BIRZEIT UNIVERSITY

Faculty of Engineering & Technology

Department of Electrical & Computer Engineering

ENEE4113-COMMUNICATIONS LAB

Report#1

Experiment#4: Frequency Modulation

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Abstract

This experiment aims to convert theoretical understanding of frequency modulation (FM) into a useful application. Both signal and communication fundamentals will be covered. In the fundamentals of communication, frequency modulation and demodulation will be performed, FM modulator sensitivity will be comprehended, and carrier zero crossing will be grasped. In terms of signal fundamentals, low-pass filter properties will be discussed, and the function and application timing of pre-emphasis will be understood.

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Theory

Angle Modulation

A type of carrier modulation used in transmission networks for telecommunications is called angle modulation. This class includes frequency modulation (FM) and phase modulation (PM), which work by encoding a message signal by changing the frequency or phase, respectively, of a carrier signal. This is in contrast to the practice of altering the carrier's amplitude in amplitude modulation (AM) transmission, which was one of the first major modulation techniques extensively employed in the early days of radio broadcasting.[1]

Types of Angle Modulation

Angle consist of Phase and Frequency so Angle Modulation is divided into

- Frequency Modulation
- Phase Modulation

Frequency Modulation

Regularity The method of modulation involves changing the carrier signal's frequency in relation to the message signal's amplitude. The carrier signal's amplitude and phase stay constant in this situation. Instantaneous frequency change in relation to the message signal is what this method entails. The frequency of the modulated signal increases with an increase in the amplitude of the baseband or message signal, and decreases with a reduction in the amplitude of the baseband or message signal.[2]

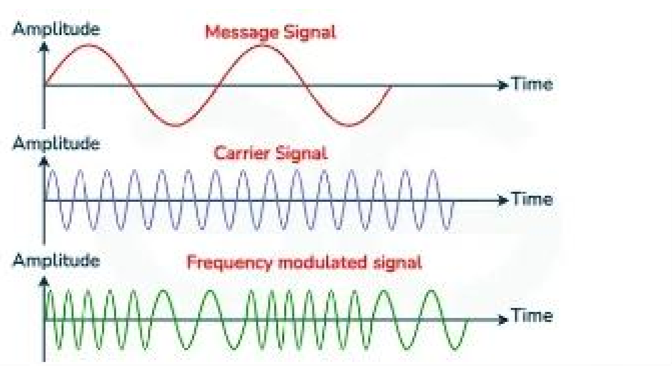

Figure 1:Frequency Modulation[2]

Mathematical Representation of Frequency Modulation

A frequency-modulated signal is expressed as:

$s(t) = A \cos(\phi_i(t))$

where s(t) is the standard frequency-modulated signal and ϕ_i is the instantaneous phase angle of the modulated signal.

The instantaneous angular velocity or frequency is:

$\omega_i = \omega_c + k_f\, m(t)$

where k_f is the frequency sensitivity, m(t) is the message signal, and ω_c is the carrier frequency or velocity.

Based on the previous equation, we can write:

$\phi_i = \int \omega_i \, dt$

Substituting the value of ω_i from the previous equation, we get:

$\phi_i = \int (\omega_c + k_f\, m(t))\, dt = \omega_c t + k_f \int m(t)\, dt$

Substituting the value of ϕ_i from the above equation into s(t), we get:

$s(t) = A \cos(\omega_c t + k_f \int m(t)\, dt)$

This is the expression of a frequency-modulated wave or signal. [2]

Types of Frequency Modulation

- Narrow Band Frequency Modulation
- Wide Band Frequency Modulation[2]

Narrow Band Frequency Modulation →

Narrowband FM refers to frequency modulation with a modulation index (β) smaller than one. It only takes up a small portion of the frequency modulation and has a narrow bandwidth. The top sideband, lower sideband, and carrier make up the narrowband FM spectrum. Mobile communication is the main application for it. [2]

Wide Band Frequency Modulation →

Wideband FM refers to frequency modulation where the modulation index (β) value is more than one. Its bandwidth is unlimited. It uses a broad range of frequencies and makes up a significant portion of frequency modulation. This FM's spectrum is made up of an endless number of sidebands and a carrier.It is mostly utilized for signal broadcasting. [2]

FM Demodulation

The Signal of FM signal demulation entails separating the modulated carrier signal from the underlying message signal. The phase-locked loop (PLL) approach and the envelope detector method are the two most often utilized techniques for demodulating FM signals.

Phase-locked loop (PLL)

In essence, a phase-Locked Loop (PLL) is a system of negative feedback. It is made up of three main parts that are coupled in the form of a feedback loop: a voltage controlled oscillator (VCO), a loop filter, and a re multiplier. [4]

A voltage-controlled oscillator (VCO) generates sine waves, the frequency of which is set by the external voltage applied to it. It implies that a VCO can be created using any frequency modulator. Tracking the phase and frequency of the carrier component of an incoming FM signal is the main application for a phase-locked loop (PLL). PLL is especially helpful for the synchronous demodulation of signals with few pilot carrier cycles or AM-SC (Amplitude Modulation with Suppressed carrier) signals.
PLL is also helpful for demodulating FM transmissions when there is a lot of noise and little signal strength.[4]

This indicates that PLL is best suited for usage in data communications between spacecraft and Earth or in situations where there is a significant loss along the transmission line or path.
It has been used in commercial FM receivers lately. [4]

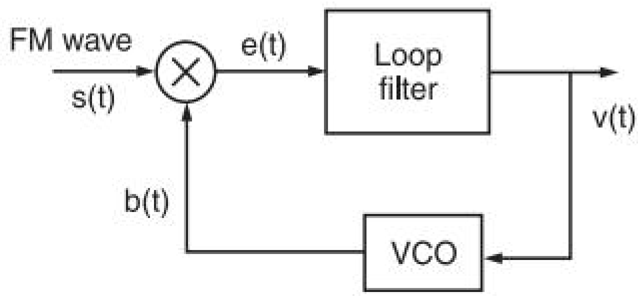

Figure 2:The block diagram of a Phase-Locked Loop (PLL)[4]

FM Demodulation by envelop detector

A previously modulated signal can be demodulated by an envelope detector by eliminating all of its high frequency components. The carrier frequency is filtered out by the low-pass filter formed by the capacitor and resistor.[5]

Phase Modulation

Phase modulation is the process of altering the carrier signal's phase in relation to the baseband signal's or the message signal's amplitude.The carrier signal's amplitude and frequency remain constant in this modulation.When the message signal's amplitude is positive, the carrier signal's phase angle changes in one direction; conversely, when the amplitude is negative, the phase angle changes in the other way.[2]

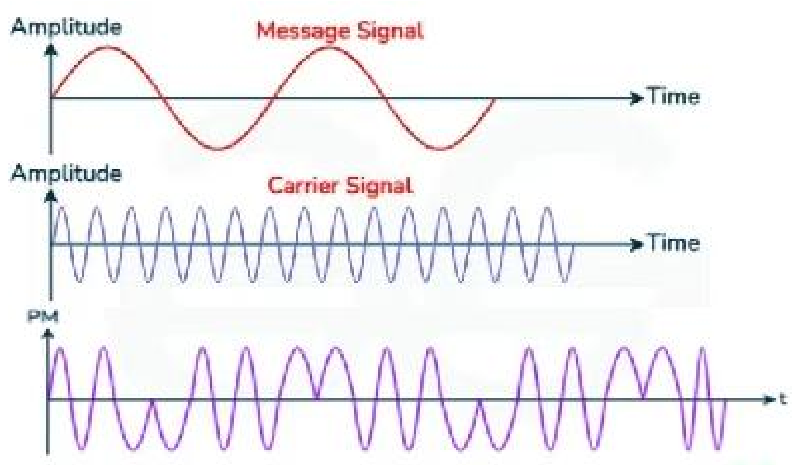

Figure 3:Phase Modulation[2]

Advantages of Frequency Modulation

- There is an improvement in signal quality.
- There is a high signal to noise ratio.
- An amplifier or repeater is not necessary for the transmission of the signal.
- less vulnerable to noise.
- high signal transmission rate.[2]

Disadvantages of Frequency Modulation

- The receiver and transmitter ought to be on the same channel.
- Not appropriate for coverage over long distances.
- need a broad range of frequencies.
- It is expensive. [2]

Applications of Frequency Modulation

- utilized in radio.
- utilized for storing magnetic tape.
- utilized for television signal transmitting.
- Used in Satellite .
- utilized in cassette recorders for video. [2]

Zero-crossing

By identifying the modulated signal's zero-crossings, a zero-crossing FM detector is a signal demodulation method that restores the original data from an FM modulated signal. The fundamental concept underlying this method is that the rate at which the phase of an FM signal changes is precisely proportional to the signal's frequency. The original information can be recovered and the frequency deviation of the FM signal approximated by identifying the zero-crossings, or the points at which the signal changes direction. [3]

Pre-Emphasis and De-Emphasis

Higher frequencies are selectively amplified during the pre-emphasis stage and selectively reduced during the de-emphasis stage. The highs can be transmitted at higher levels to overcome noise while still being received at regular levels thanks to this complimentary mechanism.
levels necessary to preserve authenticity[6]

Procedure

Part I: Modulation

Displaying the FM signal

We Assembled the components as shown in the figure. And Set the function generator to generate a sinusoidal message signal with Vss = 20V and fm = 1kHz. Set the carrier knob to the min value and start the measurement.

