase-Locked Loop (PLL) demodulator is not configured properly.

Section 2: Studying the effect of the receiver loop filter

The experiment's receiver had been implemented to enable the utilization of two receiver loop filters. Each of these filters was represented as a lowpass filter with distinct gain-bandwidth characteristics. The objective of this section was to conduct a comparison between the message signal and the demodulated signal while varying the gain of the loop filter between the two available loop filters.

At first, the components were connected as shown in figure 14.

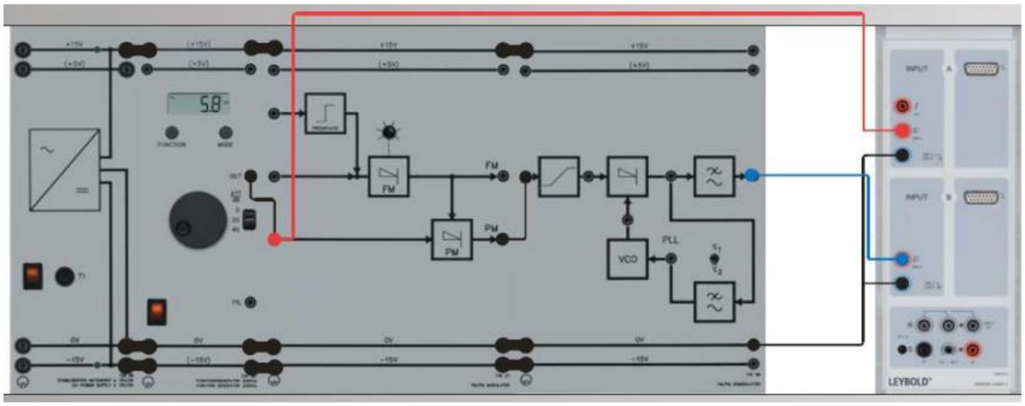


Figure 16: Components Connection for PM Demodulation

2.1: Studying Loop filters τ1 and τ2 without pre-emphasis

In this section, the Cassy Lab is to be set in FFT mode. The function generator was be configured for the generation of a sinusoidal message signal with a v_{ss} of 2V and an f_m of 500Hz. The amplitude of the demodulated signal was determined using the spectrum for each loop filter, and the values were recorded into the table.

Table 2: Table for Ad values

Message frequency (Hz)	500	1000	1500	2000	3000	4000	5000
A_d using t1 filter	10.23	5.57	2.91	1.60	0.8	0.38	0.23
A using t2 filter	2.98	2.44	1.94	1.59	0.87	0.55	0.27

Table 3: Table for Ad/Am values

Message frequency (Hz)	500	1000	1500	2000	3000	4000	5000
A_d /Am using t1 filter	10.23 /1= 10.23	5.57/1 = 5.57	2.91/1= 2.91	1.60/1= 1.60	0.8/1= 0.8	0.38/1= 0.38	0.23/1= 0.23
A_d/Am using t2 filter	2.98/1= 2.98	2.44/1 = 2.44	1.94/1= 1.94	1.59/1= 1.59	0.87/1 0.87	0.55/1= 0.55	0.27/1= 0.27

