Analysis and Simulation of Multi-Signal Amplitude Modulation over a Single Channel in MATLAB

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Abstract—**This project investigates the transmission of multiple signals over a single channel using amplitude modulation in MATLAB. The simulation explores the encoding, transmission, reception, and demodulation of five distinct signals through a shared communication medium. Using carrier signals, amplitude modulation, and demodulation techniques, the project aims to accurately recover the original signals and evaluate the fidelity of the transmission. The study also assesses error metrics to quantify the accuracy of signal retrieval.**

Keywords—Amplitude Modulation, MATLAB Simulation, Multi-Signal Transmission, Single Channel Communication, Carrier Signals, Demodulation Techniques, Signal Fidelity, Error Metrics, Communication Systems, Signal Processing.

I. INTRODUCTION

The ever-increasing demand for efficient and robust communication systems has spurred advancements in modulation techniques. Amplitude Modulation (AM) remains a fundamental technique in the transmission of signals over various channels. This project delves into the analysis and simulation of an AM system, specifically focusing on the transmission of multiple signals over a single channel.

The primary aim of this study is to explore the complexities of transmitting multiple signals concurrently through AM modulation and to investigate the challenges associated with demodulation. By conducting a comprehensive analysis of the modulation process and subsequent demodulation techniques, this research aims to offer insights into the design, performance, and limitations of such systems.

II. BACKGROUND

A. Amplitude Modulation (AM)

Amplitude Modulation (AM) is a fundamental technique in signal processing that facilitates the transmission of multiple signals over various communication channels. At its core, AM involves the multiplication of a carrier signal, $c(t)$, with a message signal, $m(t)$ - often referred to as the baseband signal.

In the context of sinusoidal signal AM, the carrier signal, $c(t)$, typically takes the form of $c(t) = \cos(\omega_c t)$, where ω_c represents the carrier frequency. The resultant modulated signal, $s(t)$, is expressed as:

$$s(t) = m(t) \cdot \mathrm{c(t)}$$

The spectrum of s(t), as revealed by its Fourier transform S(jω), demonstrates a frequency distribution centered around the carrier frequency ω_c. This shift occurs due to the multiplication of the baseband signal with the carrier frequency, as indicated by the following Fourier transform expression:

$$S(jw) = \frac{1}{2} M(j(\omega - \omega_c)) + \frac{1}{2} M(j(\omega + \omega_c))$$

B. Amplitude Demodulation

The process of demodulating an AM signal with a known carrier involves multiplication with the conjugate of the carrier signal. For instance, if the received signal $s(t)$ is modulated with a complex exponential carrier $c(t) = e^{-j\omega_c t}$, the demodulation process entails multiplying $s(t)$ by $e^{-j\omega_c t}$ to recover the baseband signal m(t).

However, when the carrier signal is a simple cosine function, $c(t) = \cos(\omega_c t)$, the demodulation process by multiplication with the same cosine carrier results in the following waveform:

$$\omega(t) = s(t) \cdot \cos(\omega_c t) = \frac{1}{2} m(t) + \frac{1}{2} m(t) \cdot \cos(2\omega_c t)$$

Demodulating this mixed wave form $\omega(t)$ necessitates passing it through an ideal low-pass filter with a cutoff frequency slightly higher than the maximum frequency in the baseband signal $m(t)$.

1. Asynchronos Demodulation:

Asynchronous demodulation introduces a modified signal format for transmission, altering the modulation approach. Here, the transmitted signal $s(t)$ is represented by:

$$s(t) = [A + m(t)] \cdot \cos(\omega_c t)$$

Where A is chosen such that A + m(t) > 0 and $\frac{K}{A}$, termed the modulation index, governs the presence of the raw carrier in the modulated signal. Notably, the message signal essentially represents the envelope of the received $s(t)$, allowing for demodulation.

III. METHODOLOGY

The simulation and analysis conducted in this project relied on MATLAB, leveraging its robust signal processing and simulation capabilities.