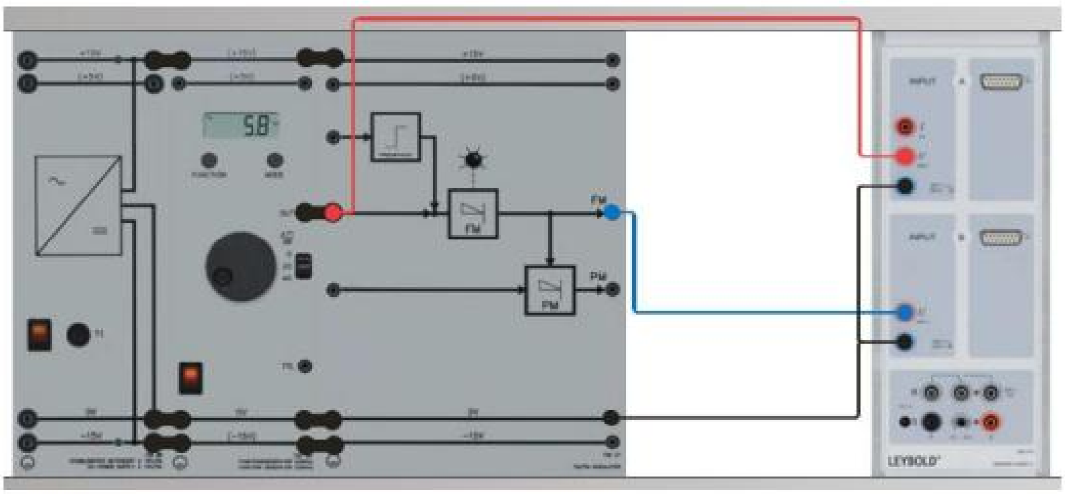

Figure 4:The FM modulating setup

The message signal in the time domain was represented by cassy lab :

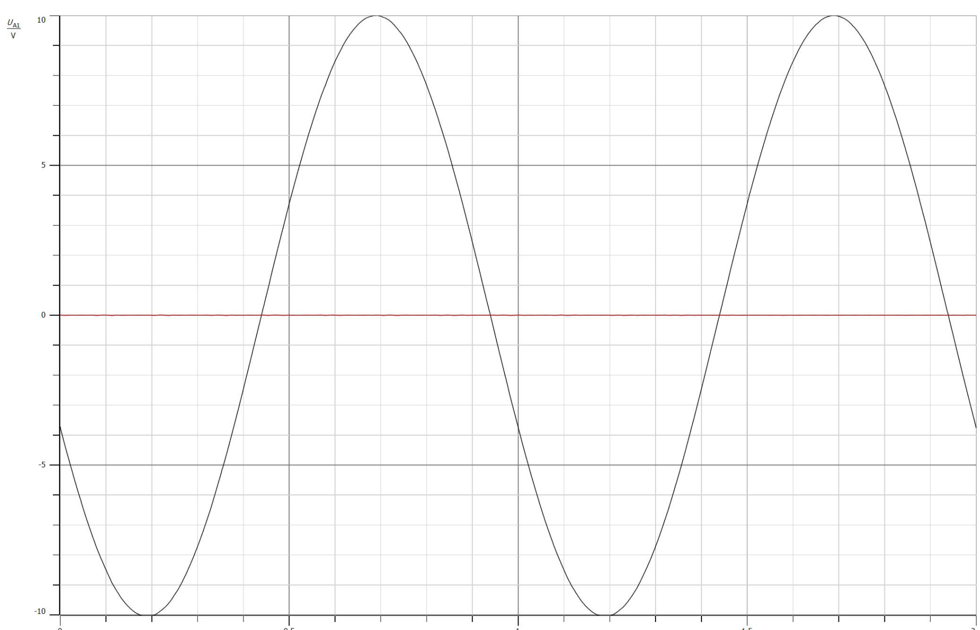

Figure 5:The message signal in the time domain

And in Frequency domain :

In this section, the Cassy Lab was set to FFT mode.

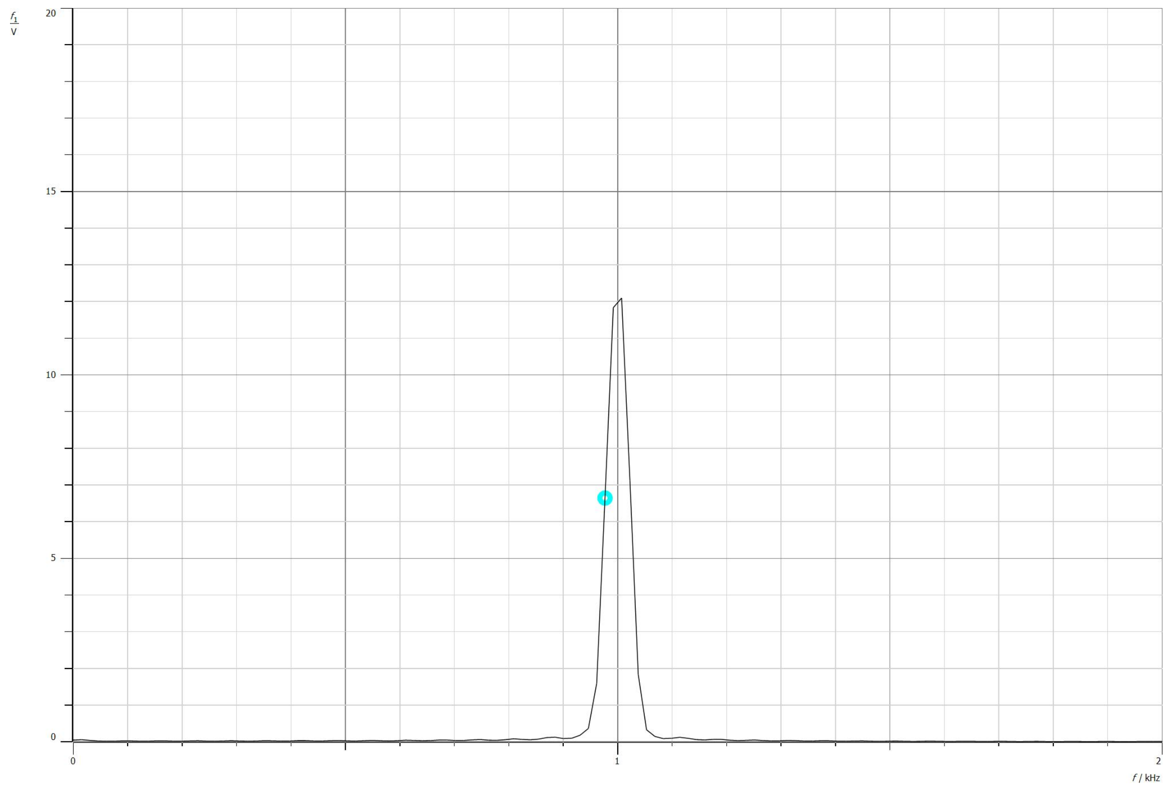

Figure 6:The message signal in the frequency domain

And the modulated signal was represented by cassy lab:

Vss=20v && fm=1KHKH

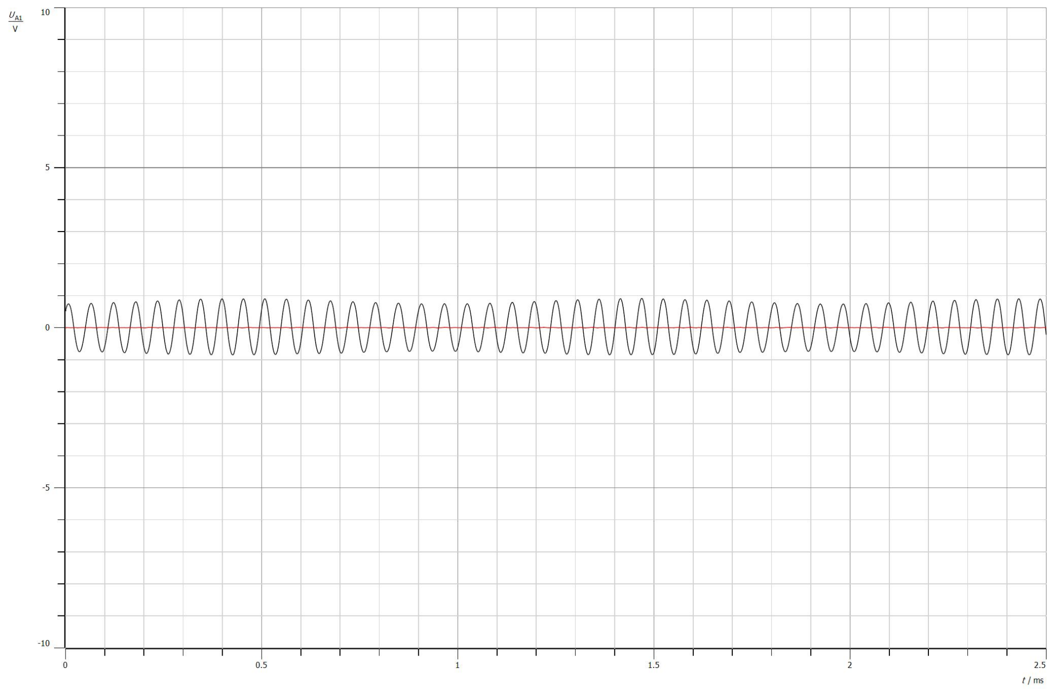

Figure 7:Time domain modulated signal and message signal

And in Frequency domain :

In this section, the Cassy Lab was set to FFT mode.

