FACULTY OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENEE 4113, Communication Laboratory

Experiment. 1 Report

Normal Amplitude Modulation and Demodulation

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Abstract

This experiment tests the idea of Normal Amplitude Modulation (AM) and demodulation procedures. The primary objective is to learn the modulation process through varying the message and carrier waves and compare two demodulation techniques: coherent and envelope detection.the experiment compares time and frequency domain representations of AM signals with different modulation indices ($\mu < 1$, $\mu = 1$, and $\mu > 1$). The results demonstrate the effect of the modulation index on the spectrum and waveform of the signal. Additionally, the study examines the impact of modifying the message signal frequency and amplitude on the modulated waveform. Demodulation is assessed based on comparison between the recovered signal and the original message, with determination of each method's strengths and weaknesses. The findings confirm theoretical models of amplitude modulation and provide insight into practical implementation within communication systems.

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Theory

Amplitude Modulation or AM

Amplitude Modulation (AM) is a fundamental modulation technique where the amplitude of a high-frequency carrier wave is varied in proportion to the instantaneous amplitude of the message signal. This modulation technique was one of the first developed for radio transmission, making it essential for early radio communication systems.

AM is used in a variety of fields including radio broadcasting, aviation communication, and even in older television transmission systems. The basic idea is that the carrier wave remains at a constant frequency while its amplitude is changed to encode the message signal, which could be audio, video, or data.

AM was initially developed by pioneers such as Reginald Fessenden, who transmitted the first voice transmission over long distances in the early 1900s. Over time, the technique evolved into more efficient forms like Single-Sideband Modulation (SSB) to optimize bandwidth usage. [1]

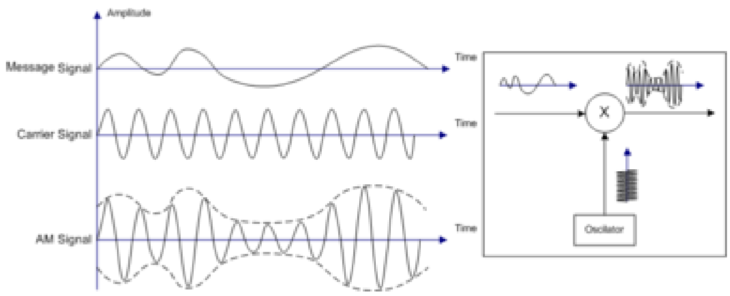

Figure 1 AM modulation [2]

Mathematical Representation of AM

Mathematically, an AM signal is represented as:

- $s(t)=A_c[1+\mu \cos(2\pi f_m t)] \cos(2\pi f_c t)$ → (Equation 1)

where:

- S(t): The modulated signal.
- m(t): The modulating signal (message signal).
- Ac: The amplitude of the carrier signal.
- fc: The frequency of the carrier signal.
- Ka: Constant that represents the modulation sensitivity.|
- The modulation index $\mu = K_a A_m$

The modulation index determines how deeply the message signal modulates the carrier. A value of $\mu = 1$ represents 100% modulation, which is ideal. Values less than 1 lead to under-modulation, and values greater than 1 cause over-modulation, which can distort the message signal.[4]

Frequency Domain Representation

In the frequency domain, an AM signal can be broken down into its components:

1- Carrier frequency: The frequency at which the carrier wave oscillates. It remains constant in AM.
2- Upper Sideband (USB): This is the frequency component generated by adding the message signal frequency to the carrier frequency, located at at fc + fm where fm is the highest frequency of the message signal.
3- Lower Sideband (LSB): This is the frequency component generated by subtracting the message signal frequency from the carrier frequency, located at fc – fm .

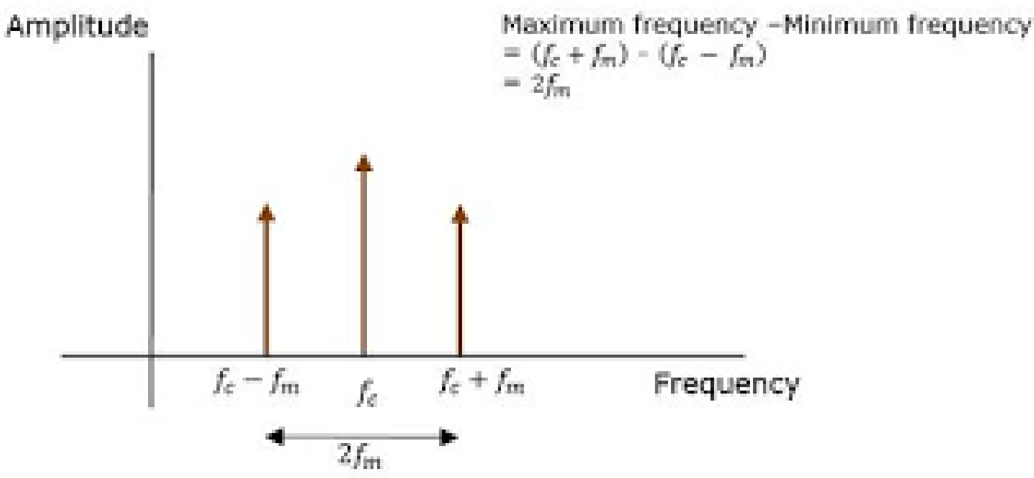

Figure 2 AM modulation in frequency domain

The bandwidth of an AM signal is:

❖ *B*= 2fm

Where fm is the highest frequency in the message signal. This results in a total bandwidth requirement that is twice the highest message frequency. This is a significant limitation of AM, especially when compared to more modern modulation techniques that use less bandwidth.

AM Demodulation Techniques

AM demodulation is the process of recovering the message signal from the modulated carrier. The two primary methods for AM demodulation are **coherent detection** and **envelope detection**.

Coherent (Synchronous) Detection

In coherent detection, the received AM signal is multiplied by a locally generated carrier signal that is synchronized with the transmitted carrier. This process effectively recovers the modulating signal by removing the carrier and high-frequency components, leaving only the message signal.

The demodulated signal is passed through a low-pass filter to remove high-frequency components, ensuring that only the original message signal remains. For effective coherent detection, the local oscillator must maintain a precise phase match with the carrier of the received signal.[4]

Envelope Detection

Envelope detection is a simpler technique, often used in AM radio receivers. It involves the following steps:

1. The AM signal is rectified using a diode.
2. The rectified signal is then filtered with a capacitor to remove the carrier frequency.
3. The result is the message signal, which is recovered by tracking the amplitude variations of the original signal.

This technique is less complex and less expensive than coherent detection but works best when the received signal is strong and the modulation index is not excessively high.

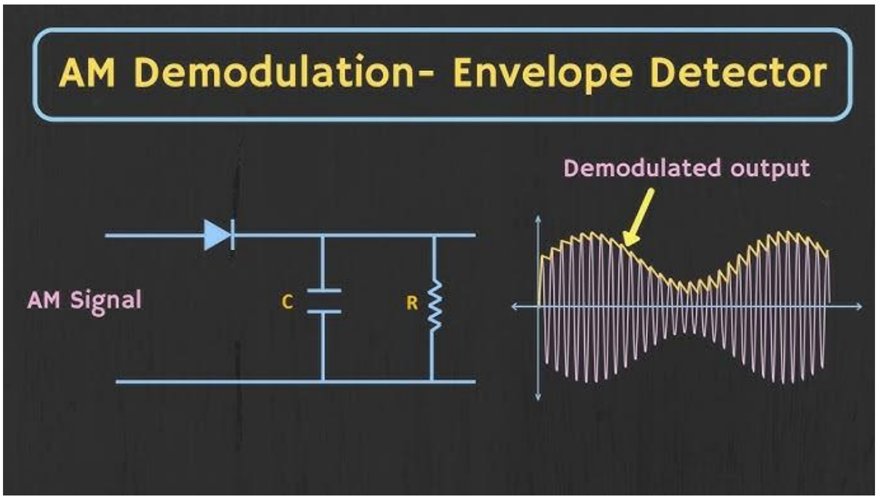

Figure 3 envelope [5]

Effects of Varying Parameters

Effect of Modulation Index

The modulation index determines how much the carrier amplitude is varied by the message signal. If the modulation index is too low (under-modulation), the transmitted signal may not carry enough information. If the modulation index is too high (over-modulation), the carrier's amplitude will be clipped, leading to signal distortion and loss of information.

- Under-modulation (m < 1): The transmitted signal is weak, and the information content is low.
- 100% Modulation (m = 1): The carrier's amplitude is fully modulated, and the transmitted signal carries the most efficient representation of the message.
- Over-modulation (m > 1): The signal becomes distorted, with the carrier's amplitude being clipped, which leads to a significant loss of information.