A. *Signal Modulation*

The signal modulation process involved the multiplication of each individual signal, including Bird Chirp, Gong, Chu-Chu, Laughter, and Splat, with carrier signals generated at specific frequencies. The carrier frequencies were set at 40 kHz, 45 kHz, 50 kHz, 55 kHz, and 60 kHz, corresponding to the distinct signals. These modulated signals were generated using MATLAB's signal processing capabilities and were subsequently visualized for analysis.

B. *Signal Demodulation*

The demodulation of the transmitted signals employed an asynchronous demodulation approach. The received modulated signals, which had undergone simulated channel transmission, were processed to recover the original message signals. The demodulation process included envelope detection using the Hilbert transform, followed by necessary adjustments such as DC offset removal and signal filtering to isolate and recover the individual signals.

C. *Graphical Display and Analysis*

For comprehensive analysis, graphs displaying both original and modulated signals were generated. The temporal characteristics and frequency spectra of the original signals, Bird Chirp, Gong, Chu-Chu, Laughter, and Splat, were plotted and examined. Additionally, the spectra of the modulated signals after each step in the modulation process—showcasing the effect of each stage on the signal—were graphically represented to visualize the alterations induced by modulation and channel transmission.

This methodology was designed to provide an in-depth understanding of the complexities involved in transmitting and recovering multiple signals using AM modulation, shedding light on the system's robustness and limitations.

IV. SYSTEM DESIGN

The design architecture adopted for the amplitude modulation (AM) system was structured to accommodate the simultaneous transmission of multiple signals over a single channel. The utilization of AM modulation was chosen due to its simplicity and effectiveness in transmitting varying types of signals. The design comprised distinct stages encompassing signal modulation, channel simulation, and signal recovery through demodulation.

A. *Block Diagram Overview:*

The system design followed a block diagram architecture, commencing with the loading of pre-recorded signals, which were then modulated using carrier signals at specified frequencies. Subsequently, the modulated signals were passed through a simulated channel, emulating real-world transmission conditions. The received signals, affected by channel noise and distortions, underwent demodulation for signal recovery. The recovered signals were then assessed for fidelity against the original signals.

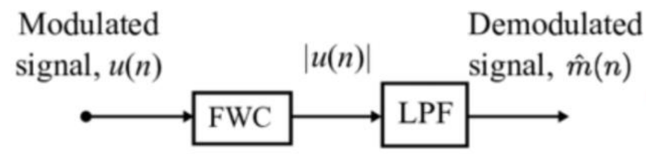

Figure 1: Asynchronous Demodulation process

B. *Design Choices and Justifications:*

i. **Carrier Frequency Selection:**

The choice of carrier frequencies—40 kHz, 45 kHz, 50 kHz, 55 kHz, and 60 kHz—was a critical design consideration. These frequencies were carefully chosen to ensure separation and avoid interference between the multiple transmitted signals. Each signal was modulated with a distinct carrier frequency to facilitate their simultaneous transmission without spectral overlap.

ii. **Need for Filtering:**

In the demodulation process, filtering played a pivotal role in isolating the original message signals. An ideal low-pass filter was employed to eliminate unwanted noise and higher frequency components introduced during modulation and channel transmission. The cutoff frequency of the filter was meticulously calculated based on the maximum frequency present in the original signals, allowing for accurate signal recovery while suppressing noise and carrier frequencies.

iii. **Signal Adjustment:**

Adjustments such as DC offset removal were incorporated to enhance the accuracy of the recovered signals. The removal of DC components ensured that the demodulated signals accurately represented the original message signals, enabling a more precise assessment of the demodulation process.signals.

C. *Calculation for Cutoff Frequencies:*

The cutoff frequencies for the filtering stage were determined using the Nyquist theorem and the maximum frequency content present in the original signals. Calculations were performed to set the cutoff frequencies slightly higher than the maximum frequency to retain the integrity of the recovered signals while effectively attenuating noise and carrier components.