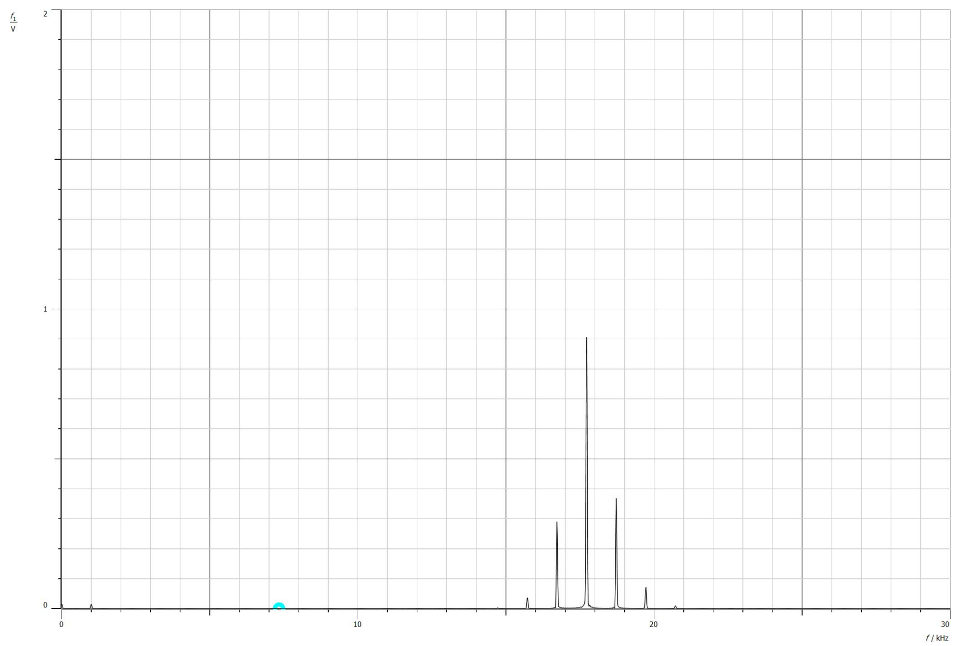

Figure 8: Frequency domain modulated signal

Discussion

The frequency modulation response is displayed in the time domain in Figure (7) and in the frequency domain in Figure (8). The FM signal appears as a sinusoidal waveform. In FM modulation, the frequency of the modulated signal varies in relation to the amplitude of the modulating signal.

However, due to the narrow variation range, this shift is difficult to notice. The amplitude of the message signal affects the modulated signal. When the Vss value is lowered, the frequency of the modulated signal increases.

Setting the carrier frequency to exactly 20kHz:

The function generator was configured to produce a message signal with Vss = 0V . The modulated signal S(t) represented the carrier signal at 20 kHz.

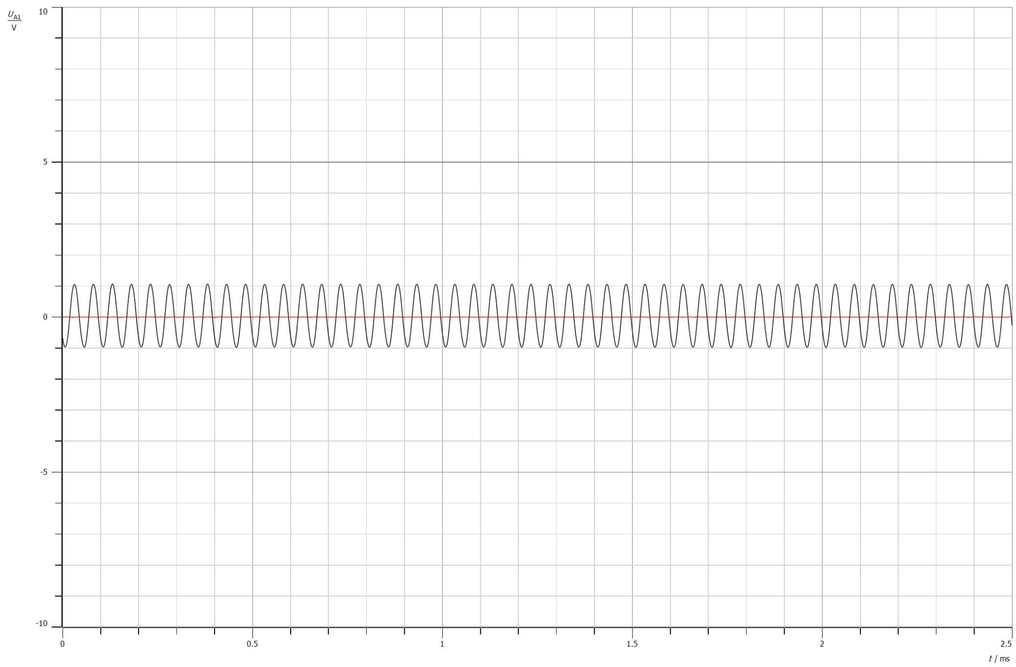

Figure 9:Time domain carier signal

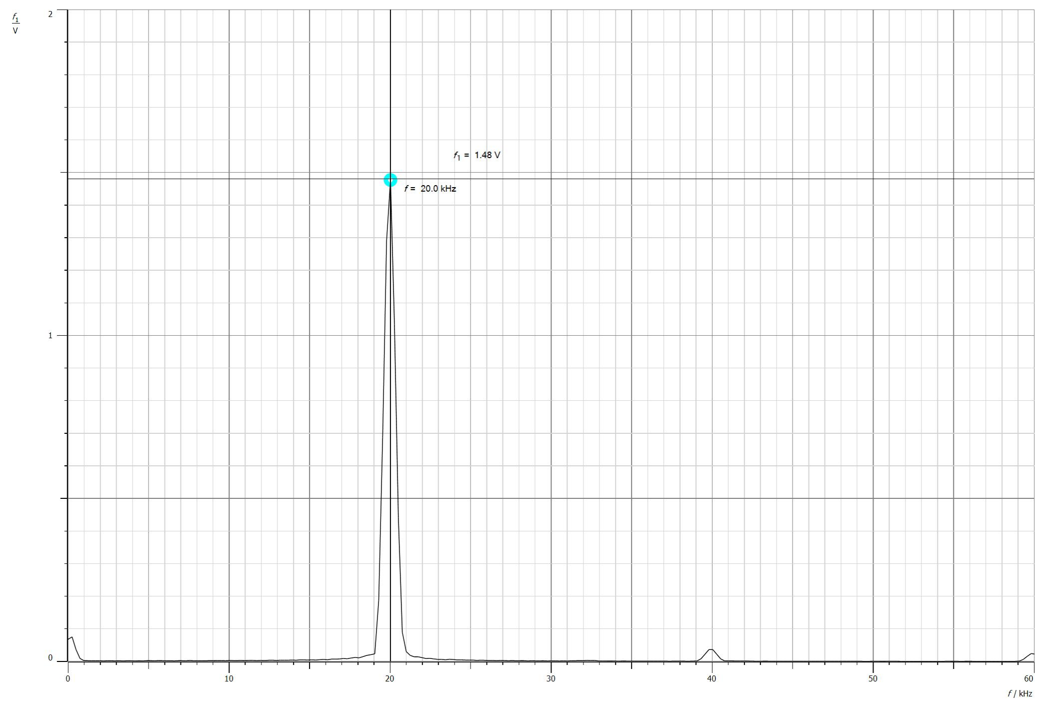

Figure 10:Frequency domain carier signal

Discussion

When the message signal Vss = 0V was produced by the function generator, it meant that both FM and the message signal had a constant value of 0V. Consequently, the modulated signal only included the carrier signal because the message signal was zero:

$$S(t)=Ac*\cos(2*pi*fc*t) = C(t)$$

The carrier frequency was then set to 20 kHz on the x-axis of the frequency domain by adjusting the carrier knob.

The Characteristic of the FM Modulator

This section's goal is to calculate the modulator sensitivity constant, or kf, in terms of Hz per volt. The instantaneous frequency, fi(t), and the message signal have the following relationship:

$$fc + kf * m(t) = fi(t)$$

When the message signal is continuous, the formula becomes:

$$fc + kf * constant = fi(t)$$

Since the kf * constant has a fixed value in this case, fi(t) stays constant.

A DC message signal with a voltage of -10V was modulated by a carrier signal at 20 kHz. Using the spectrum, we determined the carrier frequency. Then,We increased the DC voltage in steps of two volts. And We Repeated the measurements and note them in the table

Message Voltage	Carrier Frequency	Message Voltage	Carrier Frequency
-10	19.27	**2**	20.08
-8	19.42	**4**	20.25
-6	19.47	**6**	20.39
-4	19.68	**8**	20.54
-2	19.84	**10**	20.68
0	19.97		

Table 1:The Carrier frequencies at different messages' DC Voltages

$$K_f = \frac{\Delta f}{\Delta m} = \frac{(20.68 - 19.27)}{20} =$$

$$= \frac{1.41}{20} = 70.5$$

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The 10 volt message signal's frequency deviation was calculated using:

$$\Delta f = Kf * Am$$

$$= 70.5 * 10$$

$$= 705 \text{ Hz}$$

Discussion

The magnitude of the modulating signal and the FM modulator's coefficient determine the frequency deviation.