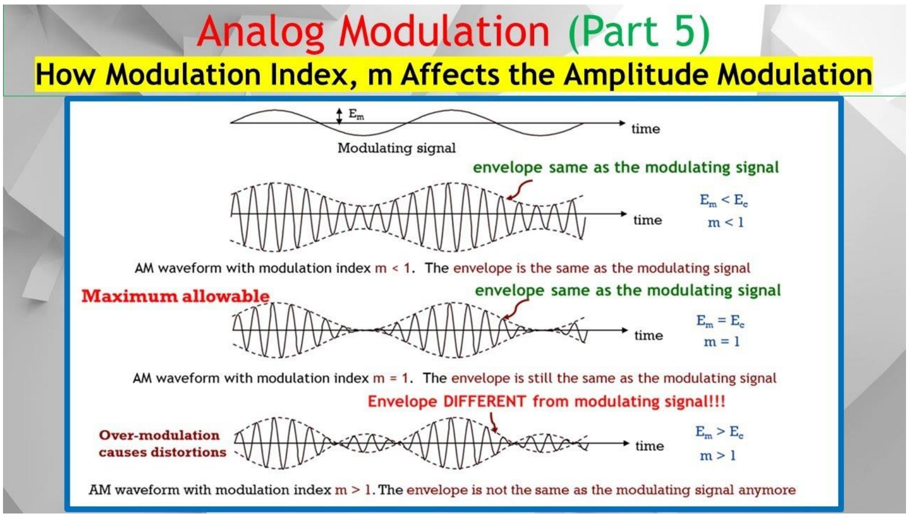

Figure 4 effect of modulation index [6]

Effect of Message Frequency and Amplitude

Increasing the frequency of the message signal shifts the sidebands outward, resulting in an increase in bandwidth. This is particularly important in applications where spectrum efficiency is a concern.

Increasing the amplitude of the message signal increases the modulation index, which increases the power required for transmission. This can lead to higher efficiency but also the risk of over-modulation and distortion.[7]

Procedure and data analysis

Part One: Normal Amplitude Modulation

1. Message Signal Generation (Time Domain)

- ❖ A sinusoidal message signal was generated using a function generator.
- ❖ The parameters set were:
    - Peak-to-peak amplitude of the message signal (Vss) is 4 volts.
    - Message signal frequency (fm) is 2 kHz.
- ❖ The signal was plotted in the time domain using Cassy Lab for five cycles.
- ❖ Observations: The generated signal was a continuous sinusoidal waveform.

→Plots of message signal in both time domain and frequency domain

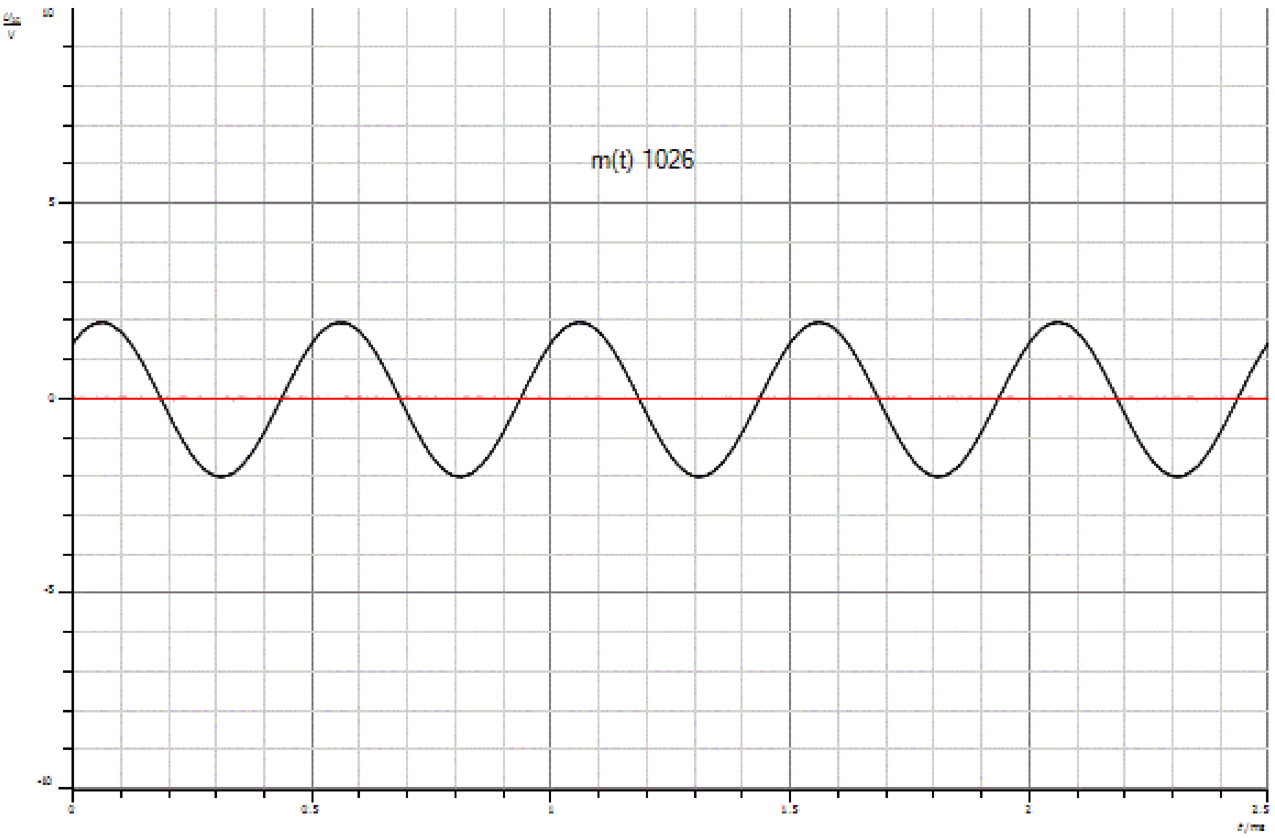

Figure 5: Message signal m(t) in Time Domain

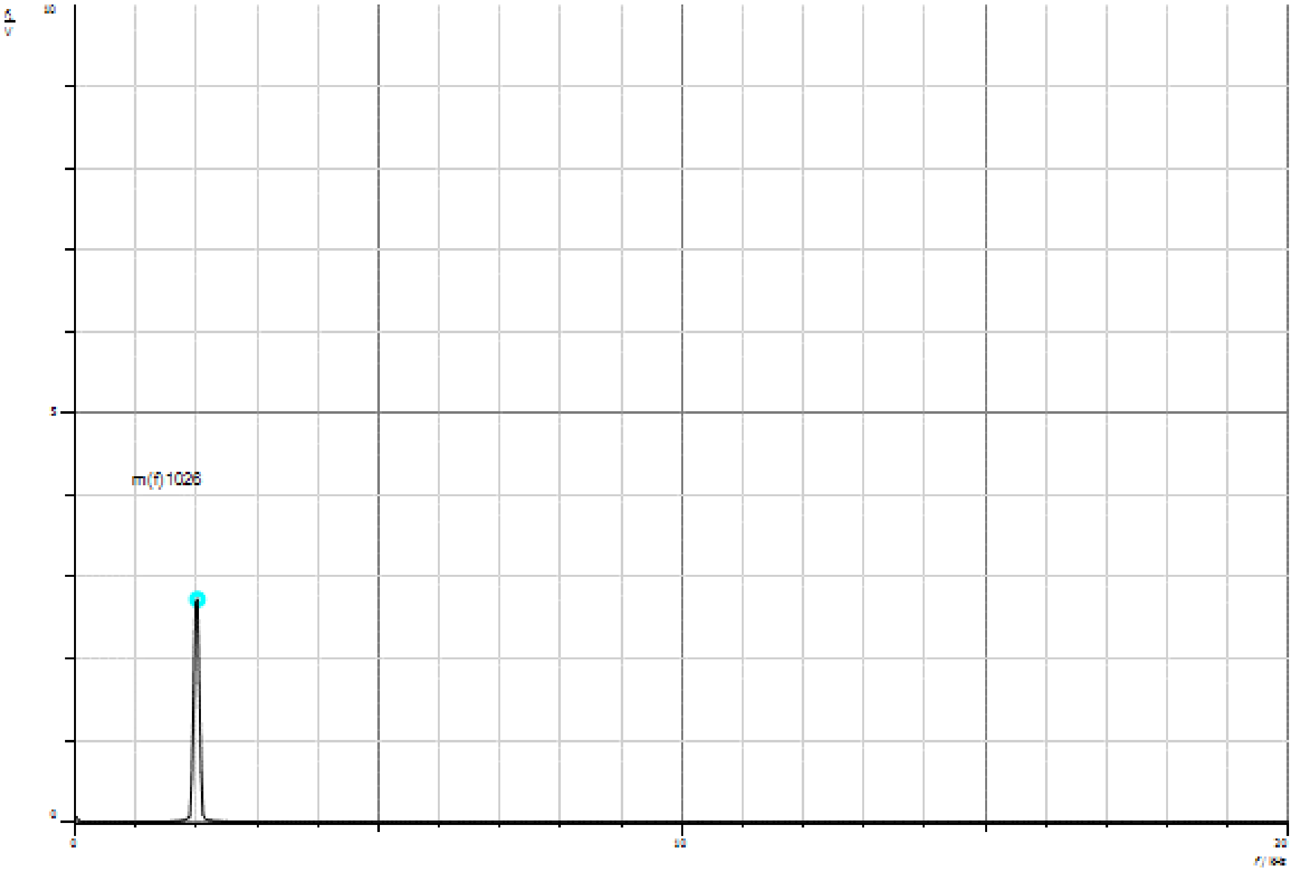

Figure 6: Message signal m(t) in frequency Domain

Discussion: The generated signal appeared as a smooth sinusoidal waveform, confirming proper function generator settings.