This design framework and the accompanying design choices were instrumental in constructing a robust AM system capable of transmitting and recovering multiple signals effectively. The selection of carrier frequencies, filtering techniques, and signal adjustments were tailored to ensure accurate signal recovery and faithful representation of the original messages.

V. RESULTS

The error metrics obtained from the comparison between the recovered signals and their respective originals provide valuable insights into the fidelity of the demodulation process. The energy values signify the discrepancy between the recovered and original signals for each transmission.

Signal 1: The energy of the error between the recovered and original signal 1 is *3.146811e+01*.

Signal 2: The energy of the error between the recovered and original signal 2 is *3.387482e+01*.

Signal 3: The energy of the error between the recovered and original signal 3 is *1.273626e+01*.

Signal 4: The energy of the error between the recovered and original signal 4 is *4.486748e+01*.

Signal 5: The energy of the error between the recovered and original signal 5 is *1.535411e+02*.

A. Graphical Analysis:

Original Signals:

The graphs displaying the original signals provide visual representations of their temporal characteristics, aiding in understanding their patterns and variations over time.

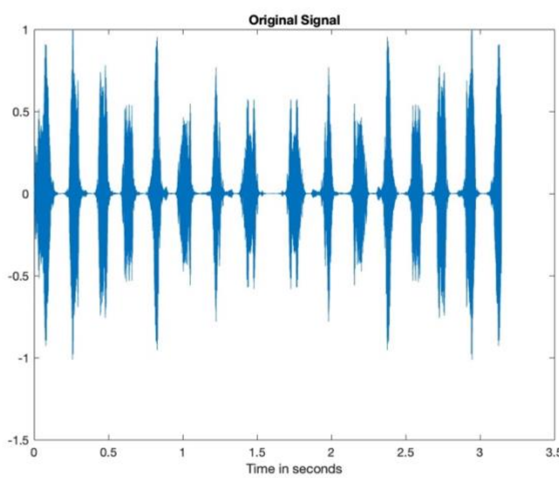

Figure 2: Original signal 1

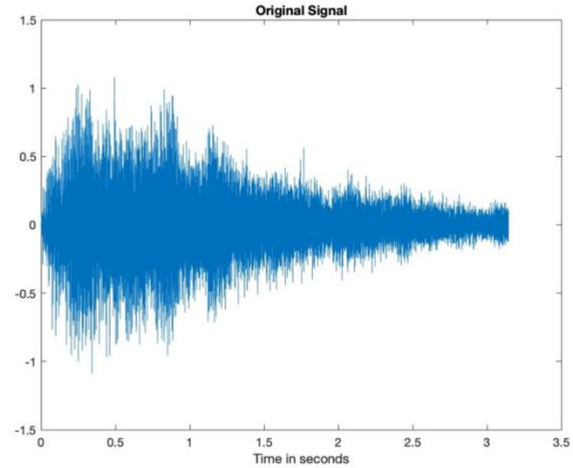

Figure 3: Original Signal 2

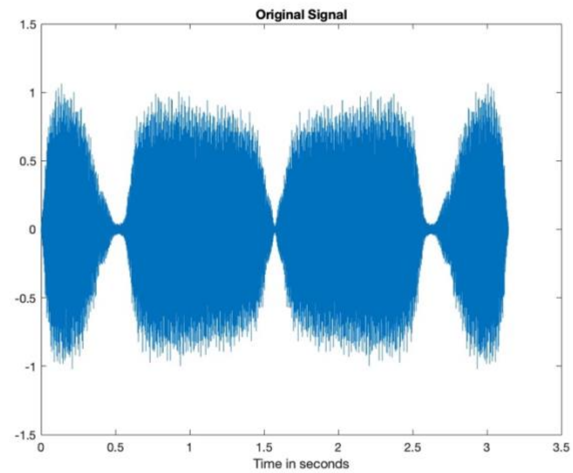

Figure 4: Original Signal 3

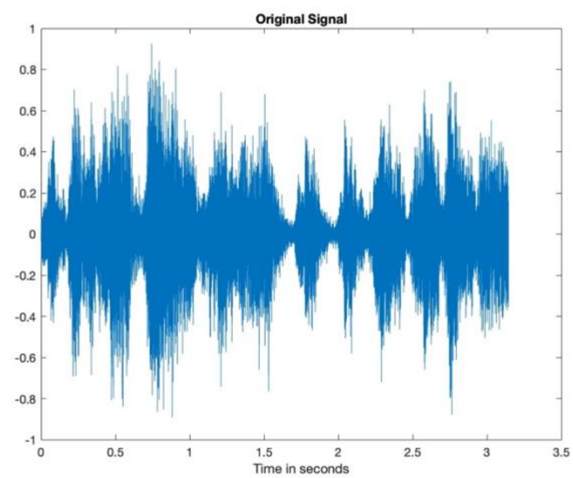

Figure 5: Original Signal 4

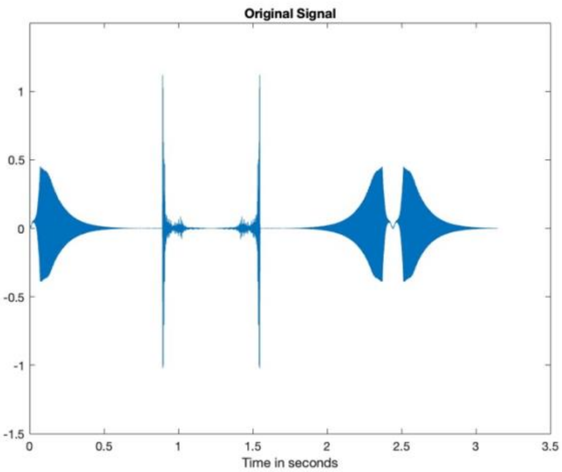

Figure 6: Original Signal 5

Magnitude Spectrum:

Original Signals: The magnitude spectrum graphs illustrate the frequency components present in each original signal, offering insights into their spectral composition.

