Department of Electronics and Electrical Communication Engineering

Indian Institute of Technology Kharagpur

# COMMUNICATION - 1

# (EC31202)

**Assignment Number: 1**

## **Title:** Amplitude and Angle Modulations

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# Amplitude and Angle Modulations

## Introduction

Modulation and demodulation are fundamental processes in the field of signal processing and communication systems. Modulation involves the modification of a carrier signal to convey information, while demodulation is the reverse process of extracting the original information from the modulated signal. These techniques play a crucial role in various communication systems, including radio broadcasting, audio transmission, and data communication.

In this assignment, we explore and analyse different modulation and demodulation techniques, focusing on amplitude modulation (AM), amplitude demodulation using a coherent carrier, amplitude demodulation using an envelope detector, frequency modulation (FM), frequency demodulation using a differentiator and envelope detection, and phase modulation and demodulation.

The goal of this report is to provide a comprehensive understanding of these techniques through code demonstrations and visualizations. Each section of the report covers one of the modulation or demodulation techniques, explaining the underlying principles, demonstrating the code, and presenting the results through figures and analysis.

## Section 1: Amplitude Modulation

In this section, we delve into the fundamentals of amplitude modulation (AM) and explore its impact on audio signals. The following code demonstrates the process of AM modulation and its effects on audio signals, considering different modulation indices.

### Code Description

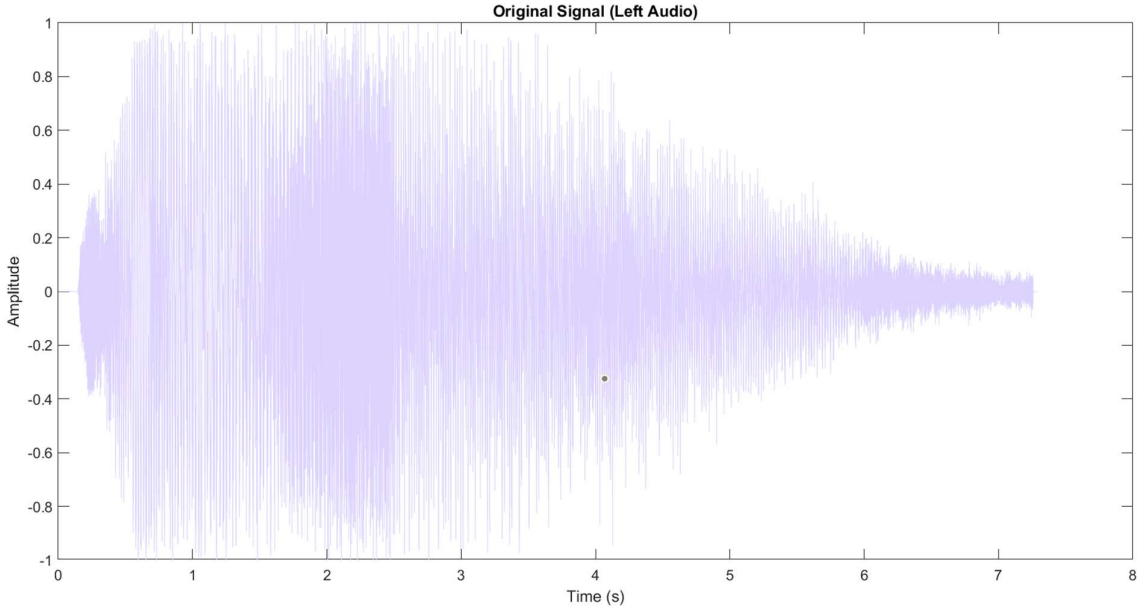
The provided code covers several key aspects of amplitude modulation:

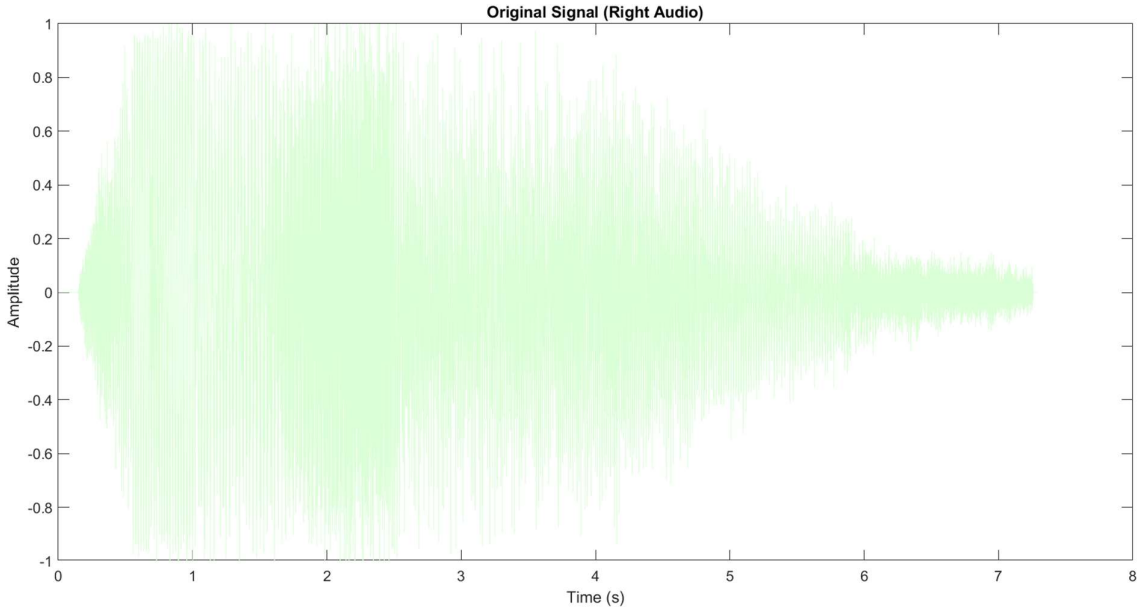
1. **Loading the Audio File:** We initiate the process by loading an audio file, "videoplayback.wav," and extracting the audio signal. Additionally, the sampling frequency (fs) is retrieved.
2. **Signal Visualization:** The original audio signal is visualized both in the time and frequency domains to provide a basis for comparison.
3. **Amplitude Modulation:** We introduce amplitude modulation (DSB – AM) to the audio signal. Different modulation indices (mu) are employed to observe the audio signal's transformation through modulation.
4. **Time and Frequency Domain Analysis:** At each step of modulation, we visualize the modulated audio signal in both the time and frequency domains, enabling us to assess the influence of AM.

## Results

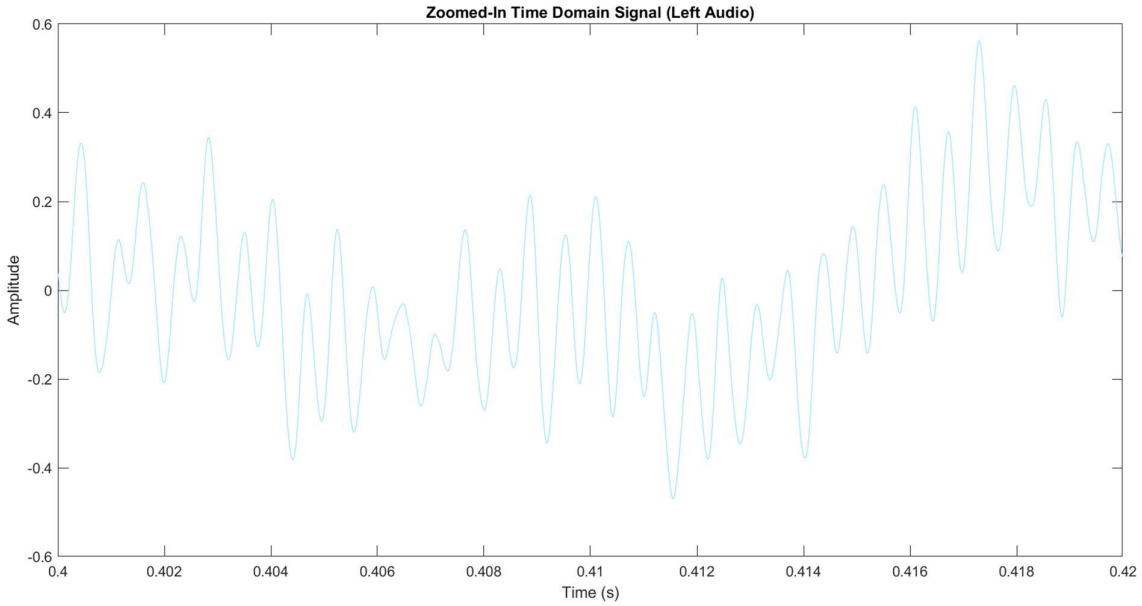
The code generates multiple figures, shedding light on how amplitude modulation affects the audio signal. We employ various modulation indices (mu) to demonstrate the impact of modulation. Figures showcase both time and frequency domain representations of the audio signal, illustrating the changes resulting from AM.