Note: I assume the value of $A_m = 1$

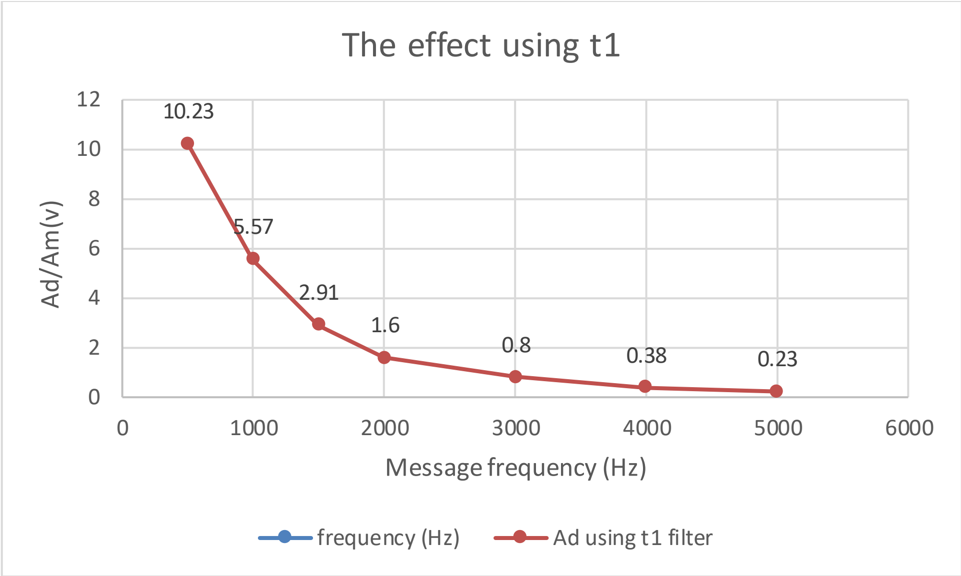


Figure 17: Ad/Am(v) vs Message frequency (Hz) Using T1

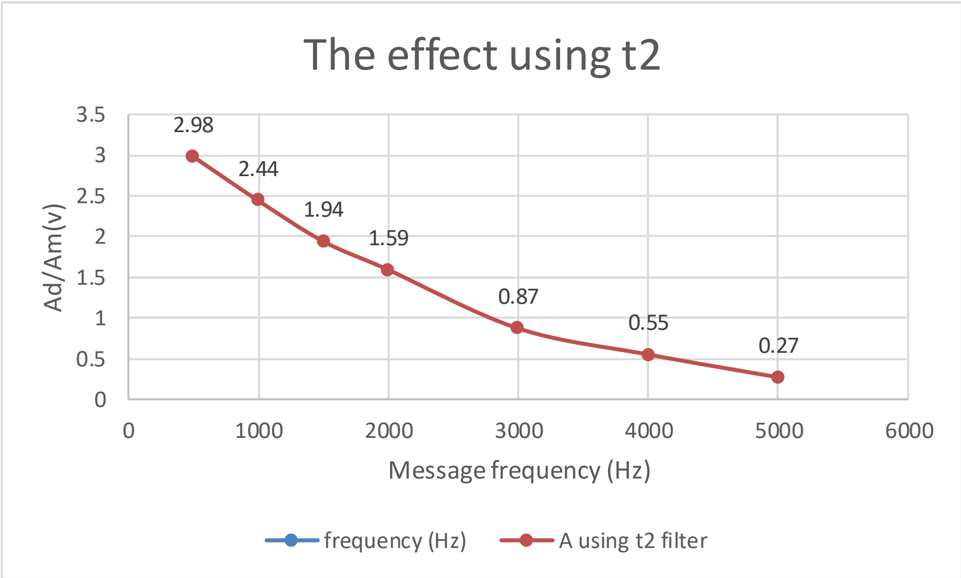


Figure 18: Ad/Am(v) vs Message frequency (Hz) Using T2

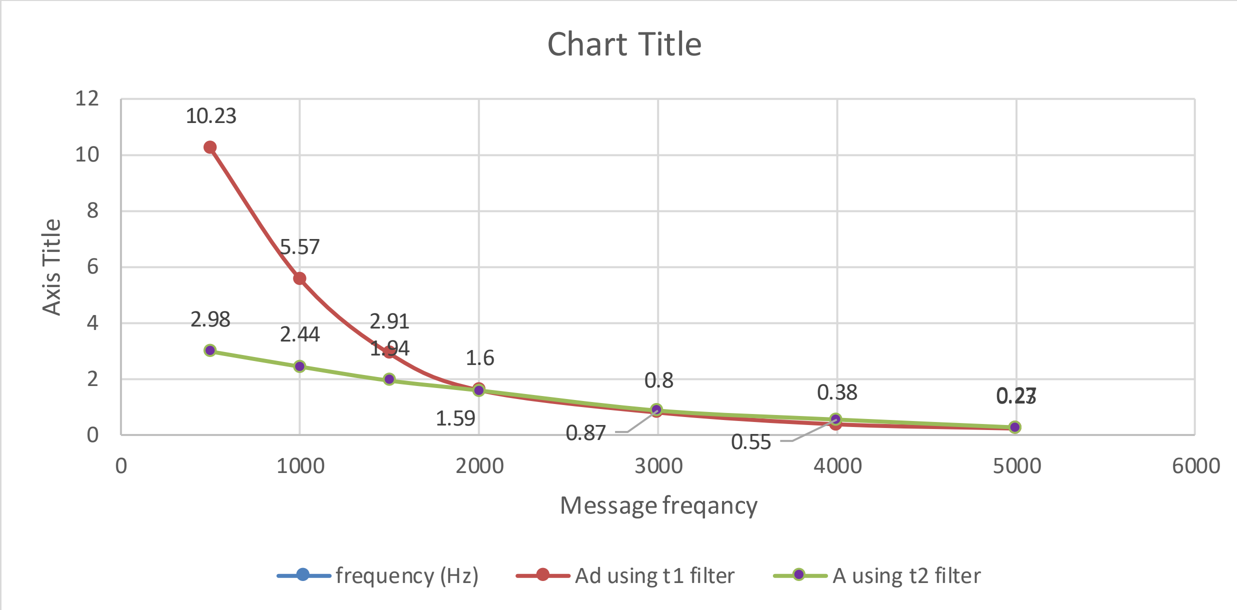


Figure 19: Ad/Am(v) vs Message frequency (Hz) Using T2 and T1

Discussion

According to the output figures, the loop filter with t1 appears to have a larger gain (Ad/Am) at lower frequencies (500Hz) than the loop filter with t2. The gain of the t1 filter, on the other hand, rapidly declines as the frequency rises, whilst the gain of the t2 filter remains mostly constant.