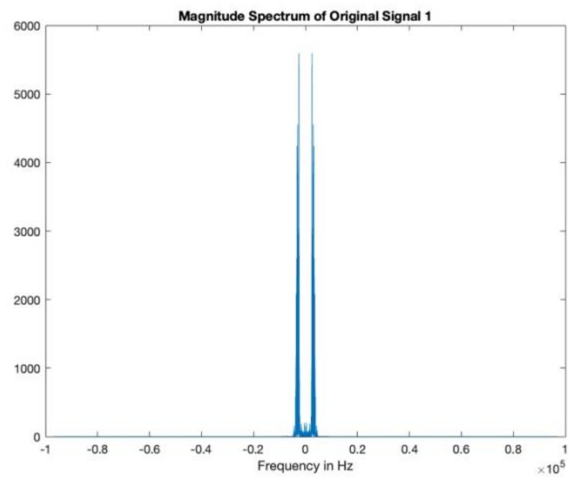

Figure 7: Magnitude Spectrum of Original Signal 1

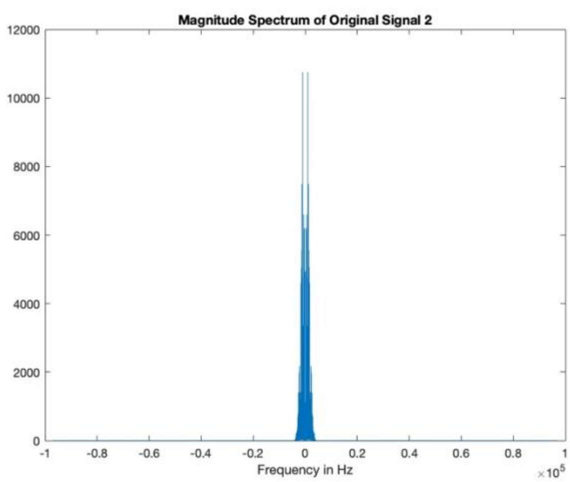

Figure 8: Magnitude Spectrum of Original Signal 2

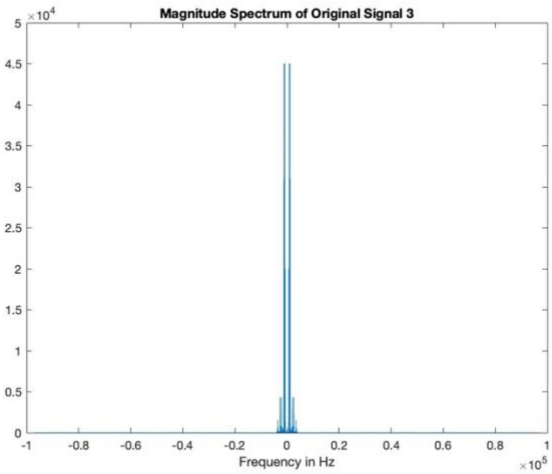

Figure 9: Magnitude Spectrum of Original Signal 3

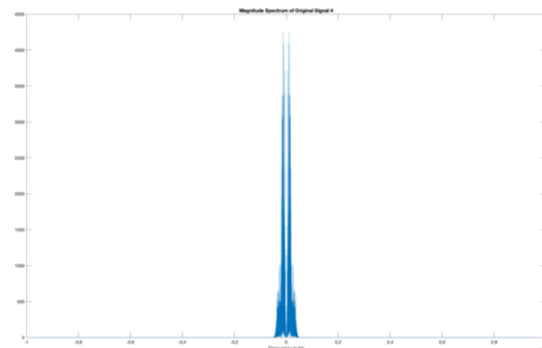

Figure 10 : Magnitude Spectrum of Original Signal 4

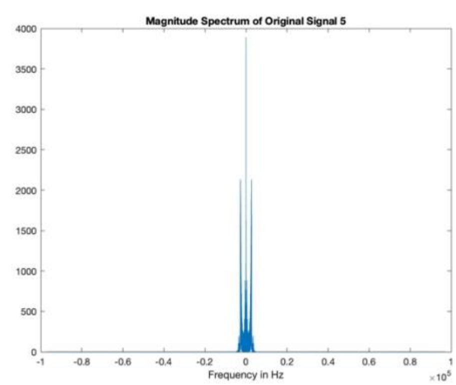

Figure 11: Magnitude Spectrum of Original Signal 5

Carrier Signals: Spectrums of the carrier signals highlight their frequencies, crucial for understanding the transmitted modulated signals' spectral shifts.