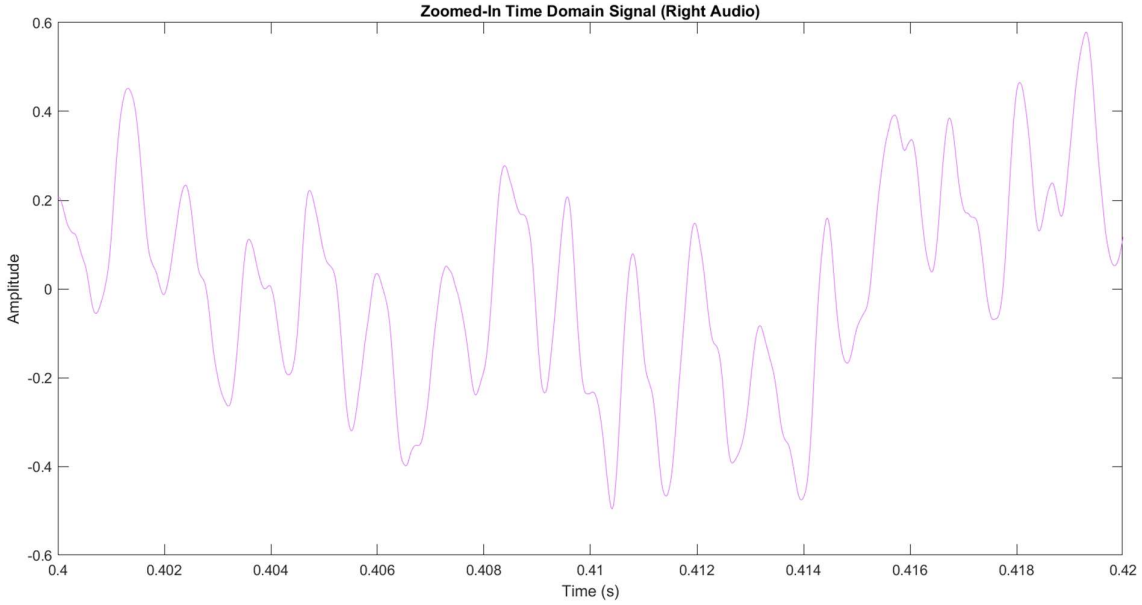
The time domain representation of the audio signal is (the left and right audio channels have been processed separately):



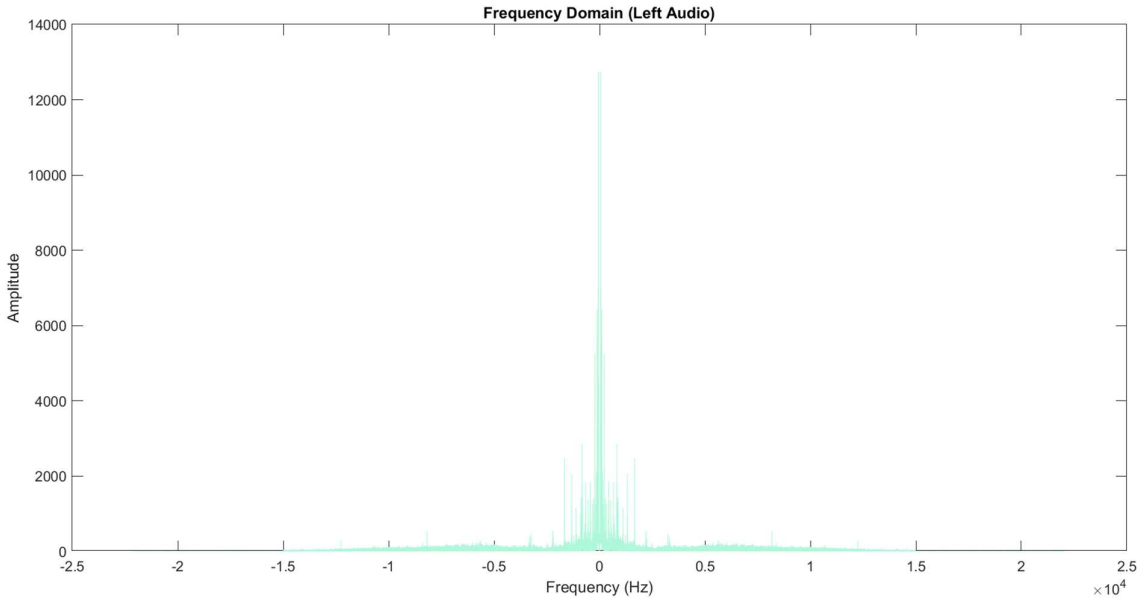



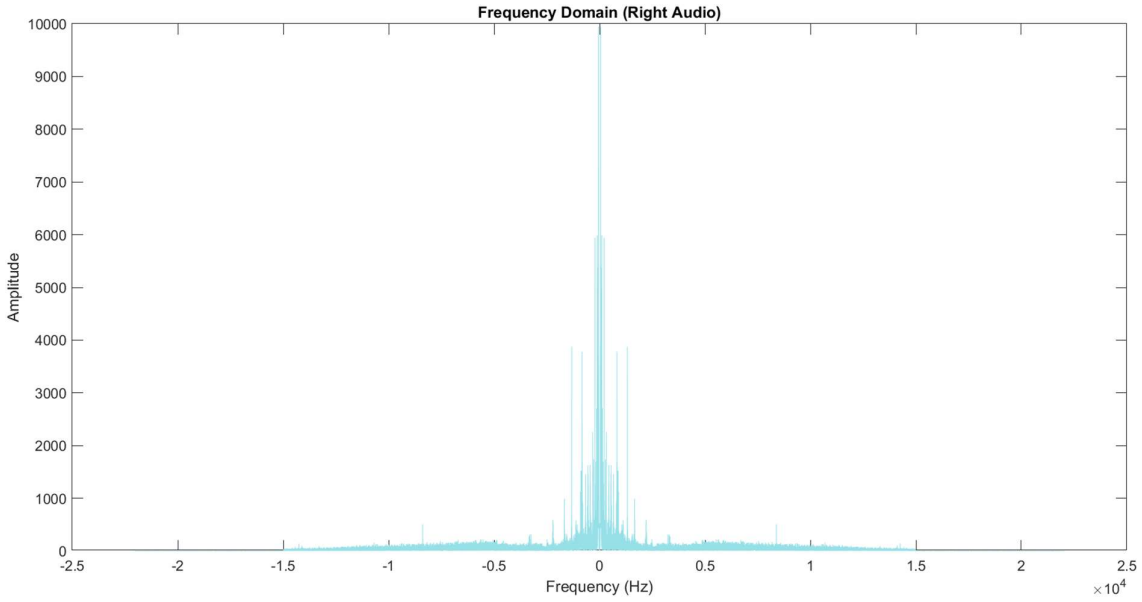

To show the signal more clearly, we can show the zoomed in signal (from 0.4 to 0.42 seconds)