Displaying the FM signal spectrum

Sinusoidal Message signal

A sinusoidal signal with Vss= 20V and fm = 3000Hz was utilized as the message signal m(t) using the same kit design.The message signal's DC offset was 0V.

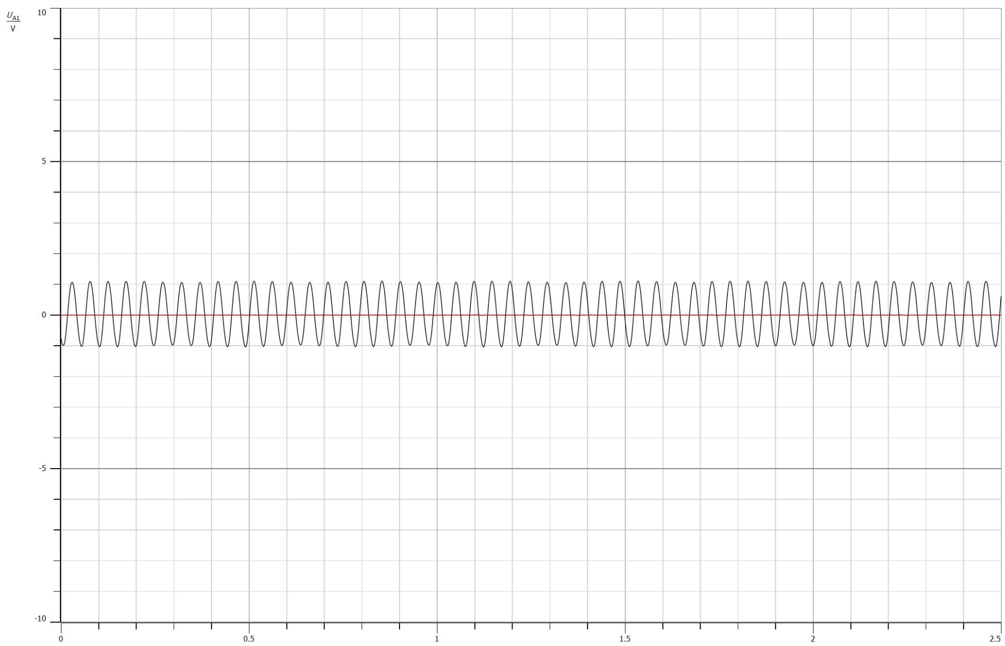

Figure 11:S(t) in time domain

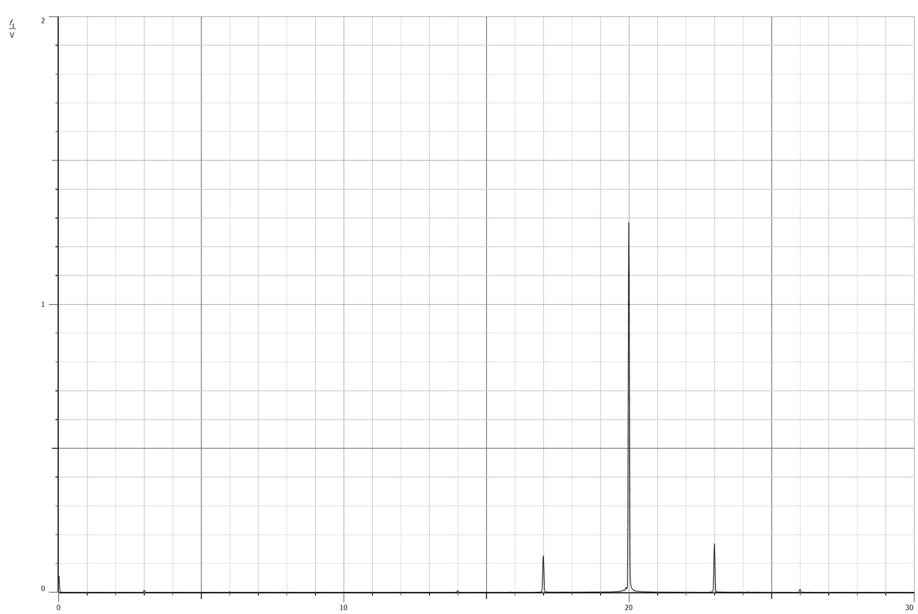

Figure 12:frequency domain represented when Vss is equal to 20V and fm equal to 3000Hz

The experiment was repeated for a message signal with the following figures, which were represented in the frequency domain and time domain, respectively, with Vss=20V And fm=200Hz :

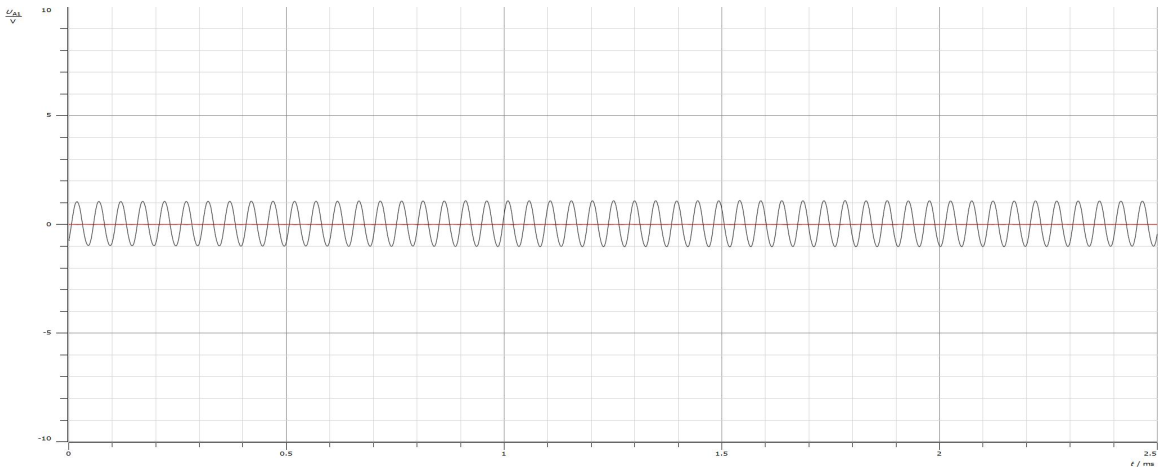

Figure 13:The modulated signal whenVss = 20V and fm = 200Hz in time domain

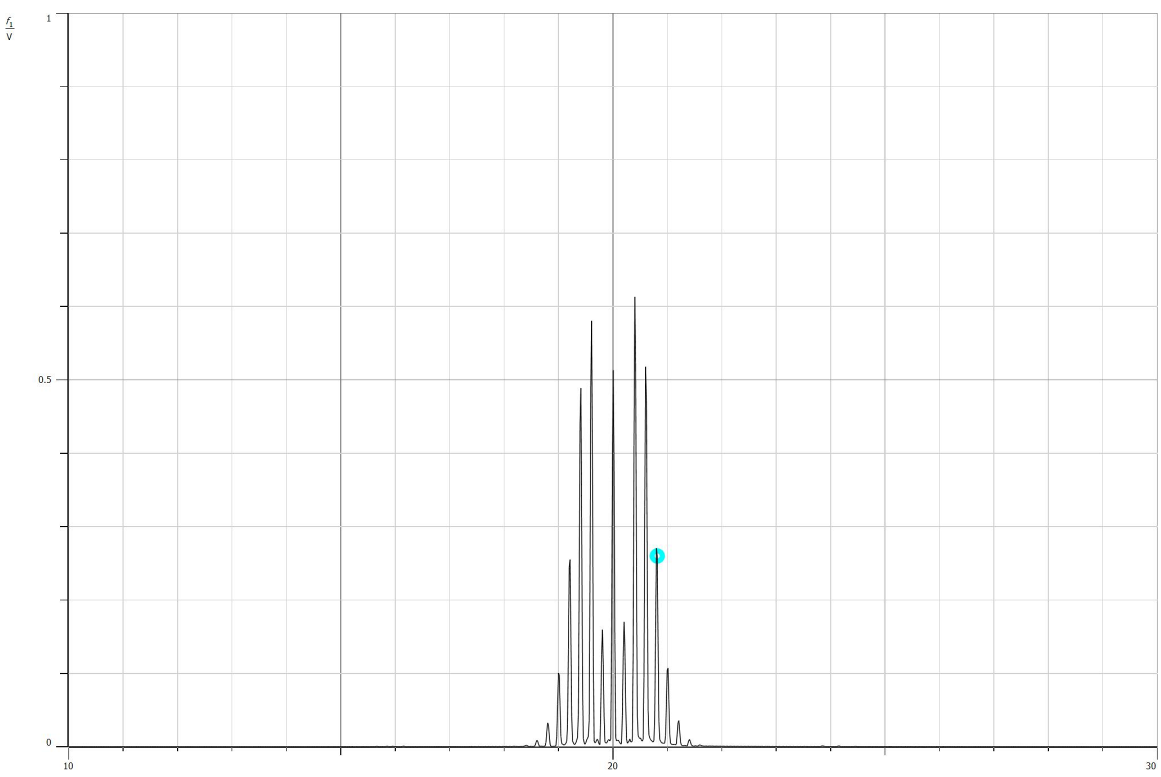

Figure 14:The modulated signal when Vss = 20V and fm = 200Hz in frequency domain

Discussion

When the frequency is set to 3000Hz, the modulation index β is determined by

B = Kf*(Af/Am)=70.5*(10/3000)=0.235 < 1

The modulation index β changes as a result of frequency changes.This observation suggests a narrowband nature to the modulation.