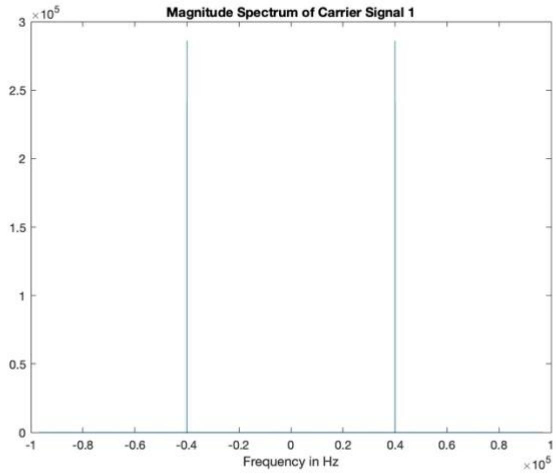

Figure 12: Magnitude Spectrum of Carrier Signal 1

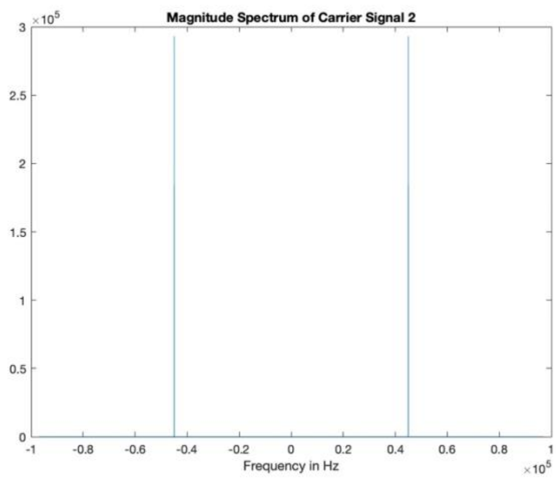

Figure 13: Magnitude Spectrum of Carrier Signal 2

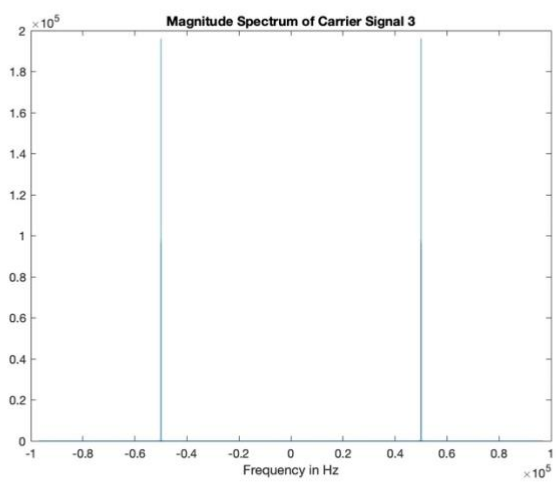

Figure 14: Magnitude Spectrum of Carrier Signal 3

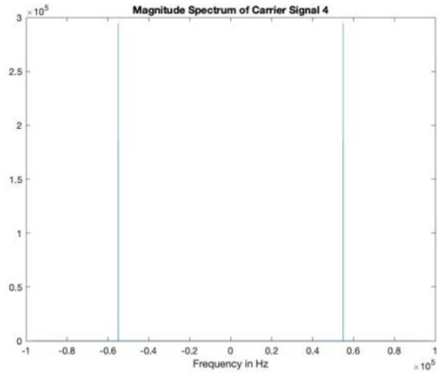

Figure 15 : Magnitude Spectrum of Carrier Signal 4

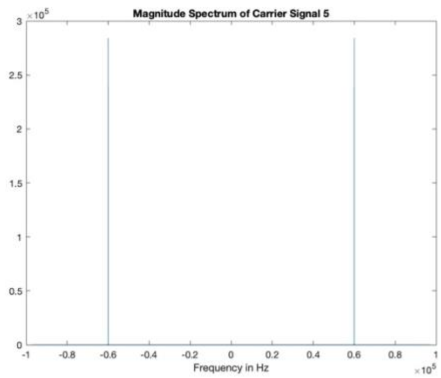

Figure 16: Magnitude Spectrum of Carrier Signal 5

AM Signals: The magnitude spectrum of the AM signals demonstrates the effect of modulation on the original signals, showcasing the frequency displacement caused by the carrier.)