Also, as compared to the t1 filter, the t2 filter has a larger gain at higher frequencies (above 2 kHz). This implies that the t1 filter may be more appropriate for low-frequency applications, whilst the t2 filter may be more suited for high-frequency applications.

The choice of filter would rely on the particular application and frequency range of interest because the two loop filters often have distinct frequency response characteristics.

Conclusion

At the end of the experiment, we learned a new modulation and its implementation technique which is phase modulation (PM). Also, we understood the demodulation strategies. We discovered that PM is a modulation technique that produces modulated signals with variable phase angles by adjusting the carrier signal's phase in proportion to the message signal.

Additionally, we studied PM demodulation using two receiver loop filters with various gain bandwidth properties. When the strength of the loop filter was changed between the two filters, the goal was to compare the message signal with the demodulated signal. We found that the demodulated signal's amplitude and phase are influenced by the loop filter selected, and this can have an effect on the strength of the recovered message signal.

Also , the phase modulation approach two domains (time and spectrum) have been studied and understood the experiment's findings help us comprehend the impact of altering a few message characteristics in order to determine how they impact the modulation and demodulation processes. The experiment was a success, and the outcomes confirmed the predictions of the theory.

References

[1] https://www.physics-and-radio-electronics.com/blog/phase-modulation/ .
Accessed on 7-8-2023 at 10:12 AM.

[2] https://electronicscoach.com/phase-modulation.html .
Accessed on 7-8-2023 at 11:30 AM.

[3] https://www.sfu.ca/sonic-studio-webdav/handbook/Demodulation.html .
Accessed on 8-8-2023 at 11:50 AM.

[4] https://www.javatpoint.com/phase-modulation .
Accessed on 8-8-2023 at 4:12 PM.

[5] Lab manual.

Appendix

الاحمر ← t_2

الأسود ← t_1

$\Delta\theta = K_p m(t)$

2.1: The Characteristic of the FM Modulator

The objective of this part is to determine the modulator sensitivity constant k_p in °/V

Using the 20 kHz carrier signal, modulate a **DC-signal** message signal starting with -1V. Load the CASSY Lab 2 example PM_TD.labx.

After that Determine the phase shift Δt (μs) between the carrier oscillations of the FM and PM output. Increment the DC voltage in steps of 0.2V and repeat the measurement of the carrier frequency filling the following table.

Message Voltage	Δt (μs)	Message Voltage	Δt (μs)
-1	-7×10^{-3} ms	0.2	0.003 μs
-0.8	-5×10^{-3} ms	0.4	0.005 μs
-0.6	-4	0.6	0.004 ms
-0.4	0.003 ms	0.8	0.006 μs
-0.2	0.001 ms	1	0.01 μs
0	0.001 ms		