When the frequency is set to 200 Hz, the modulation index β is 3.525 > 1, indicating wideband modulation.

The signal with fm= 200Hz has a wider bandwidth and more sidebands compared to the signal with fm = 3000Hz. This is because higher frequency signals result in closer sidebands, creating a broader bandwidth.

Without frequency modulation, the result is a set of cosines weighted by Bessel functions of β.

$$\cos(2\pi fct + \beta \sin(2\pi fmt)) = \sum_{-\infty}^{\infty} J_k(\beta)\cos(2\pi(fc + kfm)t)$$

Square Message signal

A square wave signal was utilized as a message signal, with Vss set to 20 volts, 50% duty cycle, and fm = 200 Hz.
Figures below show the modulated signal in the frequency and time domains, respectively.

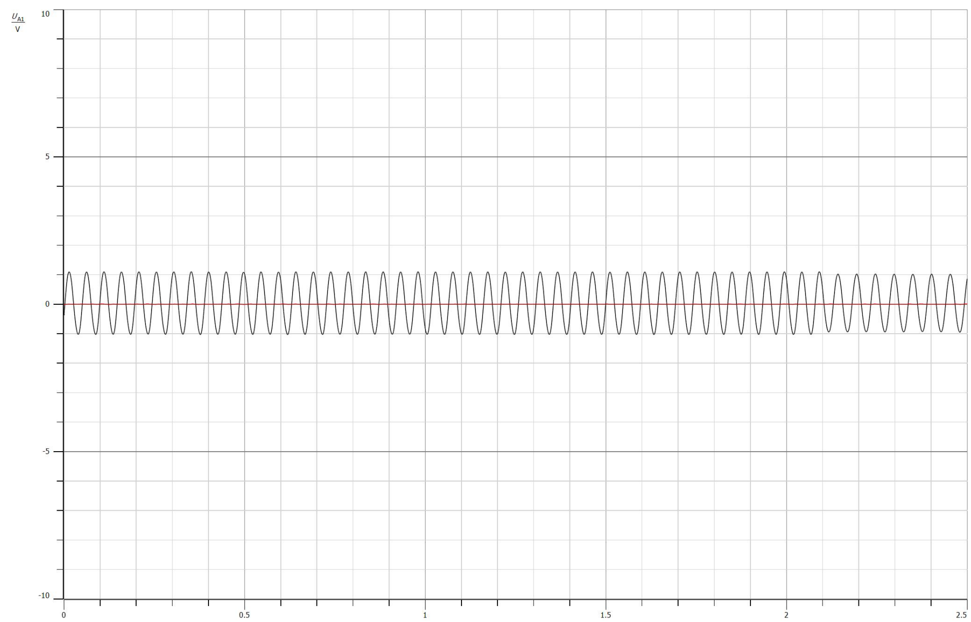

Figure 15:The time domain Modulated Signal with the squared message signal

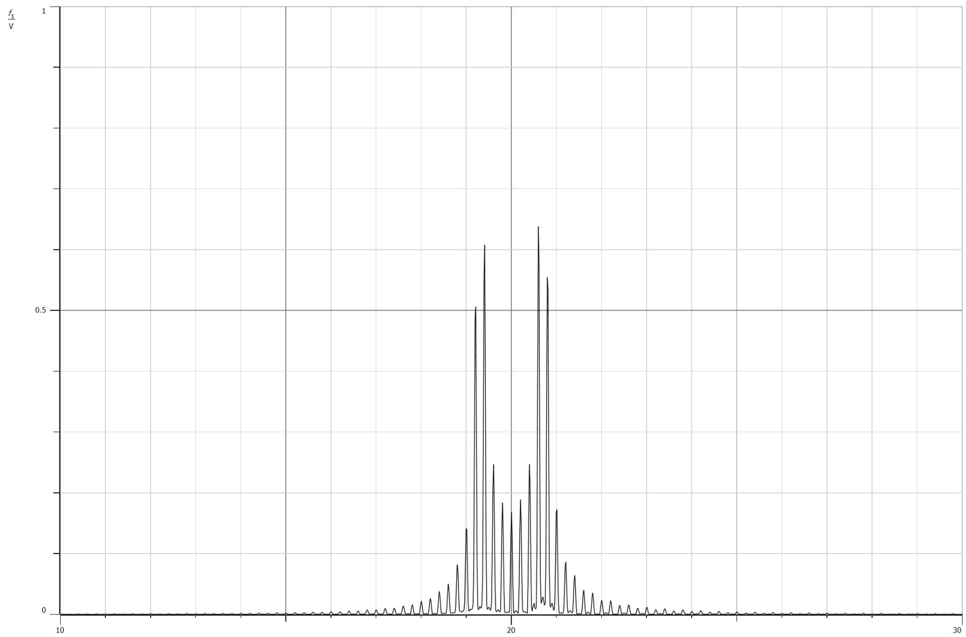

Figure 16:The frequency domain Modulated Signal with the squared message signal

Discussion

We investigated the effects of various message signal types on the spectrum of a modulated signal.

We discovered two sidebands at the carrier frequency ± the message frequency for sinusoidal communications. We observed the carrier frequency and its sidebands with square wave messages. Interestingly, since a square wave is only a mixture of sinusoidal impulses, its spectrum is quite similar to that of the sinusoidal signal.

Determining the zero carrier crossings

The spectral component at the carrier frequency is linked to the Bessel function term J0(β). Certain values of β makeJ0(β)=0. The first three values are:

$$\beta=2.4048$$

$$\beta=5.5201$$

$$\beta=8.6537$$

These zero points can be achieved by either varying the message amplitude (while keeping the frequency constant) or varying the frequency (while keeping the amplitude constant).

Varying the message amplitude while keeping the frequency constant

1. A message with a constant frequency of 100Hz. The first three values of the message amplitude that will result in zero carrier crossing filled in table 2 using this formula

$$\beta = \frac{Am * Kf}{fm}$$

Modulation index(β)	**2.4048**	**5.5201**	**8.6537**
Amplitude (V)	3.411	7.8299	12.2747

Table 2:Determining the zero crossing theoretically when the Frequency is 100Hz

As the modulating signal, a sinusoidal signal from the function generator with a frequency (fm) of 100Hz and a Vss of 0V was employed m(t). Next, the message signal's amplitude was progressively raised. Using Cassy Lab, the modulated signal's resulting spectrum was displayed as follows:

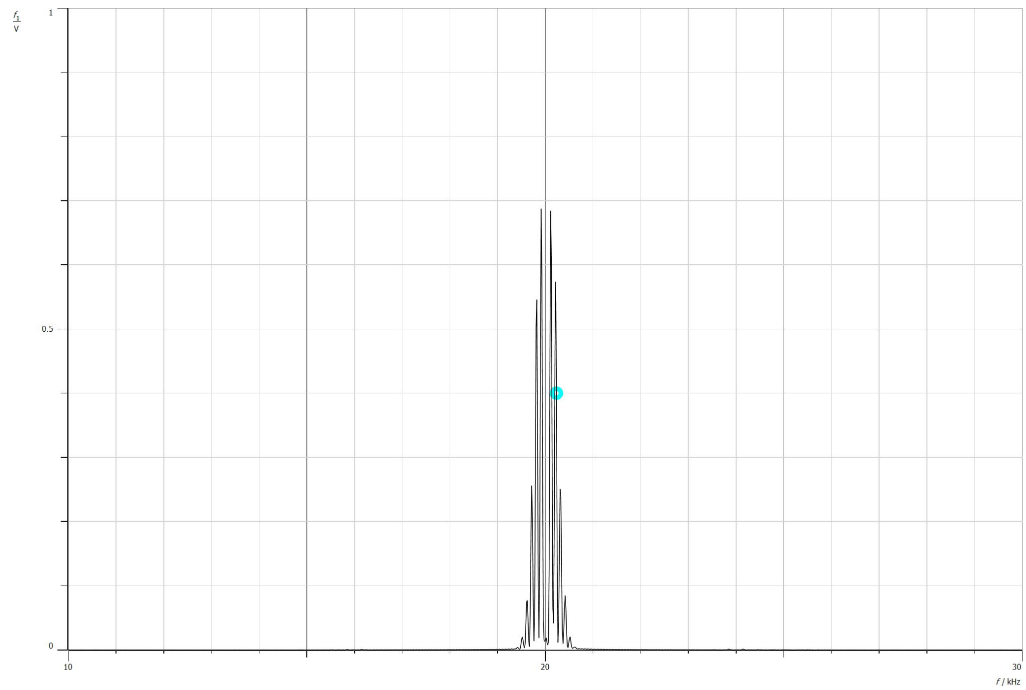

Figure 17:The modulated signal when Vss = 3.411 and fm= 100Hz (in frequency domain)

Varying the message frequency while keeping the amplitude constant.

a signal with a 10V constant amplitude. Using this formula:

$$fm = \frac{KfAm}{\beta}$$

the first three message frequency values that will cause a zero carrier crossover were computed and included into the following table.