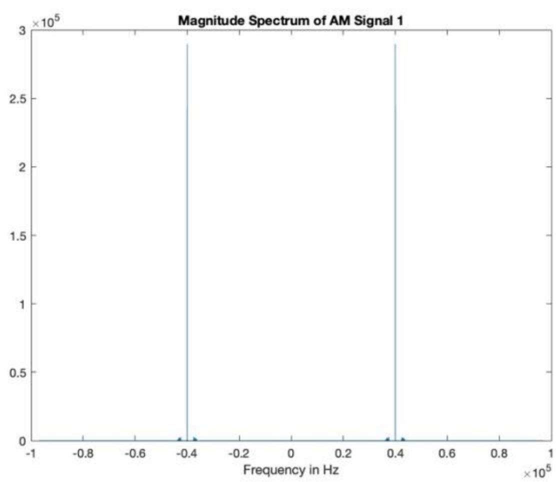

Figure 17: Magnitude Spectrum of AM Signal 1

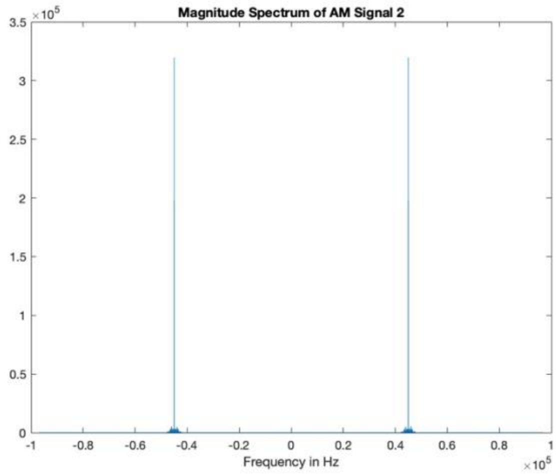

Figure 18: Magnitude Spectrum of AM Signal 2

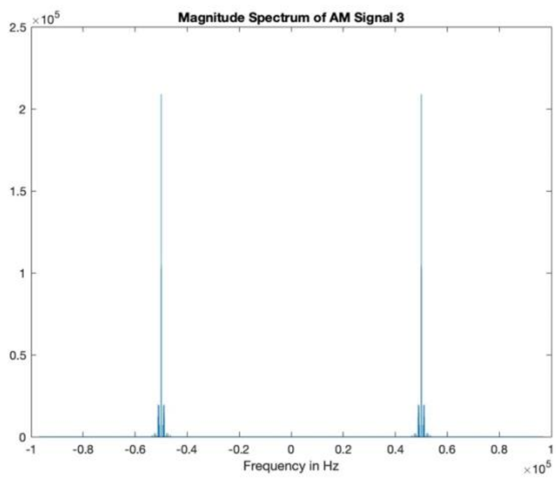

Figure 19: Magnitude Spectrum of AM Signal 3

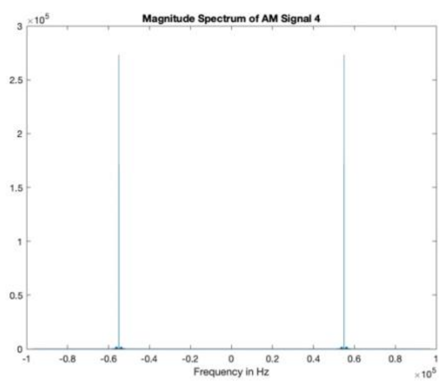

Figure 20 : Magnitude Spectrum of AM Signal 4

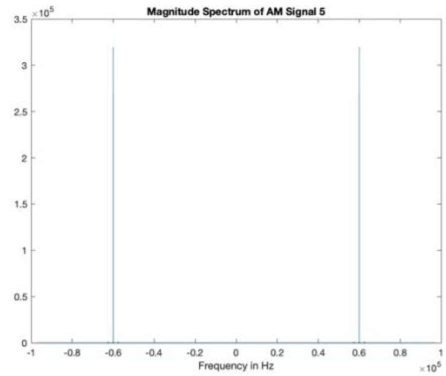

Figure 21: Magnitude Spectrum of AM Signal 5

B. Identify the Headings

The varying error energy across the signals suggests differing levels of accuracy in the recovery process. Signal 5 notably exhibits a higher error energy, indicating a greater disparity between its recovered and original versions compared to other signals. This could be attributed to complexities in its spectral composition or transmission-induced distortions.

The magnitude spectrum graphs reveal how the modulation process shifted the original signals' frequency content, emphasizing the carrier frequencies' influence on the transmitted signals.

VI. SYSTEM DESIGN

The project's comprehensive exploration of AM modulation and demodulation techniques for multi-signal transmission shed light on the intricacies involved in signal processing. While successful in transmitting and recovering signals, the evaluation highlighted areas for enhancement, emphasizing the need for further optimization to improve signal fidelity and mitigate errors. Also, the evaluation showcases the system's ability to transmit and recover multiple signals via AM modulation. While some signals demonstrate relatively low error energy, indicating successful recovery, others exhibit higher discrepancies, signifying potential areas for improvement. The spectral analysis provides a comprehensive view of the signal transformations during modulation and recovery.

VII. REFRENCES

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