2. Carrier Signal Generation (Time Domain)

- ❖ A pulse frequency oscillator was used to generate a carrier signal at 160 kHz.
- ❖ The signal was passed through a frequency divider to output a 20 kHz sinusoidal wave.
- ❖ The carrier signal was recorded and analyzed in both time and frequency domains.
    - Carrier amplitude (Ac) = 2.88V
    - Carrier frequency (Fc) = 20 kHz

→Plots of carrier signal in both time and frequency domain

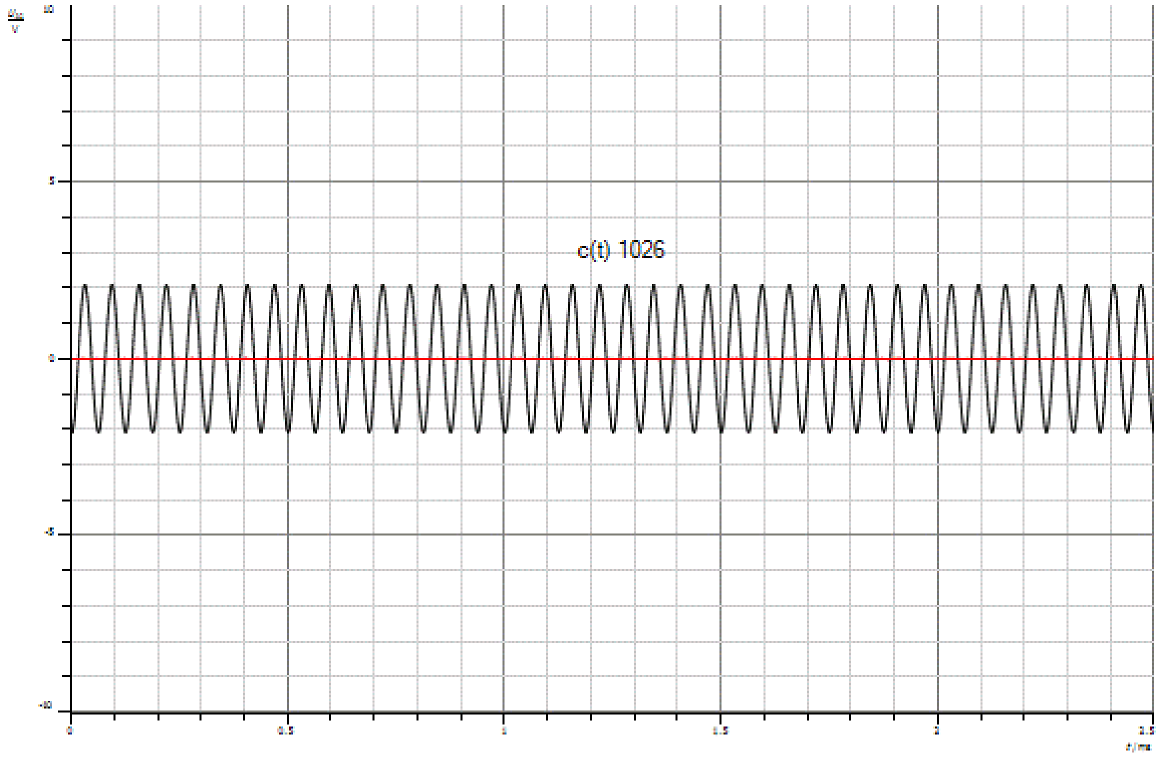

Figure 7: Carrier signal c(t) in time domain

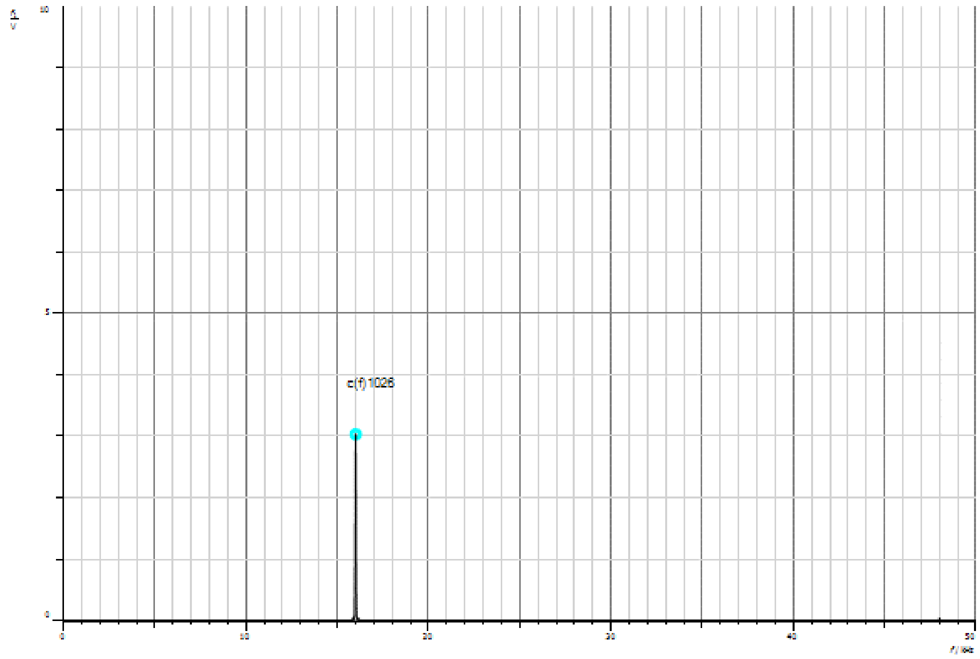

Figure 8: Carrier signal in frequency domain

Discussion: The carrier signal was successfully generated, maintaining a stable frequency and amplitude.

→ Plots of carrier signal in both time and frequency domain if we use square wave.