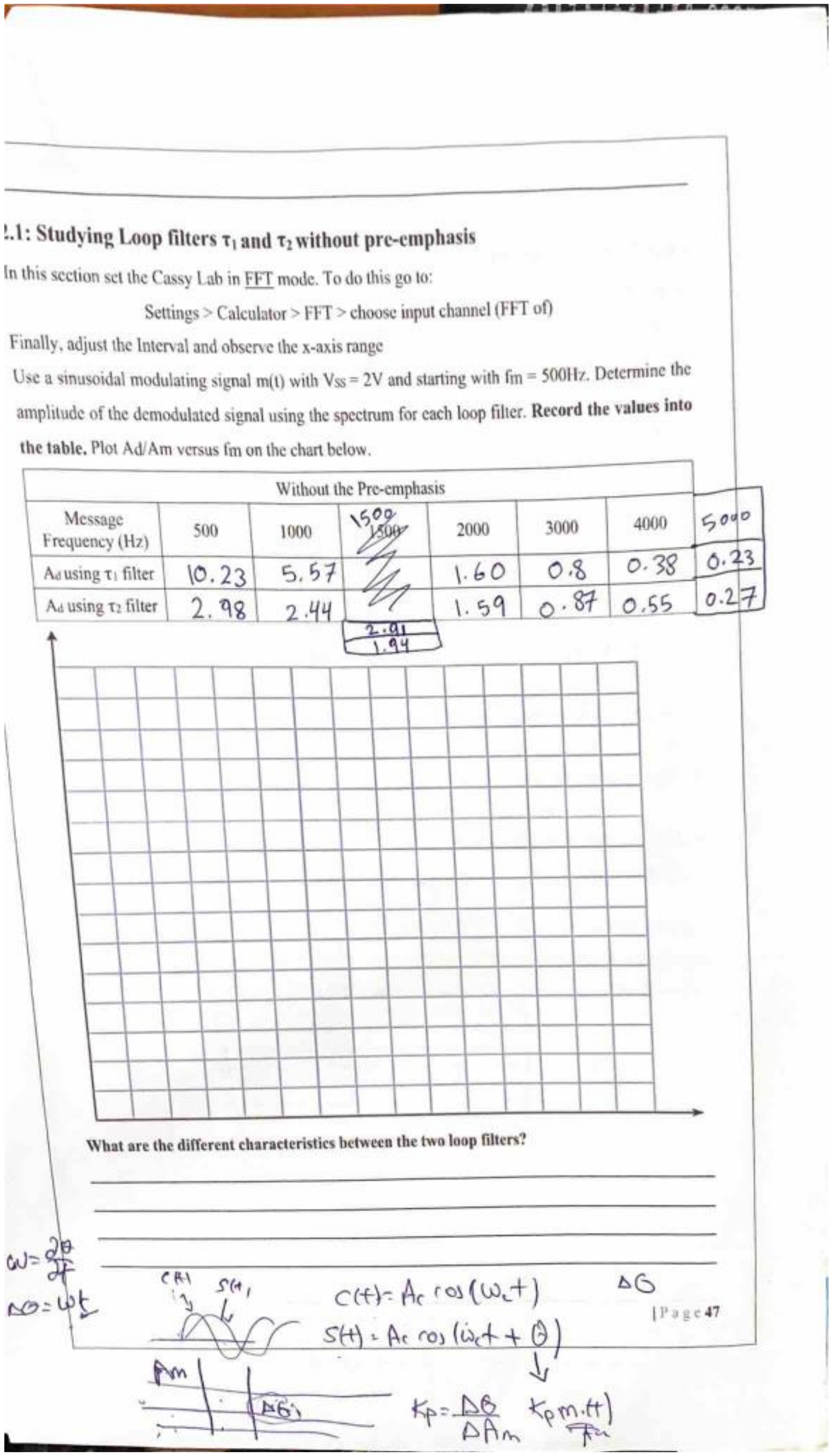
Determine the coefficient of the PM modulator k_p. Hint: use the following equation:

$$\Delta\theta = \frac{\Delta t}{T_c} 360° = (\Delta t)(f_c)360°$$

2.2: Displaying the PM signal spectrum

With the same kit setup, use a **sinusoidal** signal with V_{SS} = 2V and fm = 3000Hz as the message signal m(t). Make sure its DC offset is 0V. Plot the modulated signal spectrum using the Cassy Lab then **take a picture [in time and frequency]** of the impulses. (Adjust the x-axis range to be suitable for the plot) Repeat the measurement for a message signal V_{SS} = 2V and fm = 200Hz. plot the modulated signal spectrum using the Cassy Lab then **take a picture [in time and frequency]** of the impulses. (Adjust the x-axis range to be suitable for the plot)

Figure 20:Data Sheet 1



2.1: Studying Loop filters τ_1 and τ_2 without pre-emphasis

In this section set the Cassy Lab in FFT mode. To do this go to:

Settings > Calculator > FFT > choose input channel (FFT of)

Finally, adjust the Interval and observe the x-axis range

Use a sinusoidal modulating signal m(t) with V_{SS} = 2V and starting with fm = 500Hz. Determine the amplitude of the demodulated signal using the spectrum for each loop filter. **Record the values into the table.** Plot Ad/Am versus fm on the chart below.

Without the Pre-emphasis							
Message Frequency (Hz)	500	1000	1500	2000	3000	4000	5000
A_d using τ_1 filter	10.23	5.57	2.91	1.60	0.8	0.38	0.23
A_d using τ_2 filter	2.98	2.44	1.94	1.59	0.87	0.55	0.27

What are the different characteristics between the two loop filters?

$\omega = \frac{\partial\theta}{\partial t}$

$\Delta\theta = \omega t$

$C(t) = A_c \cos(\omega_c t)$

$S(t) = A_c \cos(\omega_c t + \theta)$

$K_p = \frac{\Delta\theta}{\Delta A_m}$ $K_p m(t)$

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Figure 21: Data Sheet 2