Modulation index(β)	2.4048	5.5201	8.6537
Frequency (Hz)	293.16	127.715	81.468

Table 3: Determining the zero crossing theoretically while the Amplitude is constant=10v.

A sinusoidal signal with a (Vss) of 20V and a frequency (fm) of 1kHz from the function generator was used as the modulating signal m(t). The frequency of the message signal was then gradually reduced. The resulting modulated signal spectrum was shown using Cassy Lab as follows:

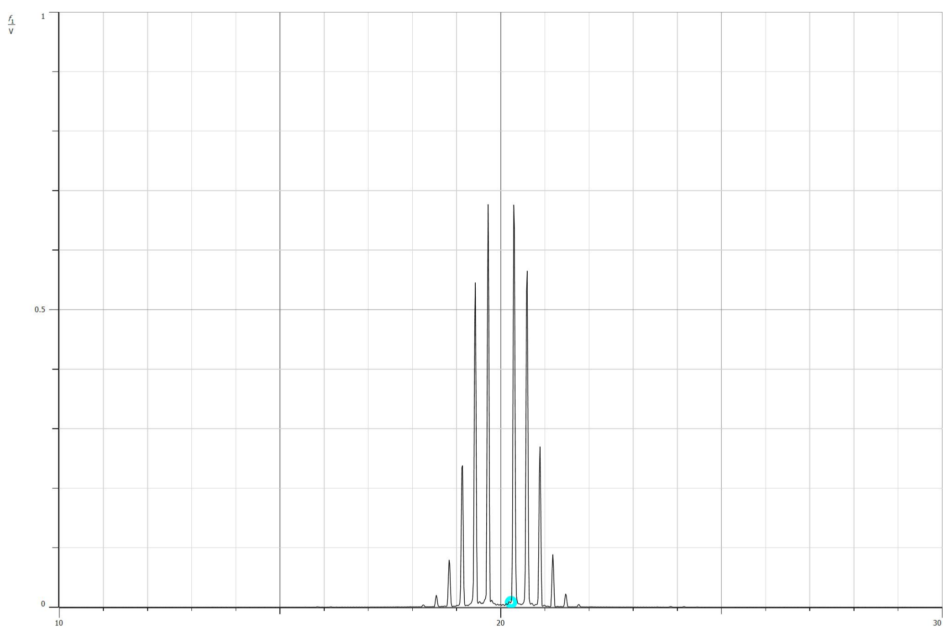

Figure 18:the carrier decay varying the frequency

When β = 2.4048 the theoretical value is 293.16 .

Discussion

In conclusion, the theoretical values calculated using the Bessel function formula are accurate and can predict zero carrier crossings. We can also conclude that varying either the message amplitude or the message frequency can result in zero carrier crossings, as expected.

Part II : FM Demodulation:

Section 1: Time domain FM demodulated signal

There was a use of a sinusoidal message signalm(t) with fm = 500 Hz and Vss = 10 V. Additionally, T2 was selected as the FM demodulator's loop filter. The figure below depicts the message and the demodulated signals.

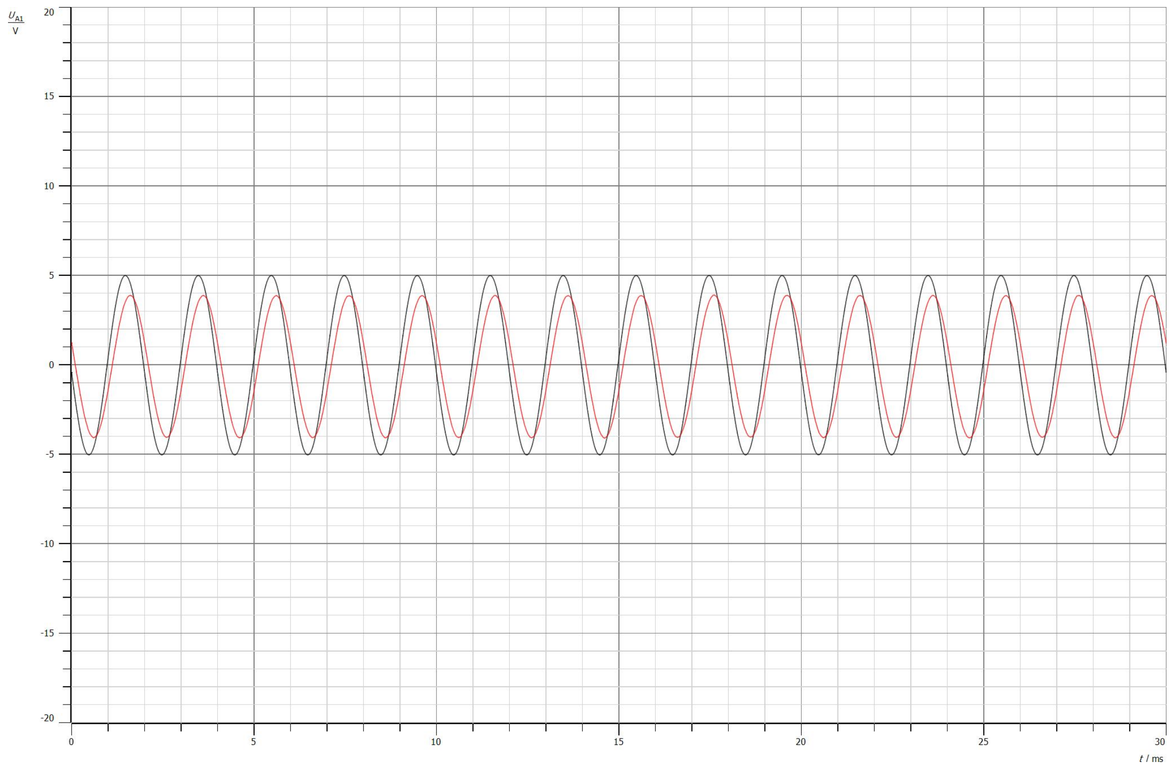

Figure 19:The modulating and the demodulated signal (in the time domain)

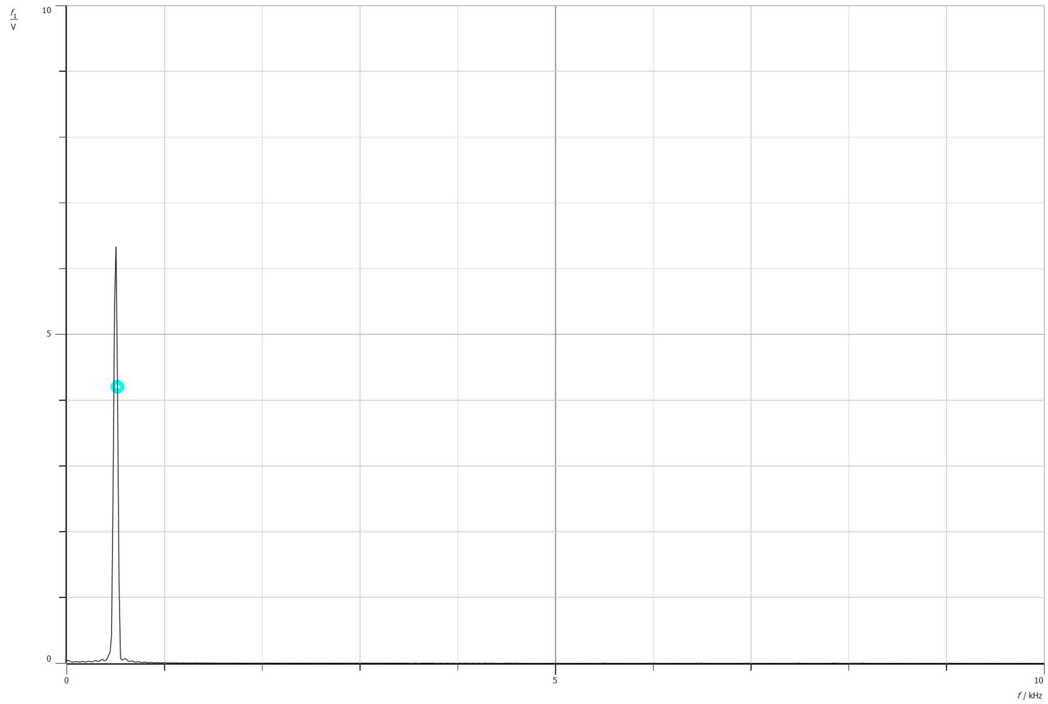

Figure 20:Demodulated signal in frequency domain

Discussion

Using a Phase-Locked Loop (PLL) demodulator, FM (frequency modulation) signals were demodulated. With very little distortion or noise, the demodulated signal nearly resembles the original message signal's form. This demonstrates how well the PLL demodulator functions with FM signals.