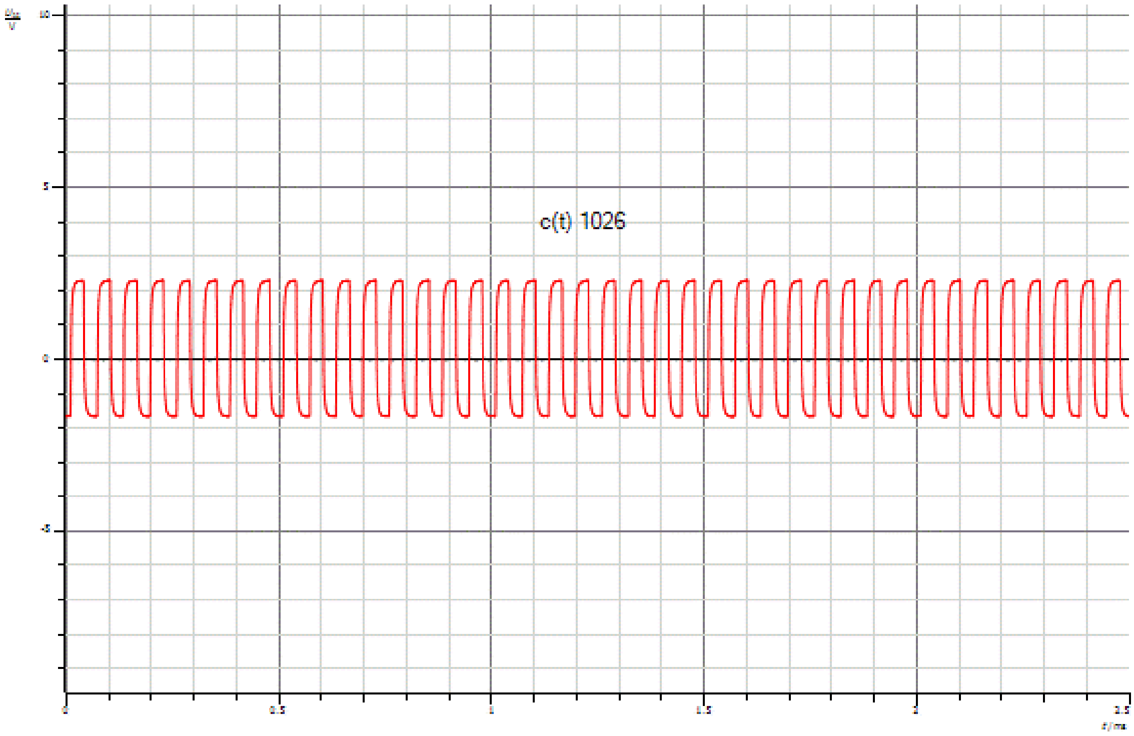

Figure 9: Carrier signal c(t) in time domain

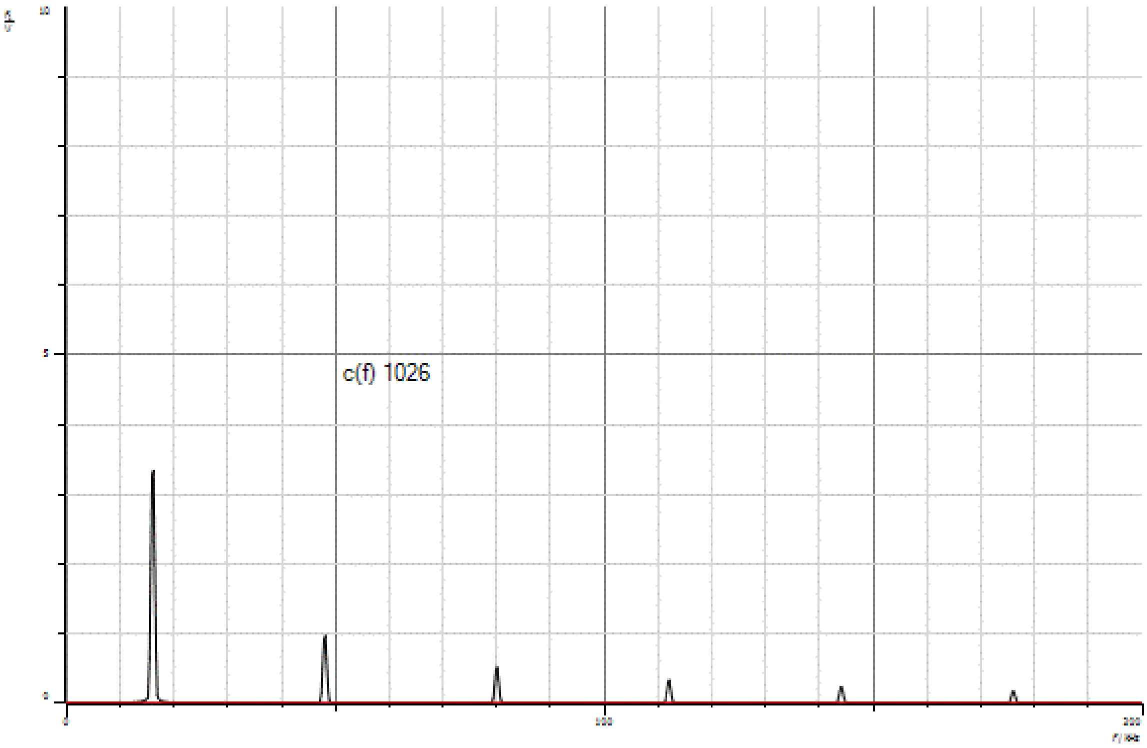

Figure 10: Carrier signal in frequency domain

3. Modulation Process (Time and Frequency Domains)

- The modulated signal s(t) is generated as follow:

$$s(t) = (1 + k\, m(t))\, c(t) = c(t) + k\, m(t) c(t)$$

- The modulated signal was recorded and plotted in both domains.
- The spectrum of the modulated signal displayed three frequency components:
    - Carrier frequency (Fc = 16 kHz)
    - Upper sideband (Fc + fm = 18 kHz)
    - Lower sideband (Fc - fm = 14 kHz)
- Bandwidth (BW) of the AM signal was measured as 4 kHz (2fm).

Experiment set-up was done according to the specifications, the function generator:

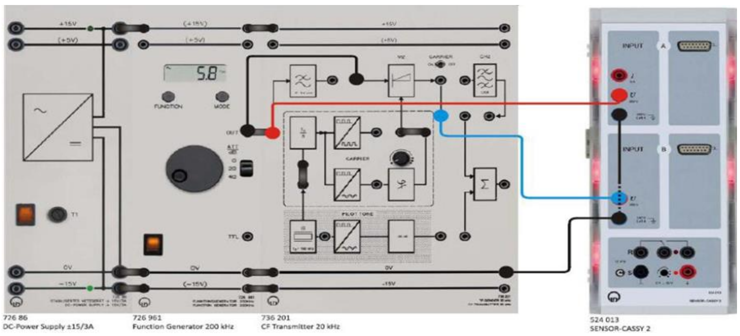

Figure 11: Connection of AM Modulation

→Plots of modulated signal s(t) in both time and frequency domain

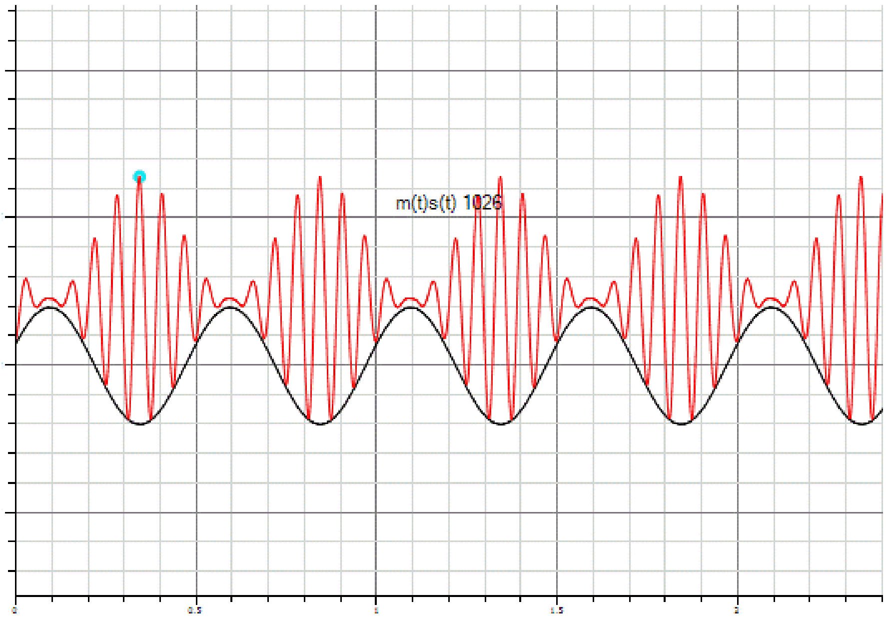

Figure 12: Modulated signal s(t) in time domain

The message signal is the envelope of the modulated signal, as shown by the plot of s(t) in time domain. The amplitude of the modulated signal reaches its maximum value at the same time that the message signal peaks. The amplitude of the modulated signal also reaches its minimum value when the message signal is at its lowest point. The message signal acts as the envelope of the modulated signal by regulating the variations in amplitude of the modulated signal.

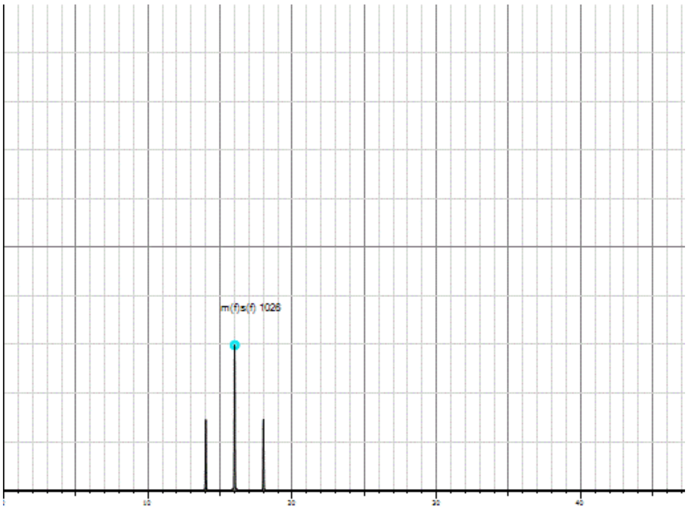

Figure 13: Modulated signal in frequency domain

Discussion: The presence of sidebands confirmed successful modulation, and the calculated bandwidth matched theoretical expectations.

→Three impulses can be seen in the frequency domain in the spectrum plot of the modulated signal s(t). These impulses are located at three different frequencies: the carrier frequency (fc = 16KHz), the carrier and message frequencies added together (fc+fm = 18KHz), and the difference between the carrier and message frequencies (fc-fm = 14KHz).

- BW = 4KHz = 2fm
- Power of USP $= \left(\frac{Ac*M}{2}\right)^2$
- Power of LSP $= \left(\frac{Ac*M}{2}\right)^2$
- Power of carrier $= \frac{Ac^2}{2}$
- Power efficiency $= \frac{P_{sides}}{P_{total}} = \frac{\mu^2}{\mu^2+2}$
- Maximum power efficiency when μ = 1, efficiency = 33%

From the plot:

Amax ≅ 4.17 , Amin ≅ 0.01

- By equation 2, μ ≅ 1, hence its critical modulation, and the modulation sensitivity Ka $= \frac{1}{2} = 0.5$, since μ $= Am\ Ka$.

4. Effect of Changing Message Frequency and Amplitude

A. *Changing Frequency:*

- At fm = 1 kHz and 3 kHz, no significant effect on modulation was observed.
- The amplitude values remained consistent.

Discussion: The frequency shift affected sideband placement but did not alter modulation depth.

→Modulated signal when Fm = 1KHz

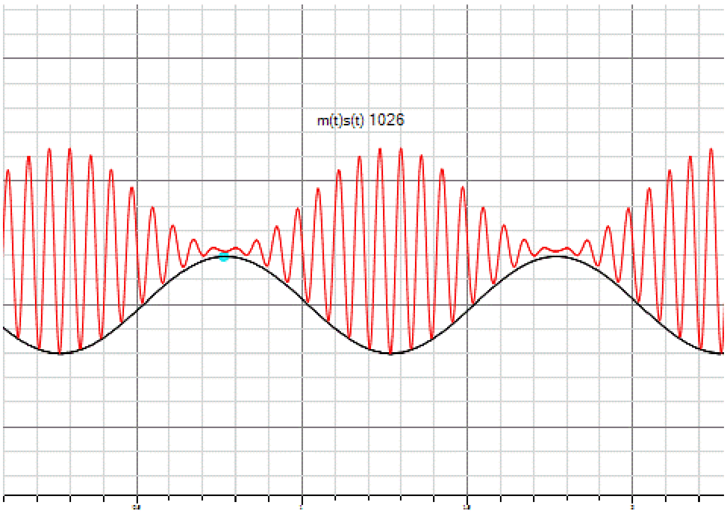

Figure 14: Modulated signal in time domain when fm = 1KHz

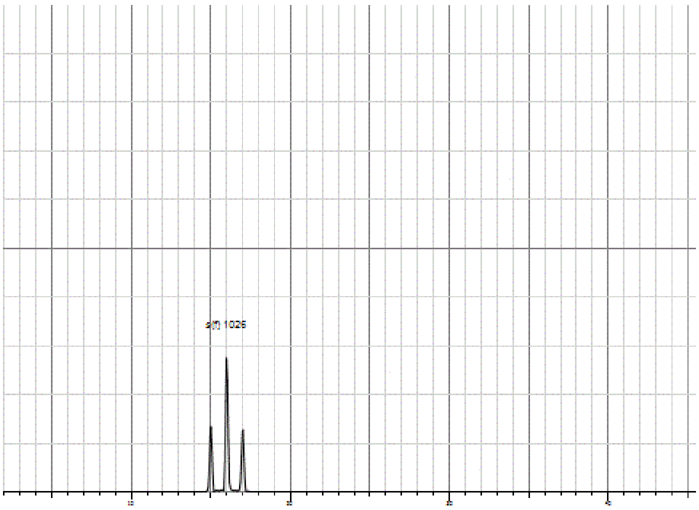

Figure 15: Modulated signal in frequency domain when fm = 1khz

From the plot:

Amax ≅ 4.15 , Amin ≅ 1.95

- By equation , μ $\cong 1$, hence its critical modulation, and the modulation sensitivity Ka $= \frac{1}{2} = 0.5$, since μ $= Am\ Ka$.

→Modulated signal when fm = 3KHz

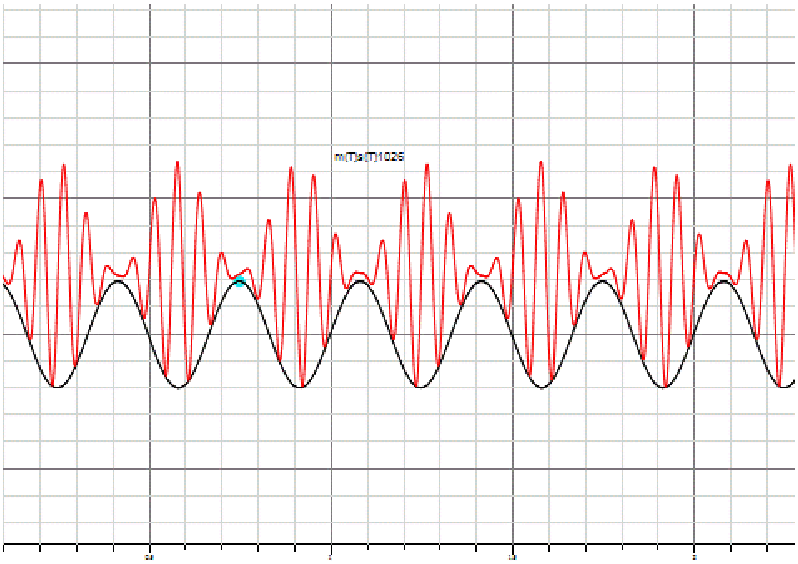

Figure 16: Modulated signal in time domain when fm = 3KHz

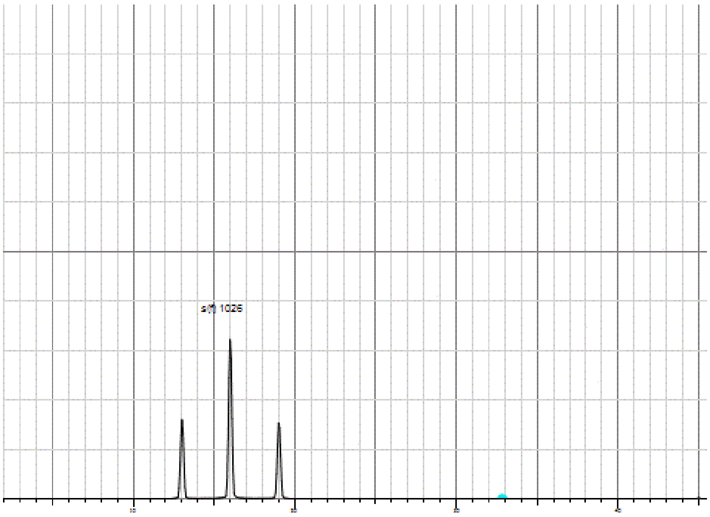

Figure 17: Modulated signal in frequency domain when fm = 3khz

From the plot:

Amax $\cong$ 3.97 , Amin $\cong$ 1.95

- By equation 2, μ $\cong 1$, hence its critical modulation, and the modulation sensitivity Ka $= \frac{1}{2} = 0.5$, since μ $= Am\ Ka$.

Discussion: The frequency shift affected sideband placement but did not alter modulation depth.

B. *Changing Amplitude:*

- Now keep fm = 2khz, and change Vss to 2V and 6V

→Modulated signal when Vss = 2V

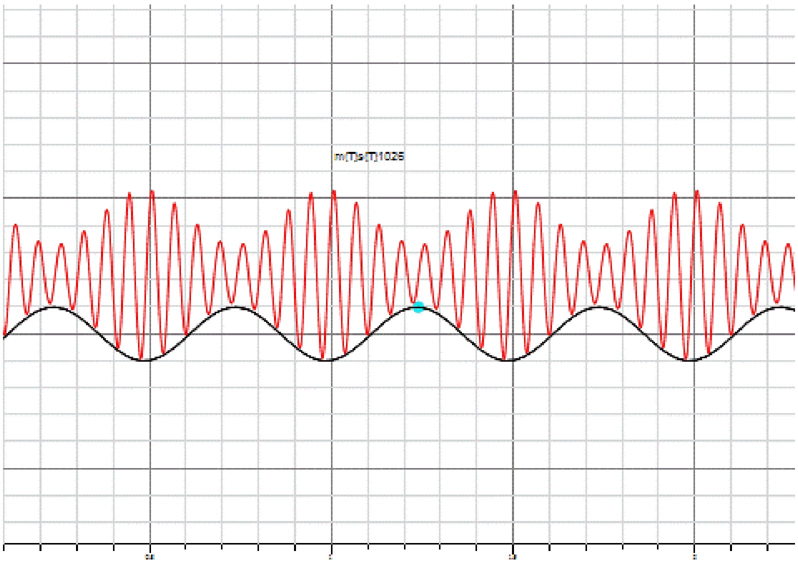

Figure 18: Modulated signal in time domain when Vss =2V

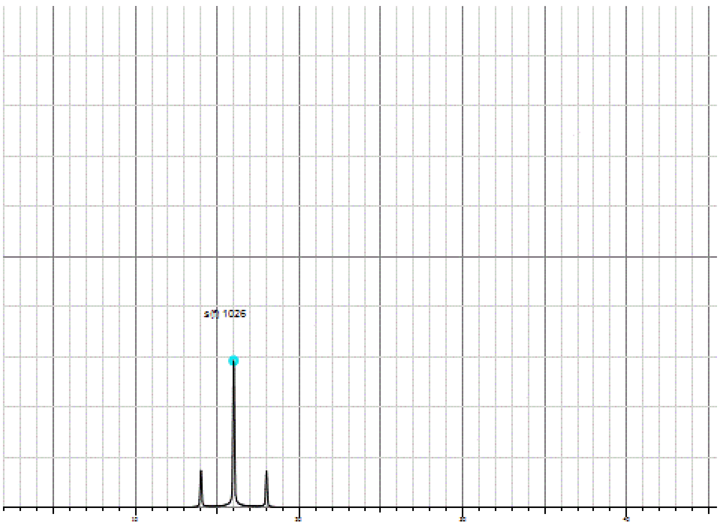

Figure 19: Modulated signal in frequency domain when Vss=2V

At Vss = 2V (Under Modulation):

Amax ≅ 3.09 , Amin ≅ 0.99

- $\mu < 1$.