Section 2: Studying the effect of the receiver loop filter:

This experiment's receiver is designed to accommodate two receiver loop filters. Every filter is an example of a low pass filter with unique gain-bandwidth properties. This section's goal is to compare the message signal and the demodulated signal when the loop filters' gains are changed between the two loops. Additionally, the parts were put together as follows:

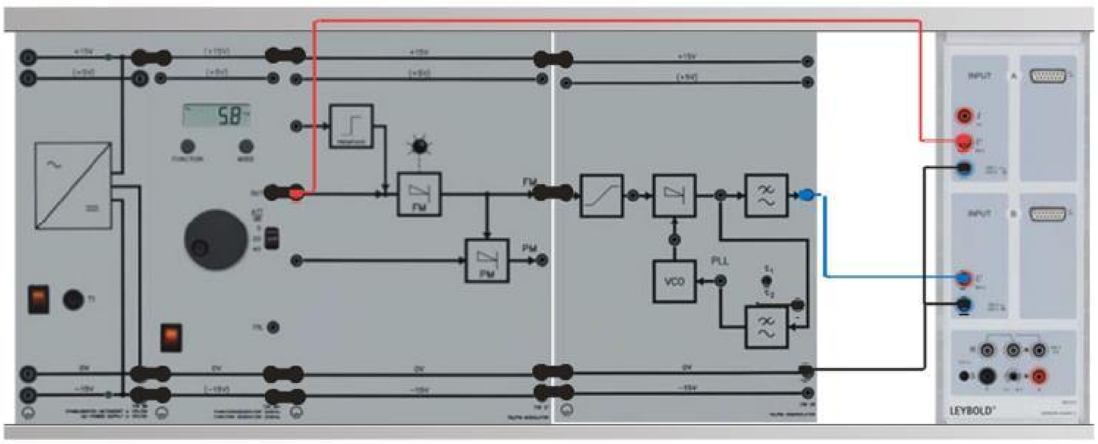

Figure 21:Setup of FM demodulation

A sinusoidal modulating signal m(t) with a VSS of 4V was used, starting with an fm of 500Hz

Message Frequency (Hz)	**500**	**1000**	**1500**	**2000**	**3000**
Ad using τ1 filter	2.53	2.40	2.50	2.56	2.46
Ad using τ2 filter	3.07	2.37	2.12	2.56	2.46

Table 4:Values of Ad/Am without pre-emphasis

Figure 22 below represents $\tau 1$, $\tau 2$ on chart without pre-emphasis :

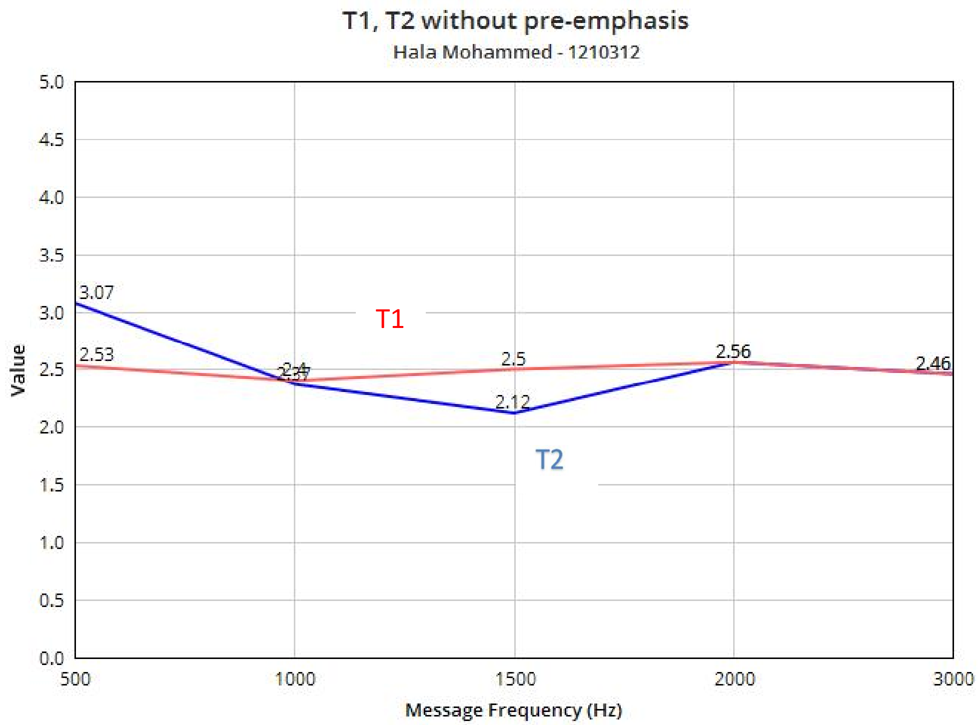

Figure 22:T1 & T2 filters without pre-emphasis graph

Studying Loop filters τ1 and τ2 with pre-emphasis

The method of pre-emphasis involves boosting the incoming signal if it falls within a certain frequency range (often high frequency). The parts were put together as shown in figure 23.

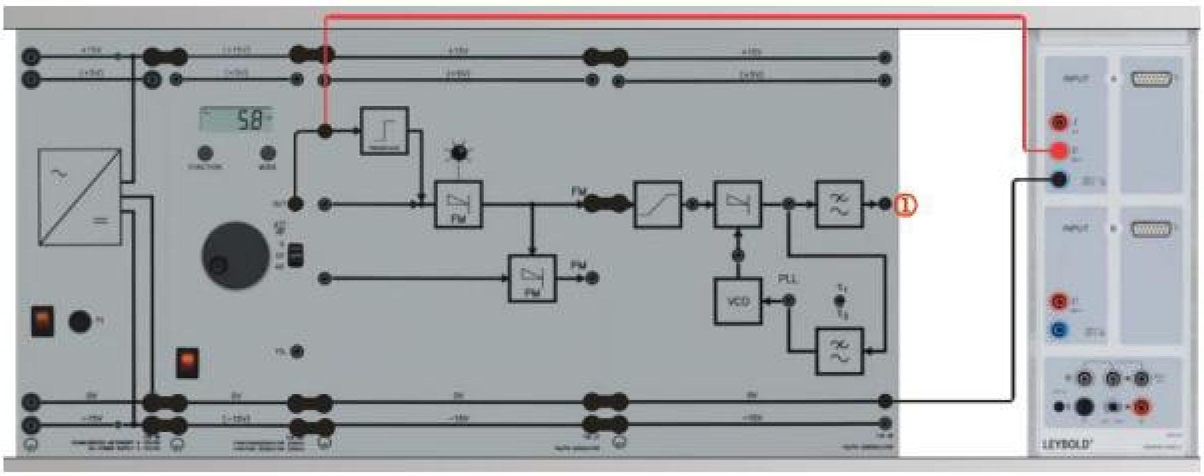

Figure 23:Pre-emphasis setup

A sinusoidal modulating signal m(t) with Vss= 4V and starting with fm = 500Hz.

Message Frequency (Hz)	500	1000	1500	2000	3000
Ad using τ1 filter	2.62	9.00	7.53	6.05	3.77
Ad using τ2 filter	2.61	10.44	5.13	5.66	4.60

Table 5:Values of Ad/Am with pre-emphasis

Figure 24 below represents $\tau 1$, $\tau 2$ on chart:

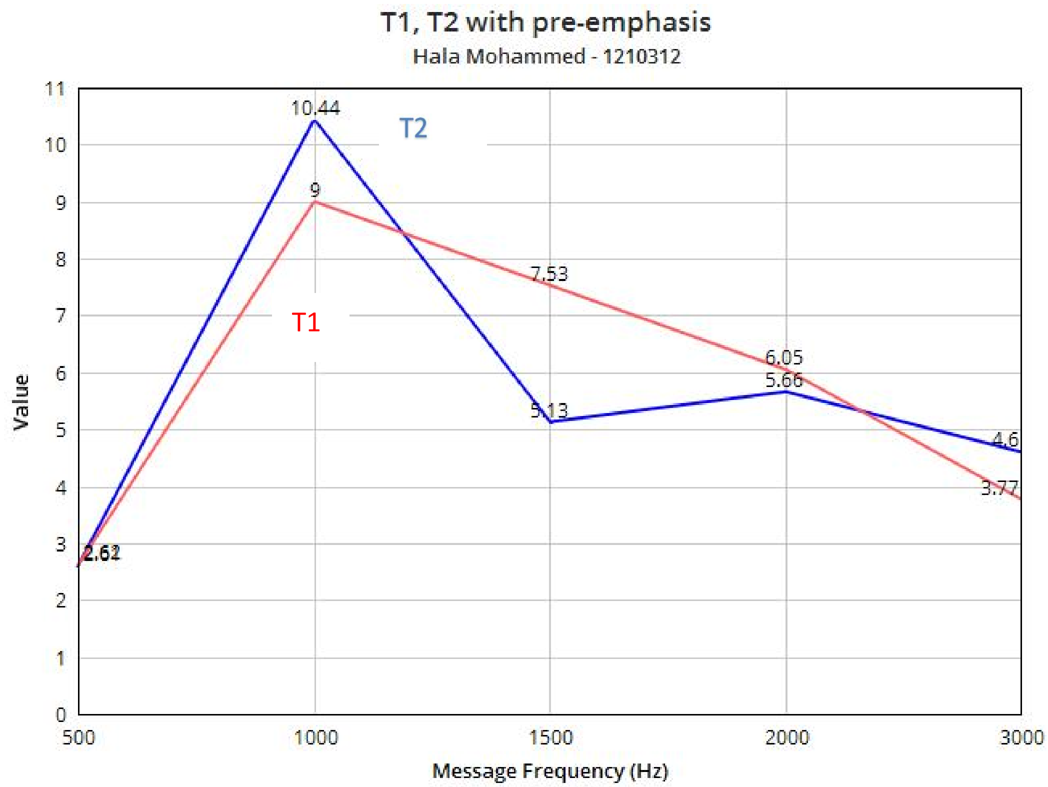

Figure 24:T1 & T2 filters with pre-emphasis graph

Then figure 25 represent $\tau 1$ with pre-emphasis and $\tau 1$ without pre-emphasis:

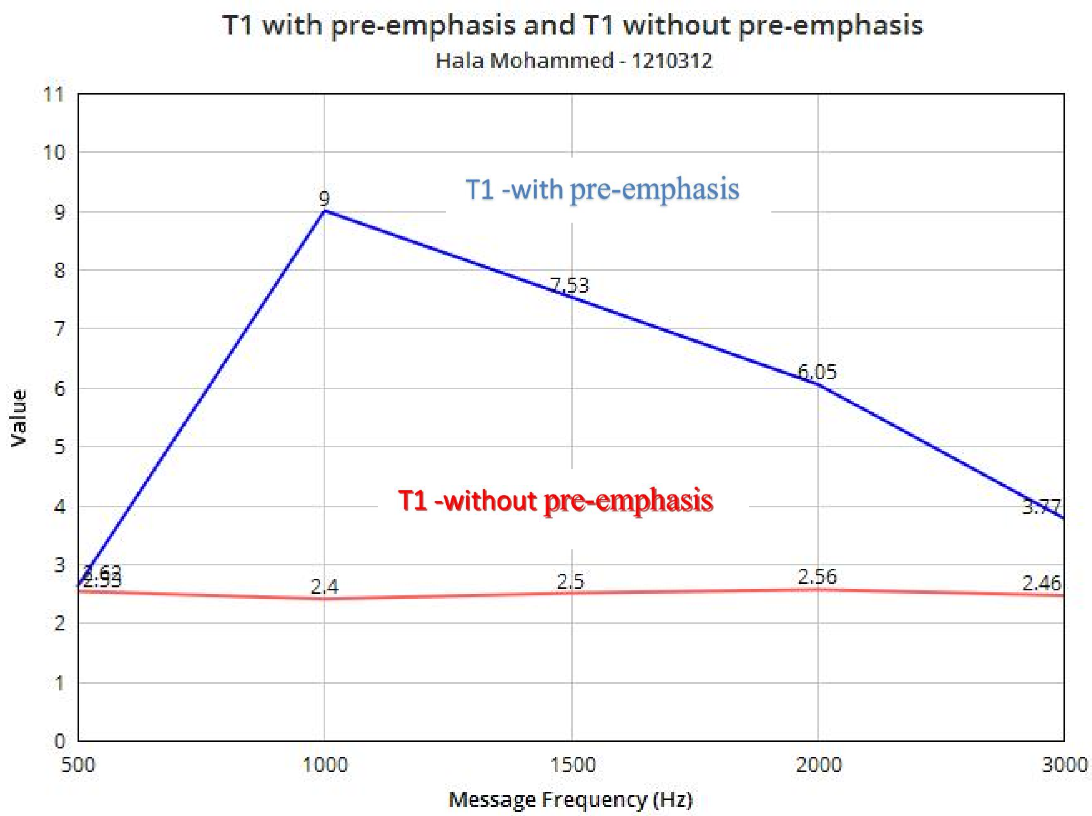

Figure 25:T1with pre-emphasis & T1 without pre-emphasis graph

Figure 26 below represent $\tau 2$ with pre-emphasis and $\tau 2$ without pre-emphasis:

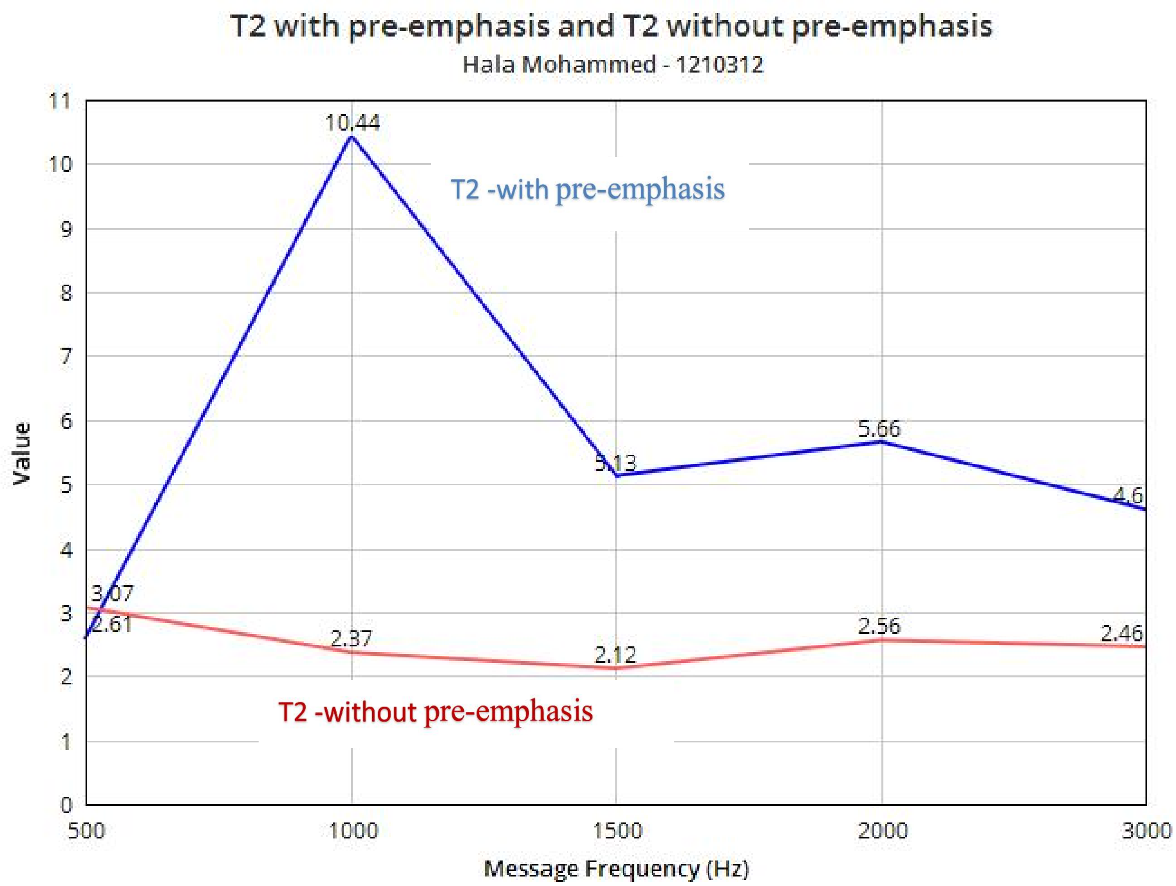

Figure 26:T2 with pre-emphasis with T2 without pre-emphasis

Discussion

The figures show that as the frequency increases, the T1 filter's amplification decreases. In contrast, the T2 filter's gain increases with frequency until it reaches the cutoff point, after which it starts to decrease[T1 & T2 filters without pre-emphasis graph].

Filters with pre-emphasis [T1 & T2 filters with pre-emphasis graph], both T1 and T2, strengthen the signal more than those without it because they enhance the signal at higher frequencies, improving reception and signal quality. The graphs demonstrate that the T2 filter gains up to the cutoff point, then starts to decline. Pre-emphasis allows both filters to boost the signal at higher frequencies, enhancing the signal's quality and reception.

Conclusion

In this experiment, a message signal and a carrier signal were combined using frequency modulation, and the sensitivity constant was determined. The study covered the method by which phase-locked loops demodulate signals. Research on the impacts and uses of both amplitude and frequency modulation revealed that pre-emphasis is crucial for improving frequency modulation demodulation, especially at higher message frequencies. In-depth facts about frequency modulation were learned, including how it works, how it differs from amplitude modulation, and how frequency modulation signals are demodulated. This experiment successfully achieved its goals of increasing knowledge of basic communication concepts like frequency modulation and demodulation, carrier zero crossing, and modulator sensitivity, as well as understanding basic signal concepts like low-pass filter characteristics and the function of pre-emphasis.

References

[1] https://en.wikipedia.org/wiki/Angle_modulation

[accessed on 24/7/2024 at 7:42pm]

[2] https://www.geeksforgeeks.org/angle-modulation/

[accessed on 24/7/2024 at 8:06pm]

[3] https://www.ee-diary.com/2023/04/zero-crossing-fm-detector.html

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[4] https://electronicspost.com/pll-fm-demodulator-phase-locked-loop-fm-demodulator/

[accessed on 24/7/2024 at 8:26pm]

[5] https://en.wikipedia.org/wiki/Envelope_detector

[accessed on 24/7/2024 at 8:32pm]

[6]https://www.daenotes.com/electronics/communication-system/pre-emphasis-and-de-emphasis

[accessed on 24/7/2024 at 8:42pm]