→Modulated signal when Vss = 6V

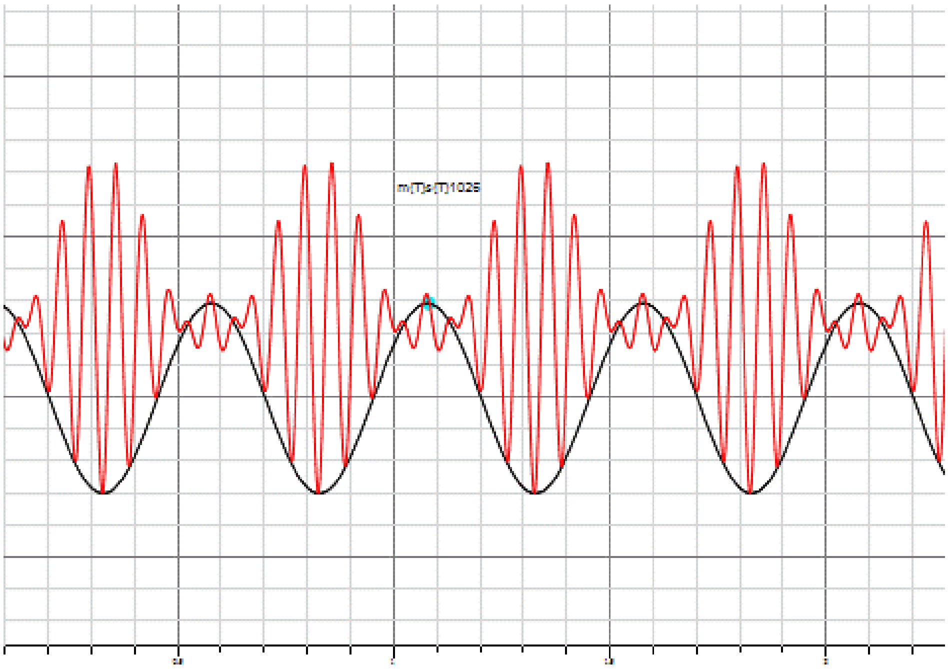

Figure 20: Modulated signal in time domain when Vss =6V

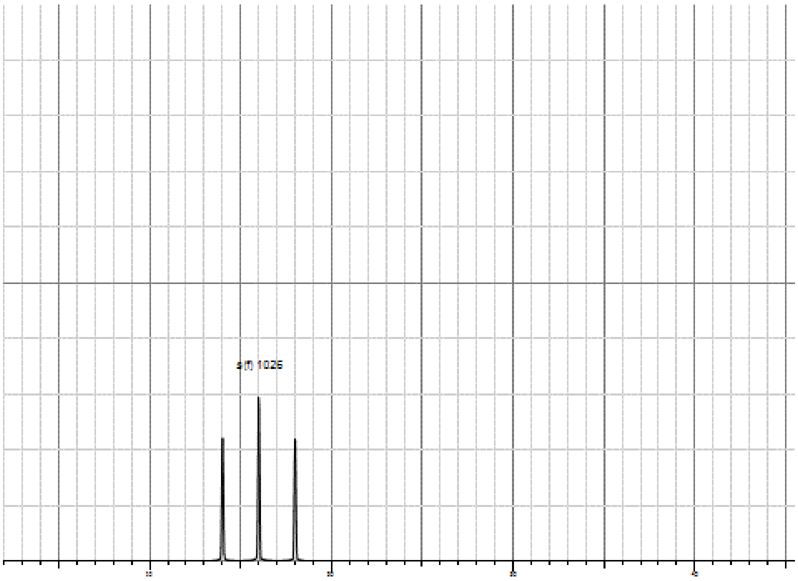

Figure 21: Modulated signal in frequency domain when Vss=6V

At Vss = 6V (Over Modulation):

Amax ≅ 5.06 , Amin ≅ 2.93

- $\mu > 1$.
- **Discussion:** The modulation index directly impacted waveform shape, with over-modulation leading to signal distortion.

5. Effect of Low Pass Filtering

- The message signal was passed through a Low Pass Filter (LPF) before modulation.
- When the cut-off frequency was above message frequency:
  - A slight phase shift and delay were observed.
- When the cut-off frequency was set to 7 kHz:
  - The LPF attenuated the signal outside its range.
  - Distortion was observed in the modulated signal due to phase shifts.

Discussion: The LPF impacted the signal, introducing phase shifts that could affect demodulation accuracy.

→When cut off frequency is larger than the maximum frequency of the message signal

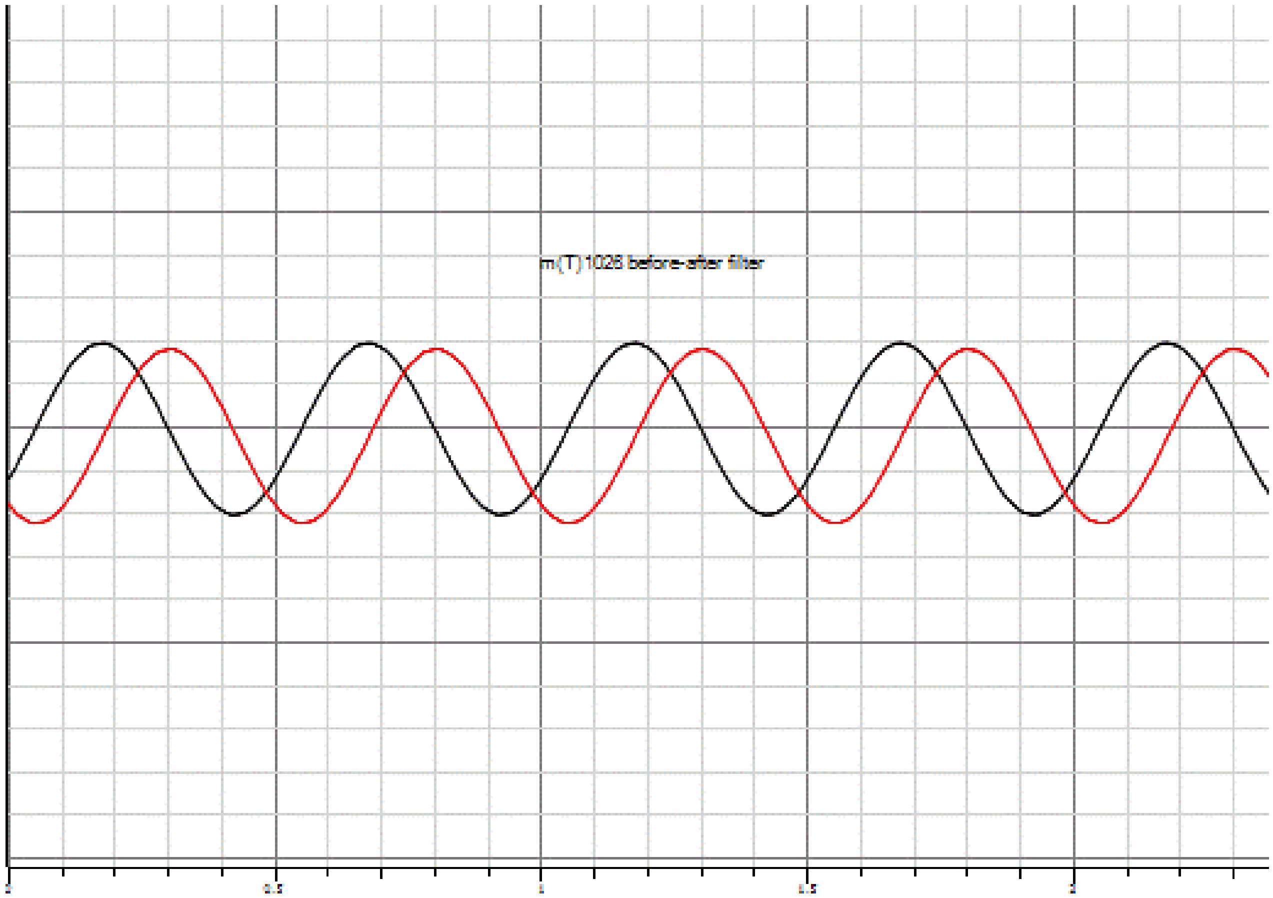

Figure 22: Message signal before and after the LPF

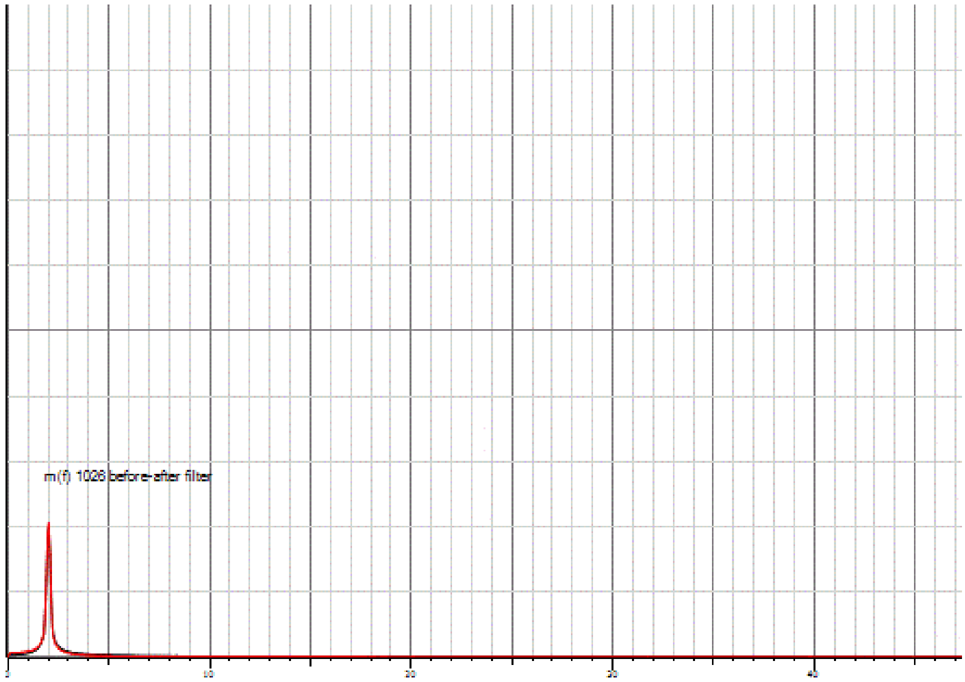

Figure 23: Message signal before and after the LPF

- We noticed that passing the signal through the LPF may result in a slight delay and a phase shift in the output signal.

→The cut off frequency of the Low Pass Filter is 7KHz

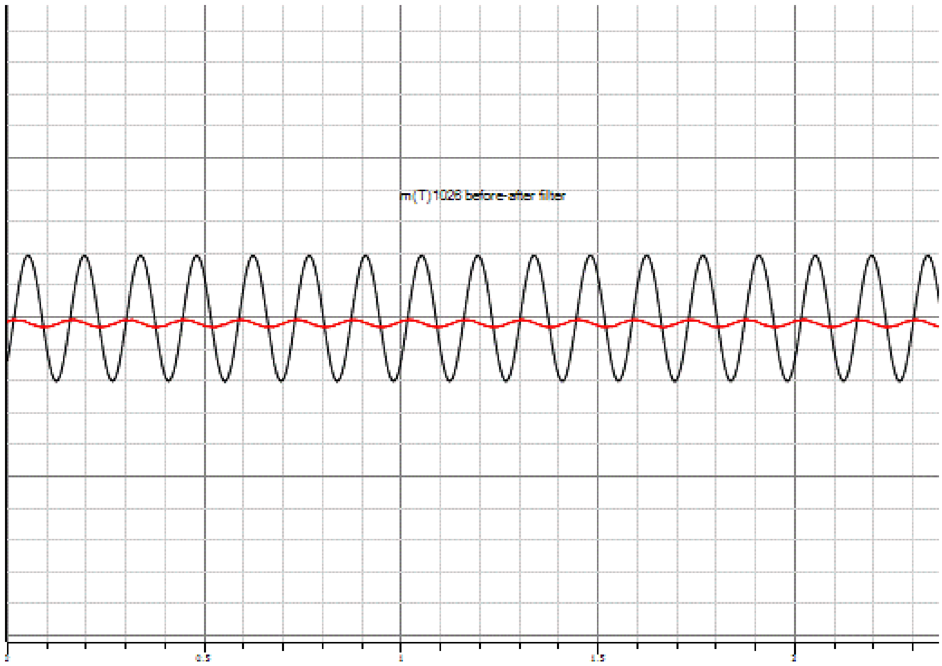

Figure 24: Message signal before and after the LPF, when cut off frequency is 7khz

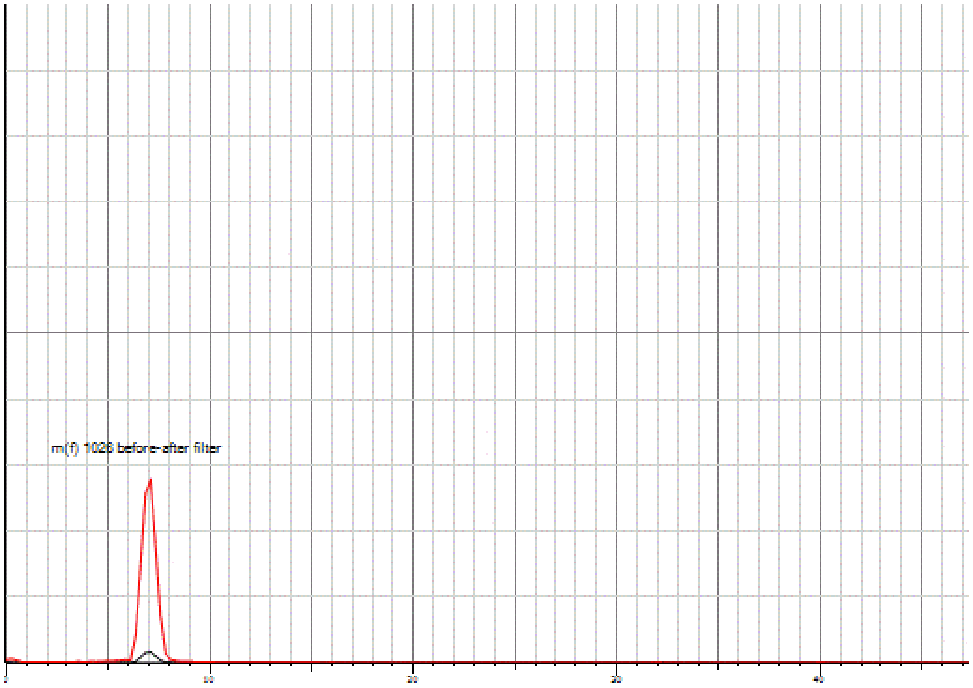

Figure 25: Message signal before and after the LPF, when cut off frequency is 7khz

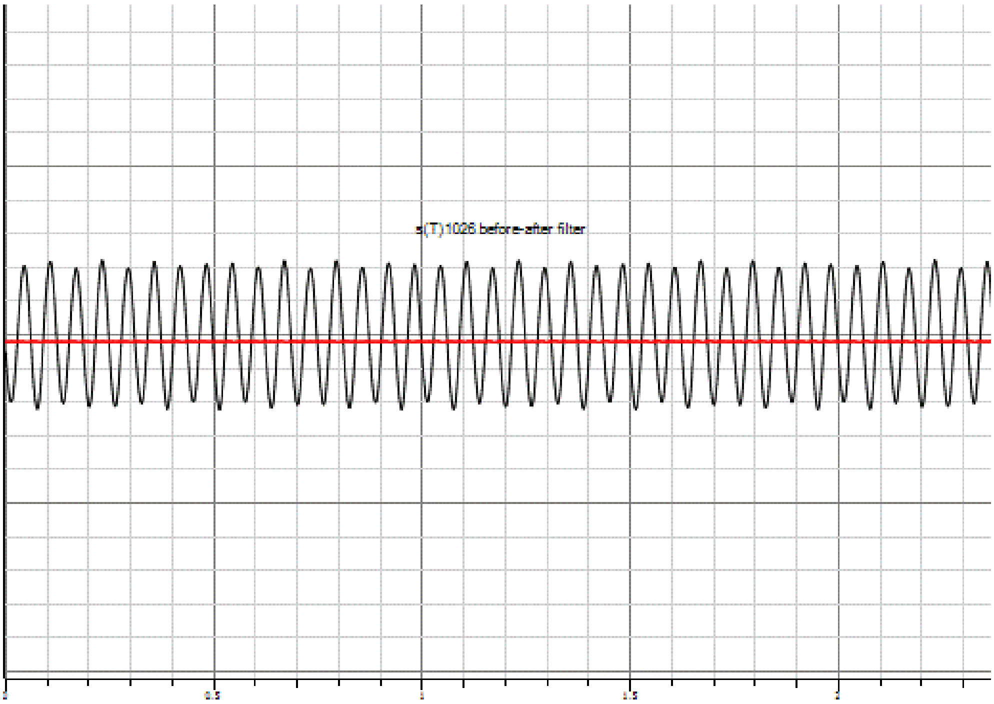

Figure 26: modulated signal before and after the LPF, when cut off frequency is 7khz

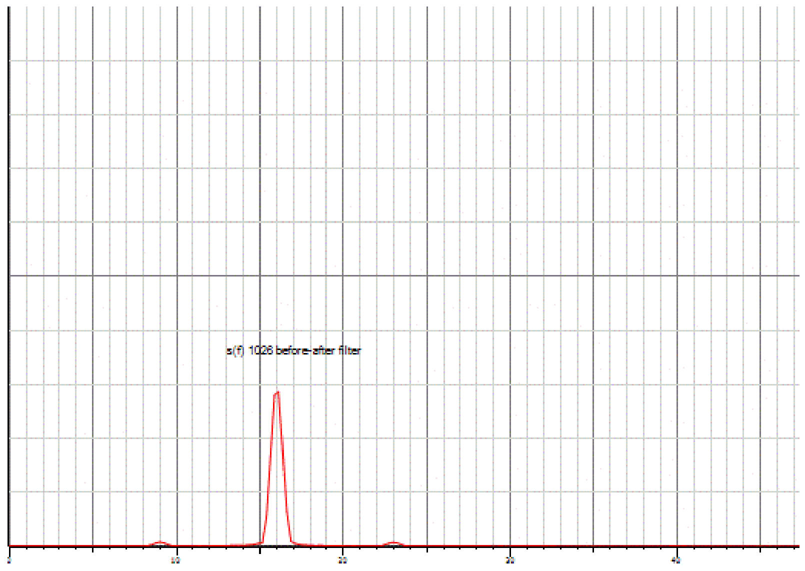

Figure 27: modulated signal before and after the LPF, when cut off frequency is 7khz

Part Two: Amplitude Demodulation

Coherent Demodulation

- In normal AM (amplitude modulation) coherent demodulation is achieved by multiplying the modulated signal with a local oscillator signal that is in phase with the carrier signal, and The output signal was observed before and after filtering.

- The phase controller (φ) was adjusted to the minimum value of 0° by moving it to the left.

- Results:
  - The demodulated signal matched the original message with minor distortions.
  - The filter helped recover a clean message signal by removing high-frequency components.

Discussion: Coherent demodulation worked effectively but required precise synchronization with the carrier.

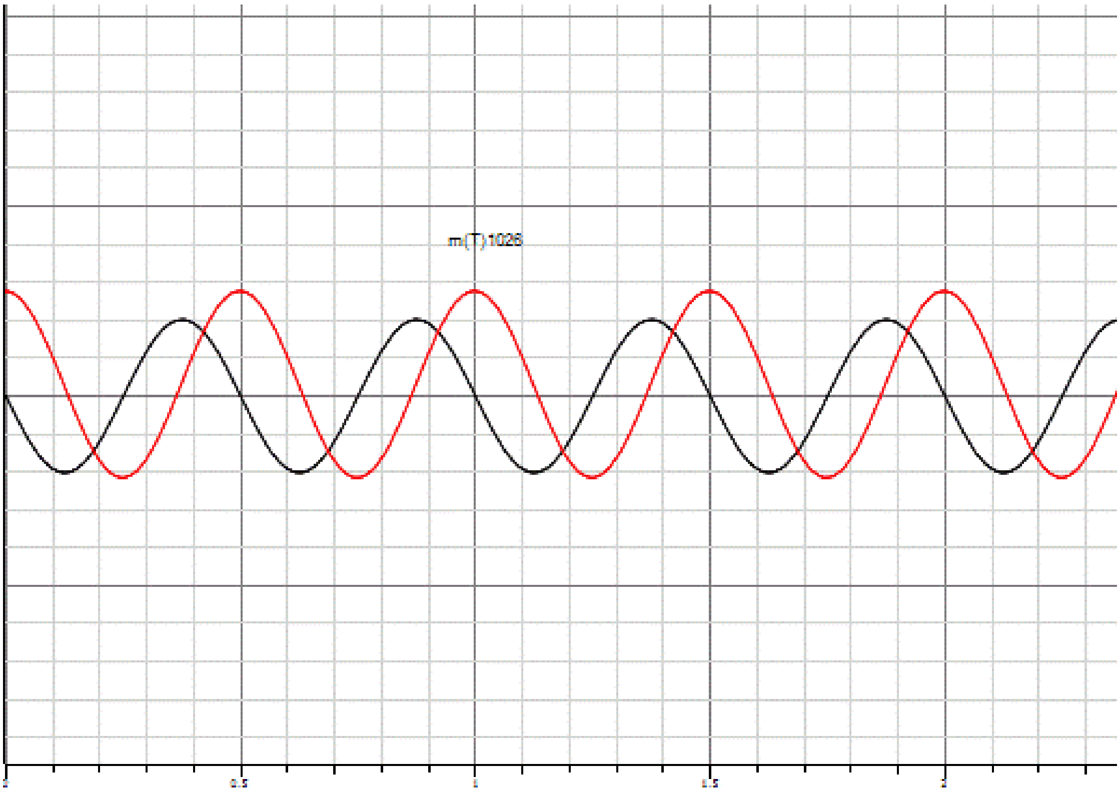

Figure 28: Coherent Demodulation output in time domain

Figure 29: Coherent Demodulation output in frequency domain

→signal Before and after filter

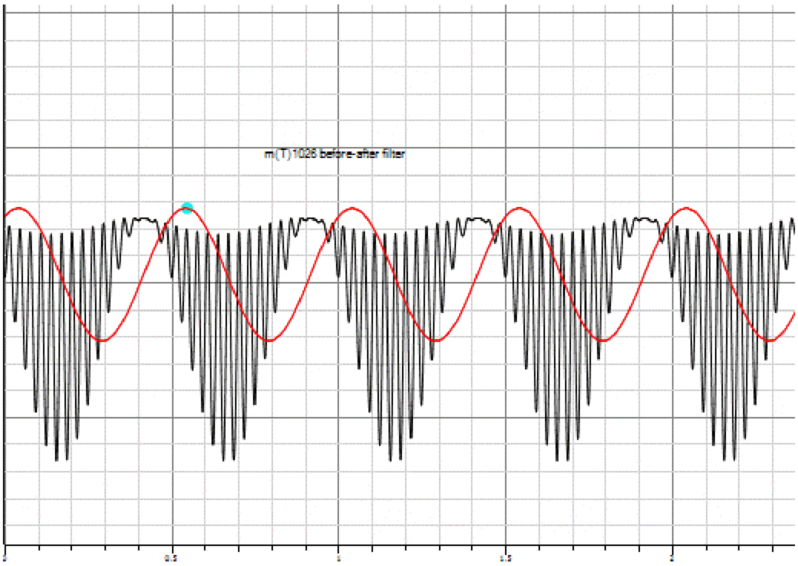

Figure 30: Coherent Demodulation output before filter in time domain

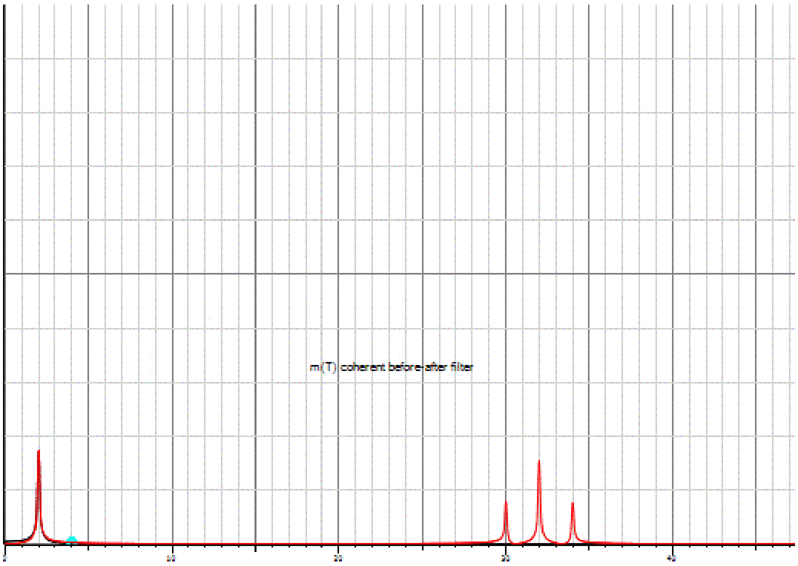

Figure 31: Coherent Demodulation output before filter in frequency domain

Non-Coherent Demodulation

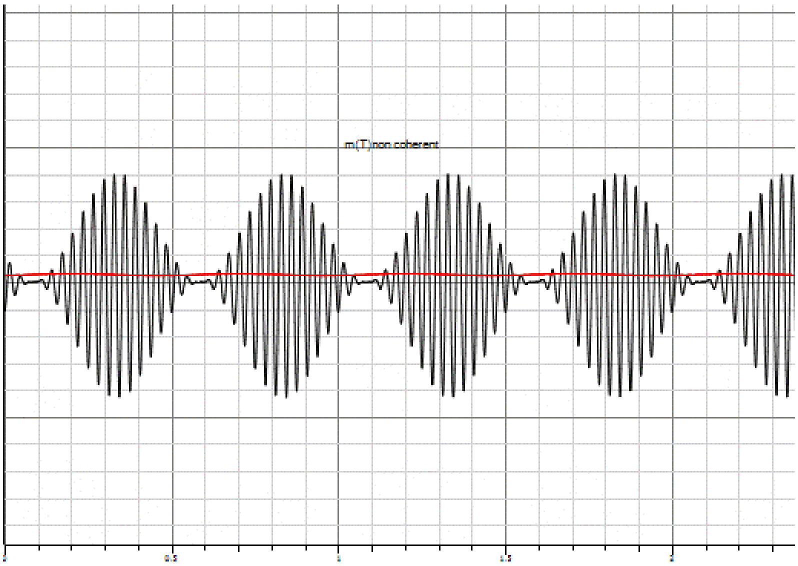

Figure 32:Non-Coherent Demodulation output in time domain

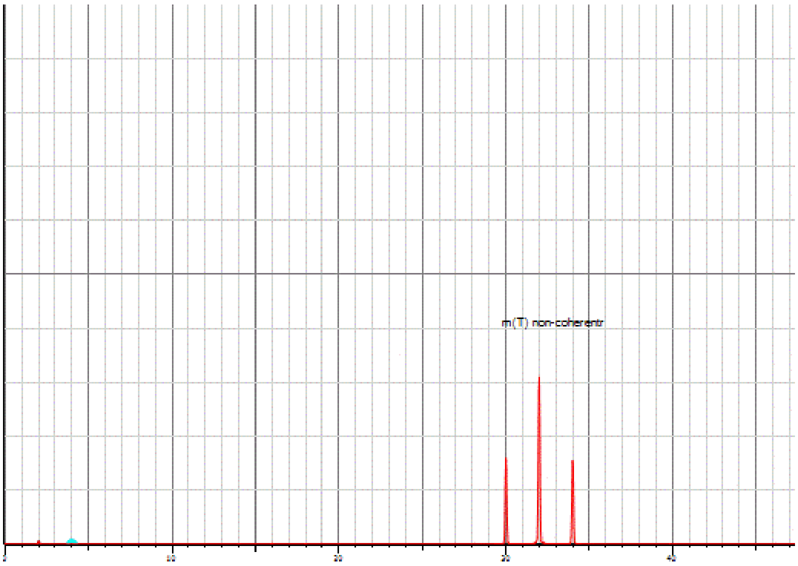

Figure 33: Non-Coherent Demodulation output in frequency domain

- The phase of the carrier was altered before demodulation.
- As the phase difference reached 90°, the demodulated signal disappeared.

Discussion: Non-coherent demodulation suffered from signal loss when phase synchronization was lost, making it less reliable than coherent detection.

Conclusion

This experiment gave us a hands-on understanding of how Amplitude Modulation (AM) and its demodulation techniques work in real-world applications. By changing the modulation index (whether it was less than, equal to, or greater than 1), we could see clear effects on the signal's shape and frequency content. These observations aligned well with what theory predicts, reinforcing our understanding of AM behavior.

When it came to demodulation, we explored two methods: coherent (synchronous) detection and envelope detection. The coherent method proved to be more precise but required careful synchronization with the carrier signal, making it more complex. On the other hand, envelope detection was simpler but could distort the recovered message, especially in cases of overmodulation. We also saw how low-pass filtering helped clean up the signal but introduced slight delays and phase shifts, which could impact accuracy.

A few challenges came up during the experiment, such as slight phase mismatches in coherent detection and some distortion due to filtering. Improving synchronization and using more advanced filtering techniques could help refine the results in future experiments.

Overall, this experiment was a great way to bridge the gap between theory and practice. It highlighted how important it is to carefully control the modulation index and choose the right demodulation technique depending on the situation. These concepts are fundamental to real-world communication systems, from radio broadcasting to modern digital transmissions.

References

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[2]

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