The frequency domain representation of the signal can be shown as:



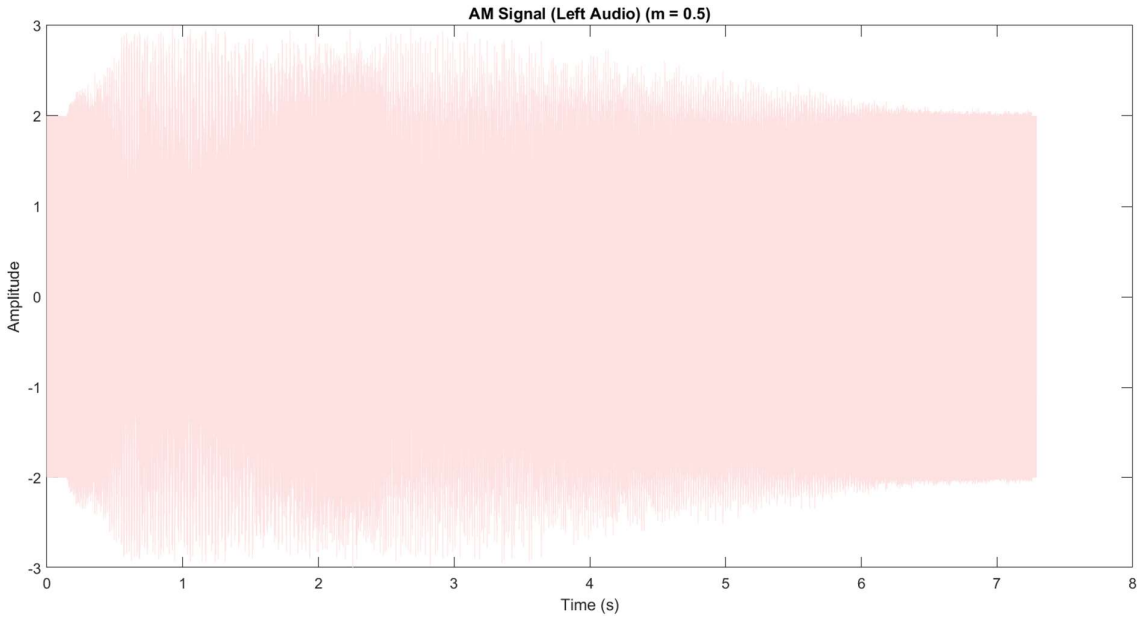


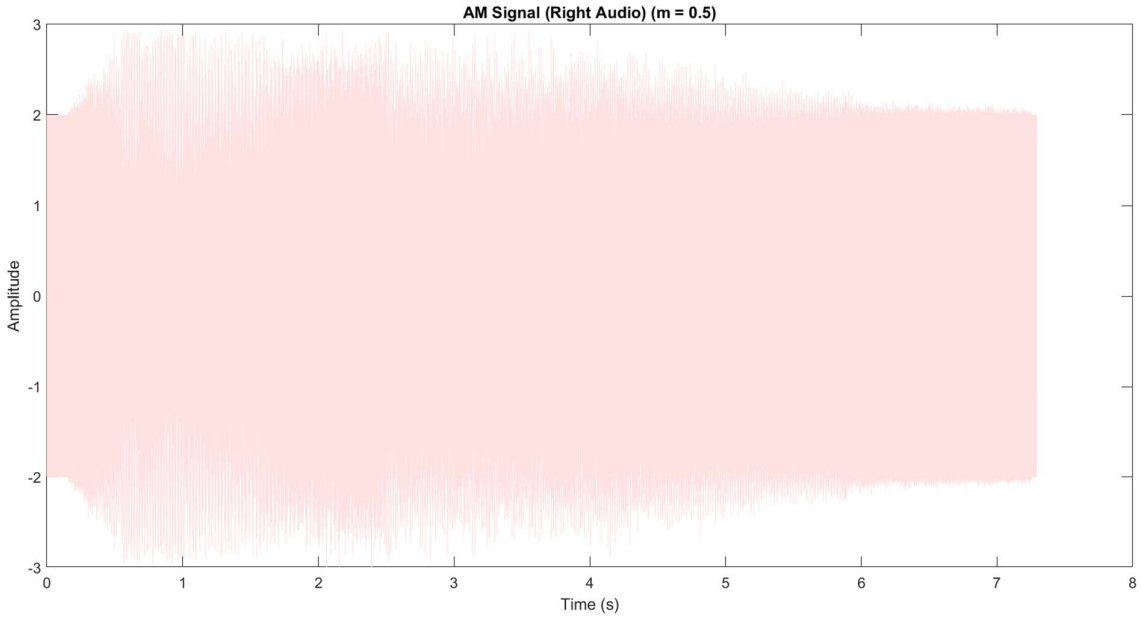

The signal has been modulated for various modulating indices.

The plots for various modulation indices can be shown as:

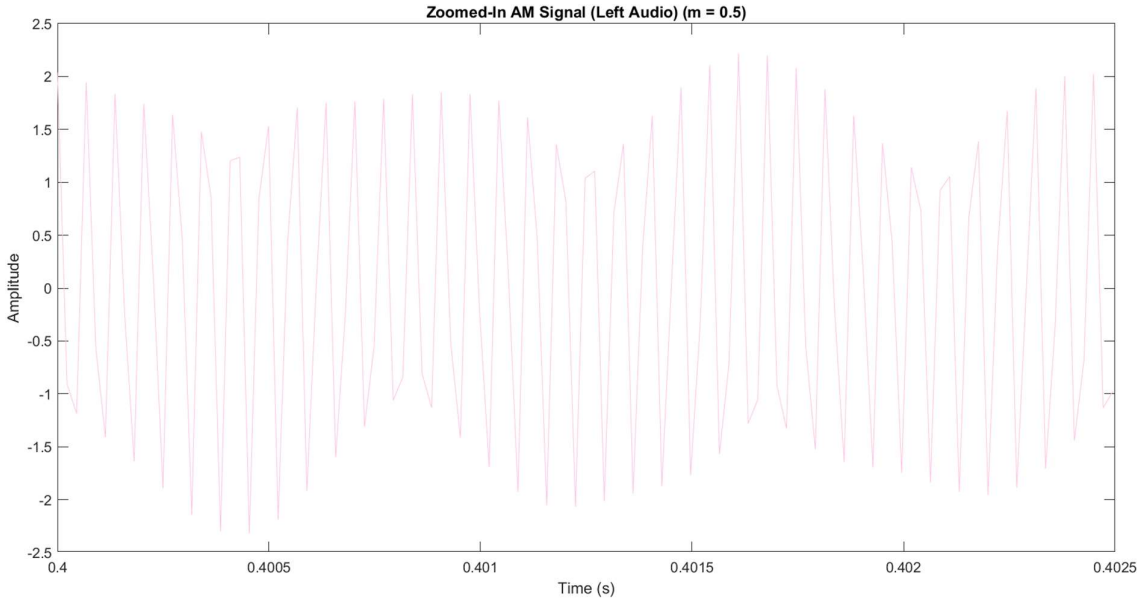
**m = 0.5:**

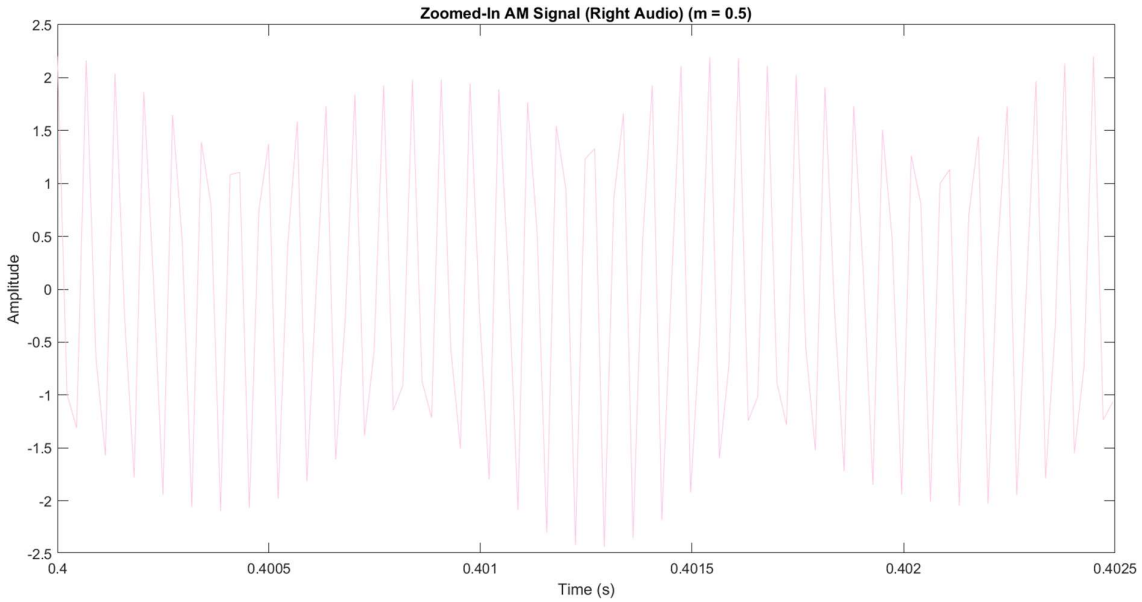
The time domain representation of the modulated signal can be shown as:



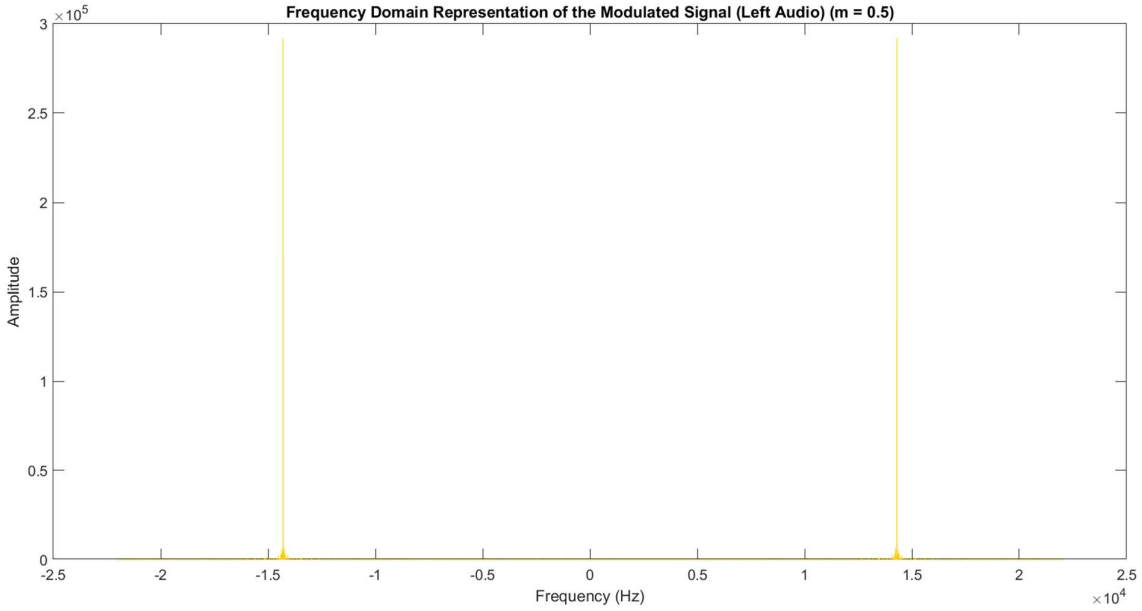


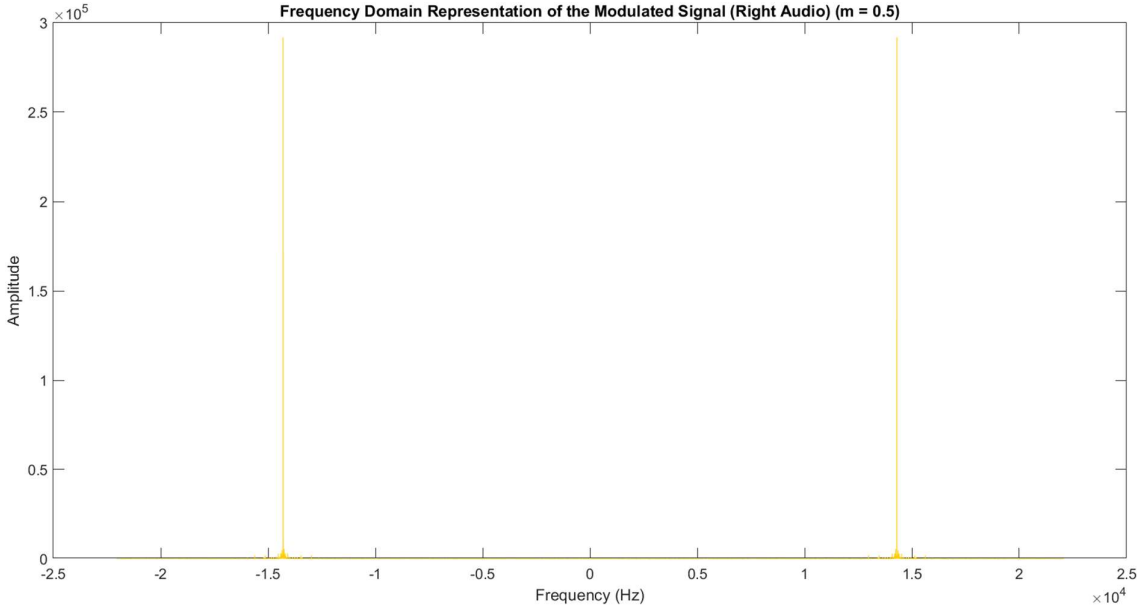

The zoomed in signal is:



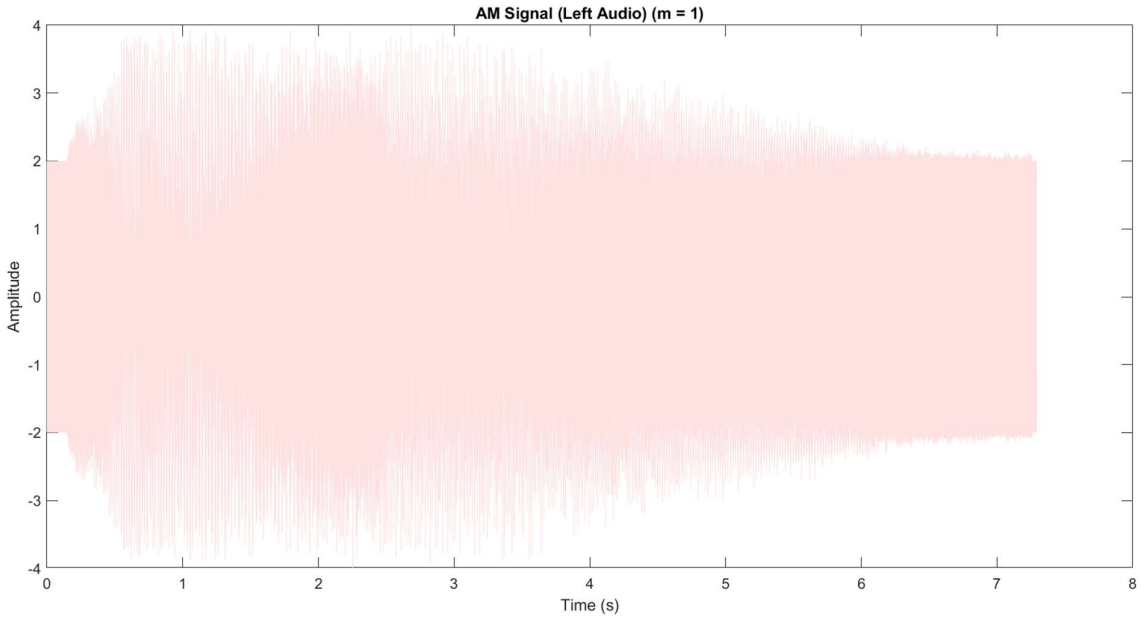
The frequency domain representation can be shown as:

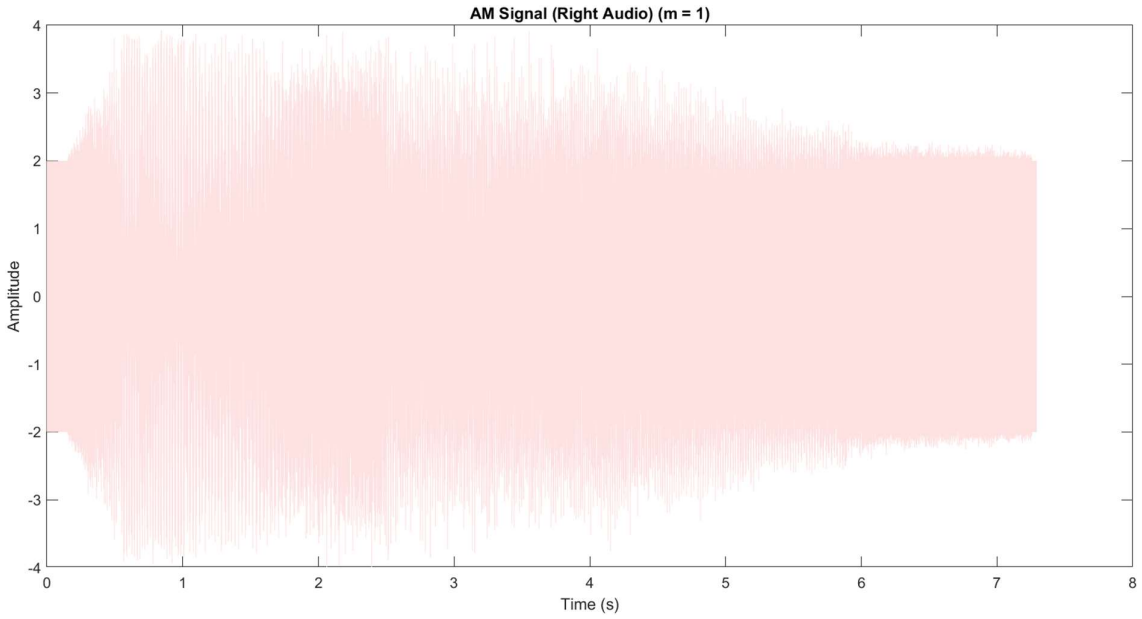


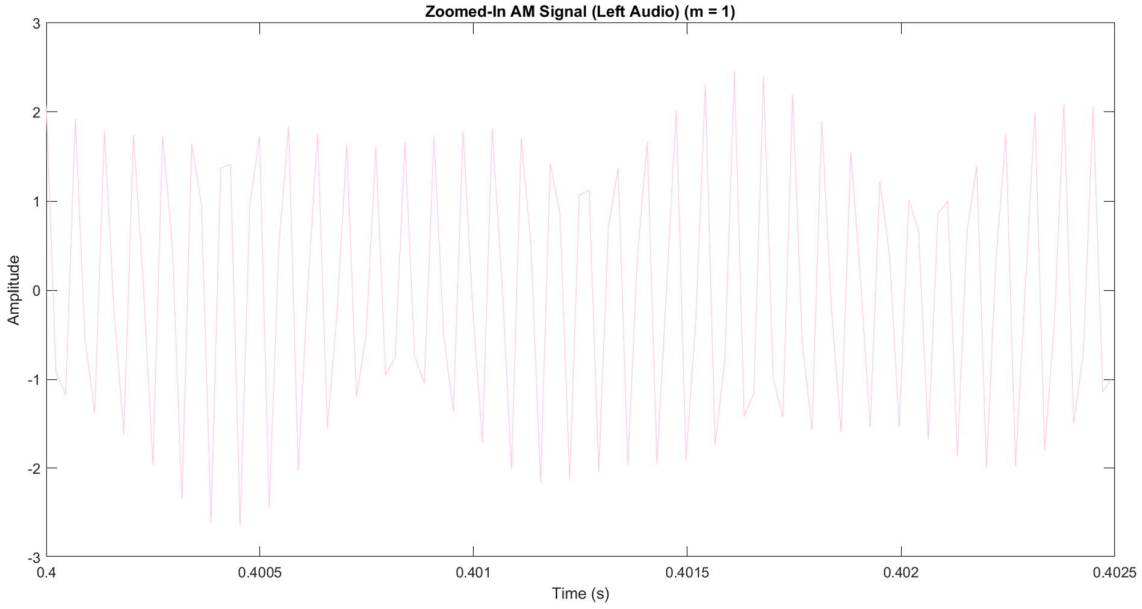
**m = 1:**

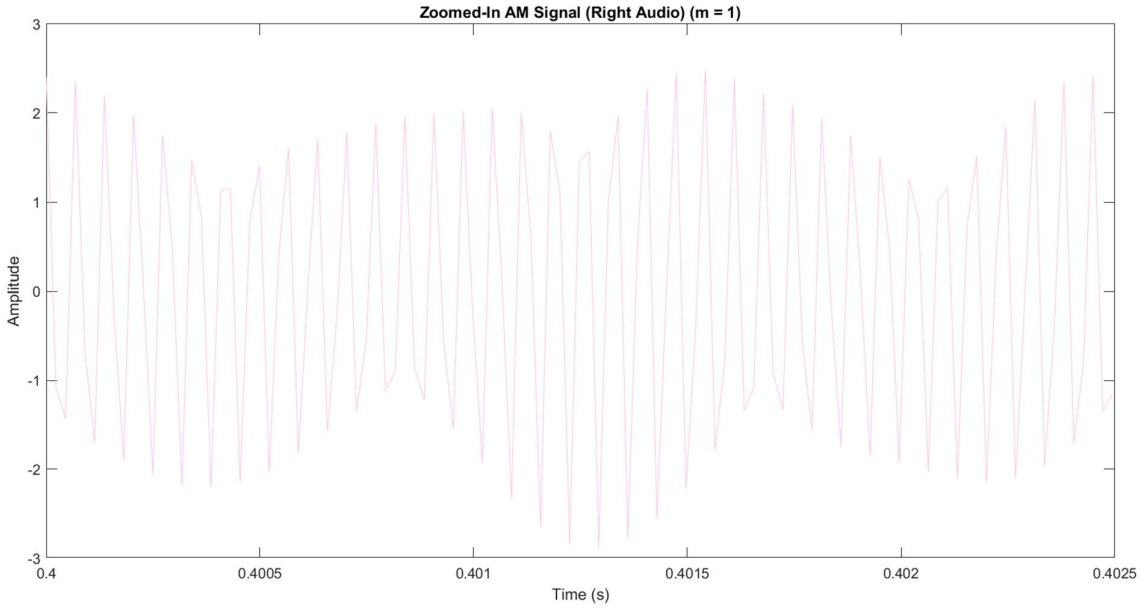
The time domain representation of the modulated signal can be shown as:



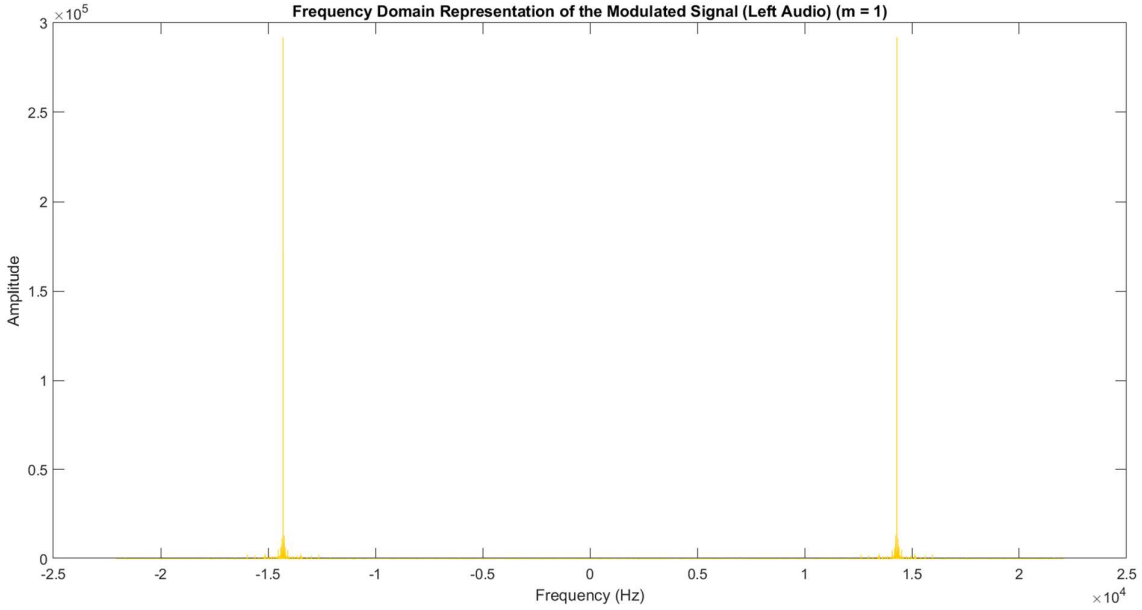



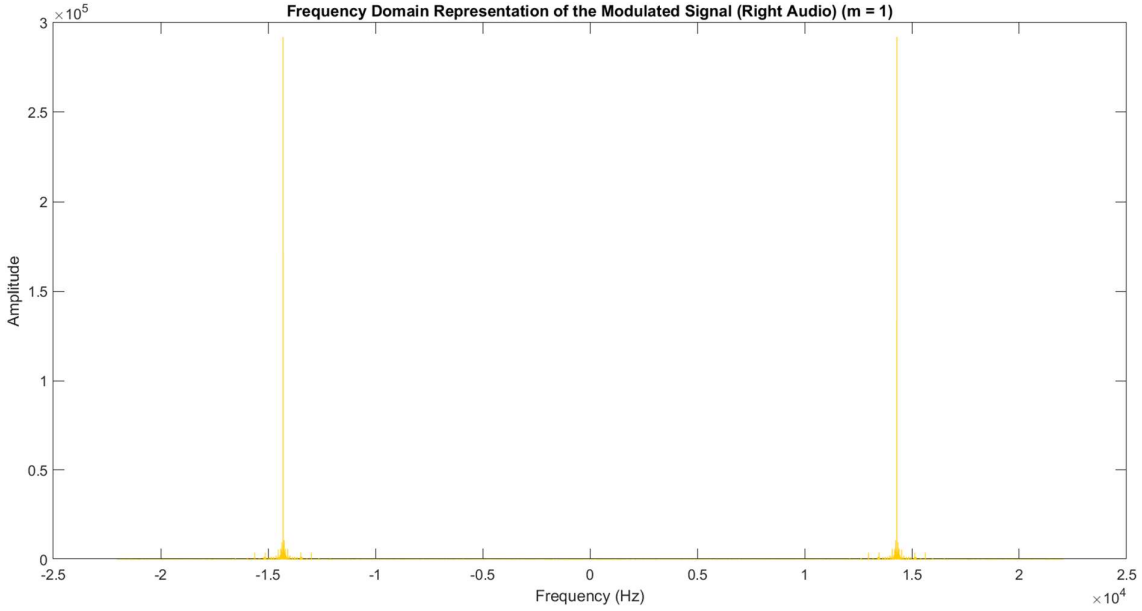
The zoomed-in signal is:



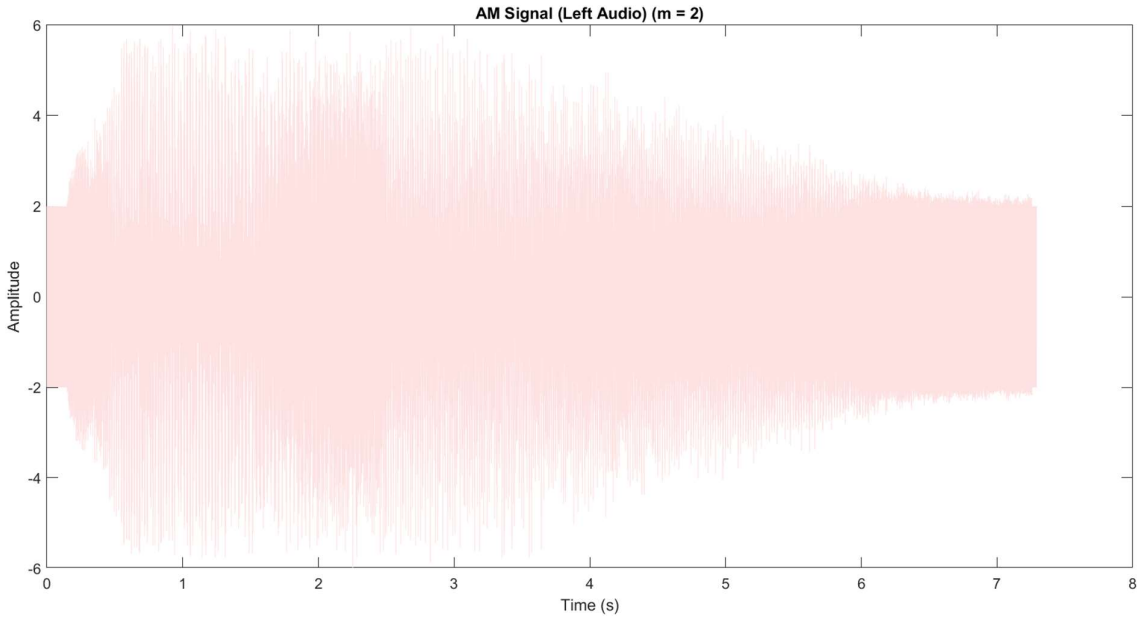
The frequency domain representation is:

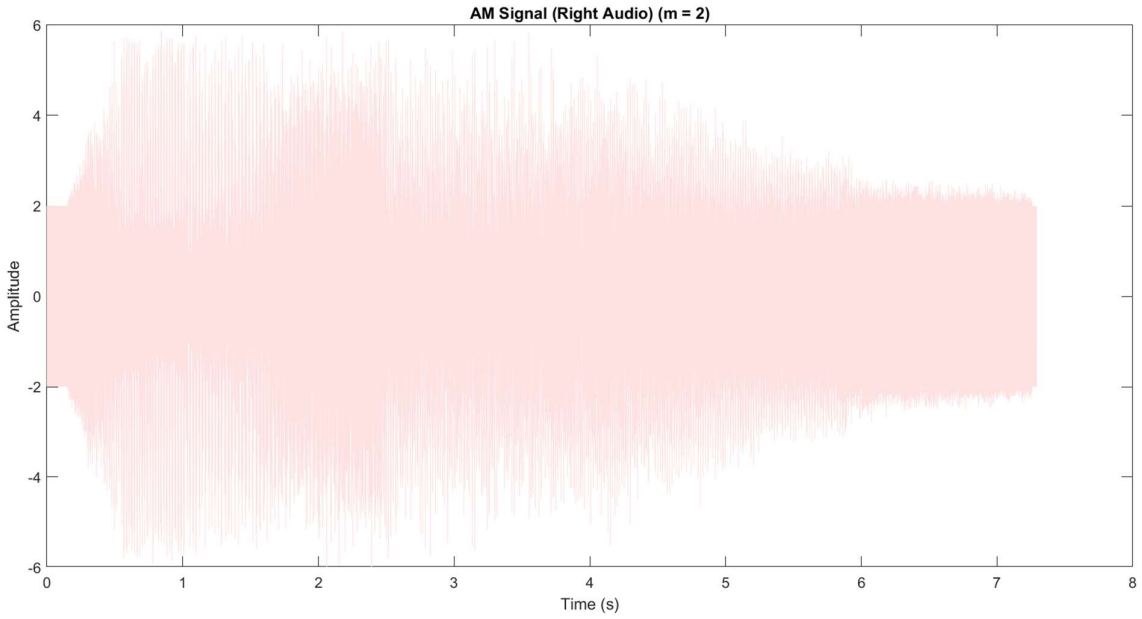


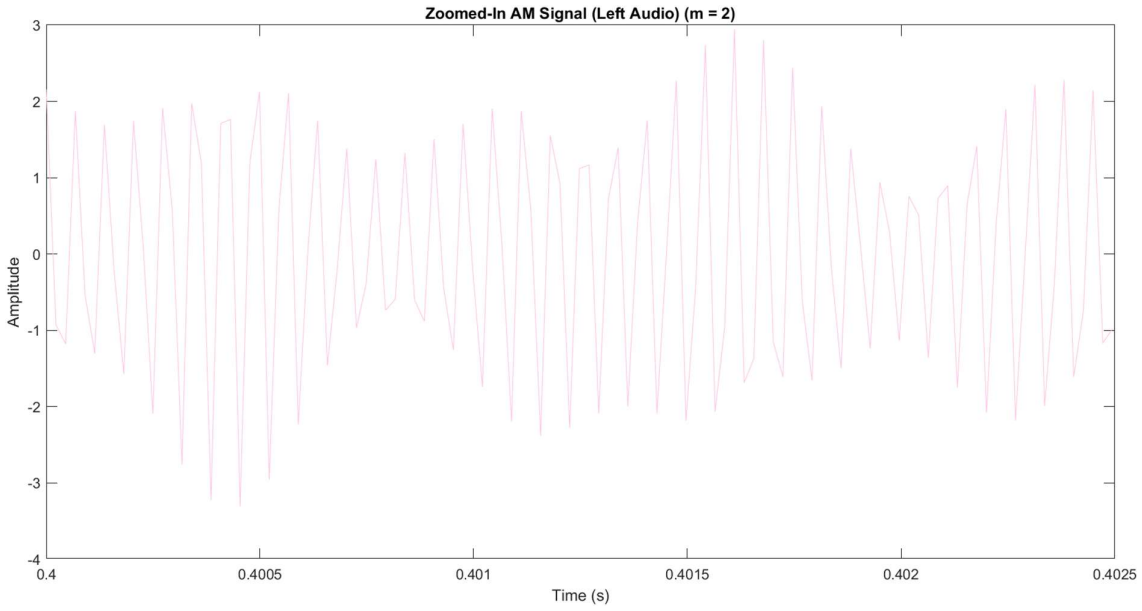
**m = 2:**

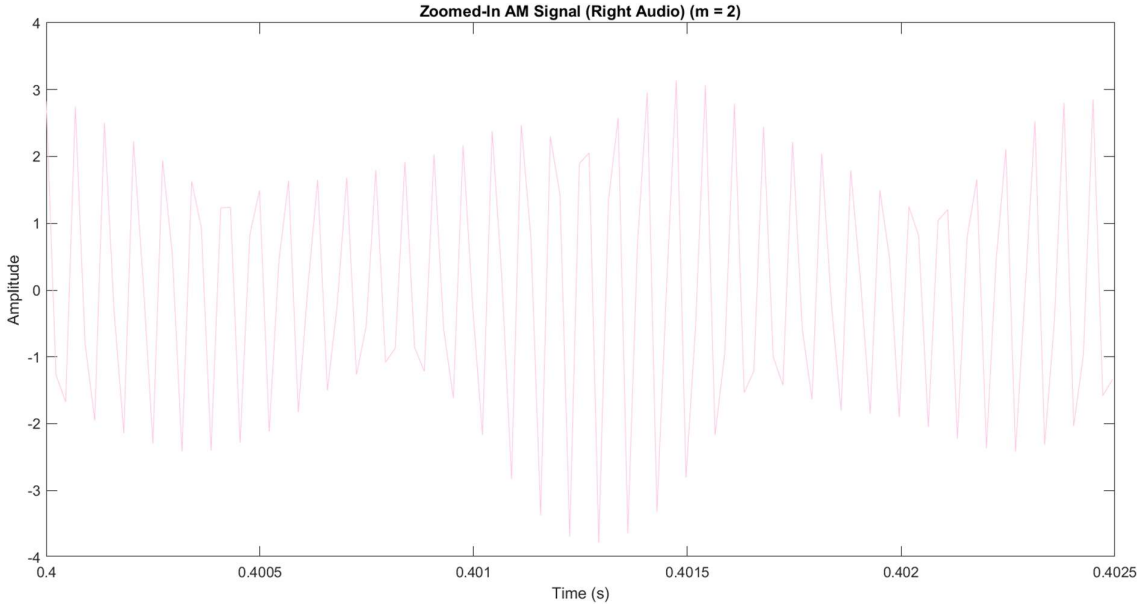
The time domain representation of the modulated signal is:



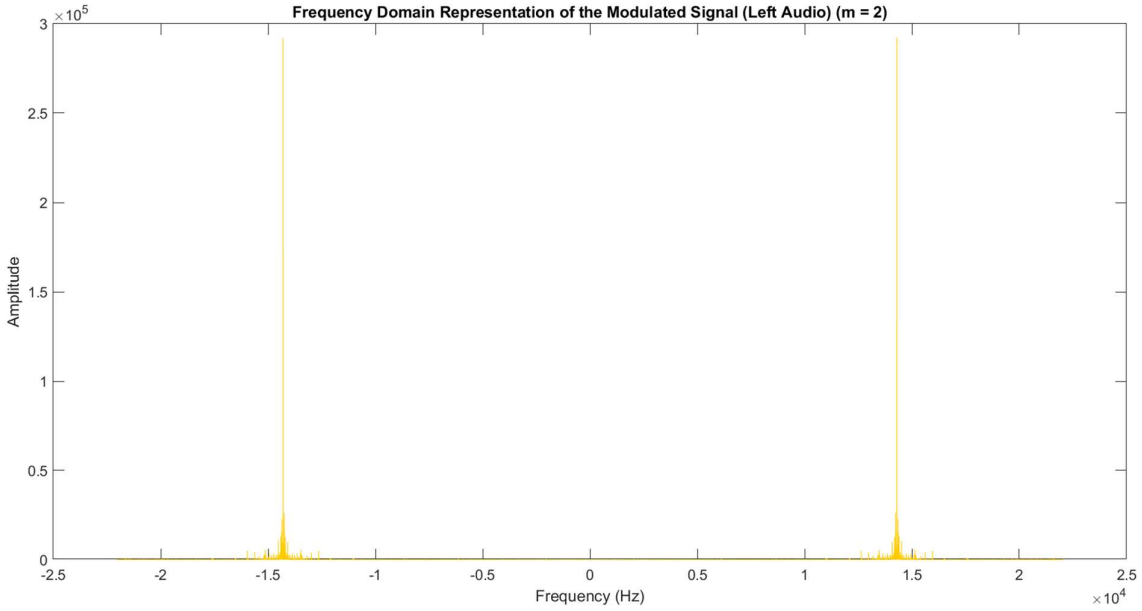



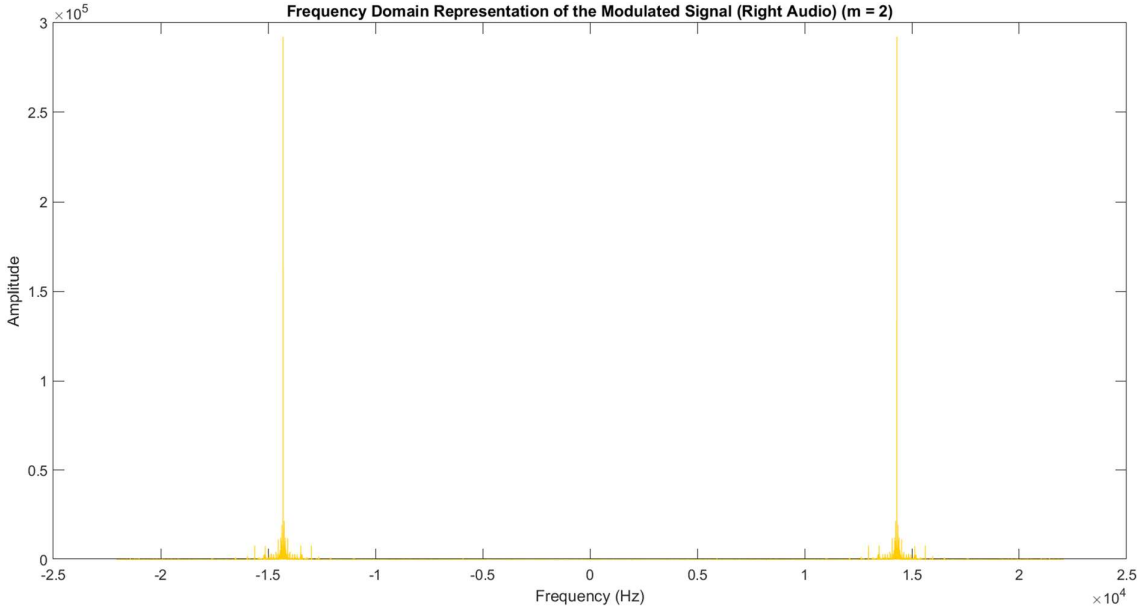
The zoomed in signal is:



The frequency domain representation is:



# Section 2: Amplitude Demodulation with Coherent Carrier

In this section, we explore the process of amplitude demodulation using a coherent carrier signal. The demodulation process involves the extraction of the original message signal from an amplitude-modulated waveform.

## Code Description

The provided code covers the following key steps in amplitude demodulation:

1. **Loading the Audio File:** We begin by loading an audio file named "videoplayback.wav." The original audio signal is extracted, and the sampling frequency (fs) is determined.
2. **Signal Playback:** The original audio is played to provide an auditory reference to the user.
3. **Modulation and Demodulation:** The amplitude modulation process is simulated by modulating the left and right audio channels with a carrier signal (DSB – SC). The modulated signals are then demodulated using a coherent carrier.
4. **Filtering:** To extract the message signal, a low-pass Butterworth filter is designed and applied to the demodulated signal. This filtering step eliminates high-frequency components.
5. **Time and Frequency Domain Analysis:** For each modulation index (mu), we analyse the demodulated signal in both the time and frequency domains to understand the effect of demodulation on the audio signal.

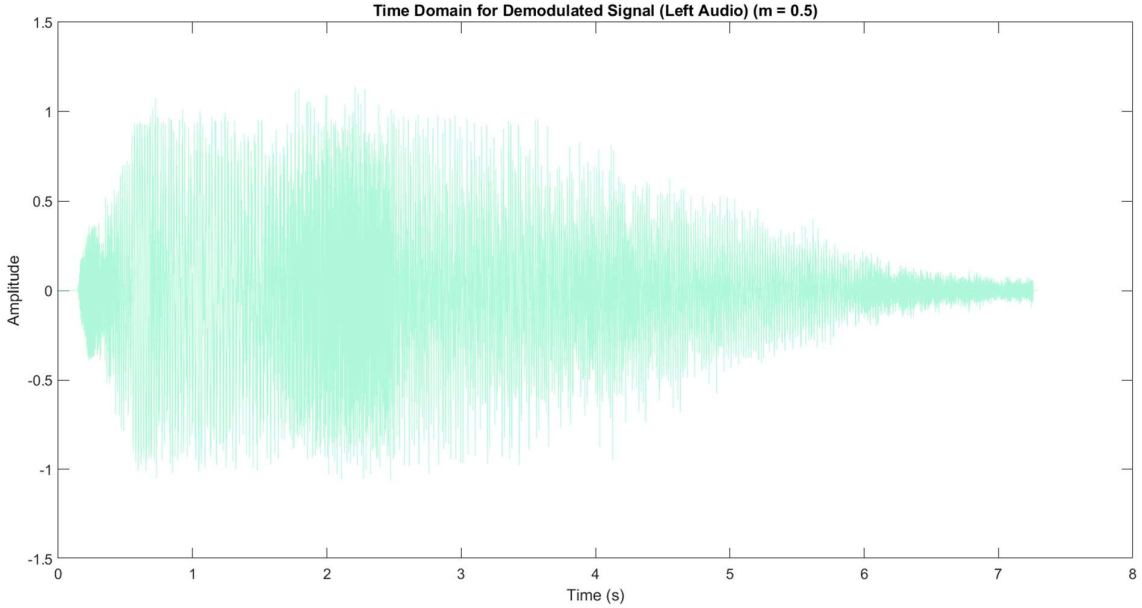
## Results

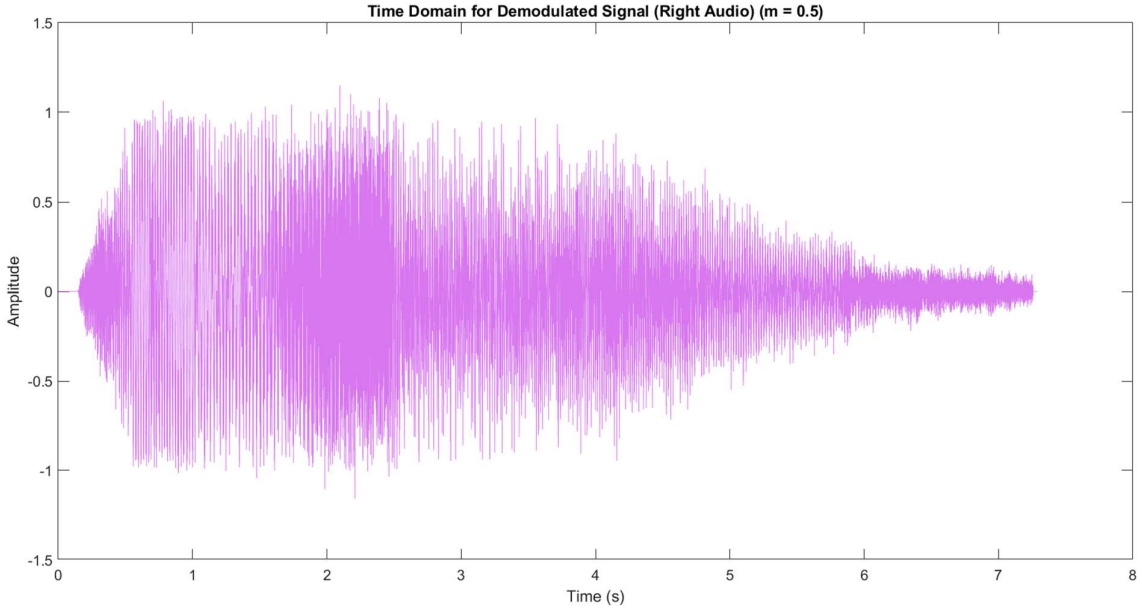
The code generates various figures and provides auditory feedback to illustrate the results of amplitude demodulation. Figures display time and frequency domain representations of the demodulated signals for different modulation indices (mu). Auditory playback of the demodulated audio signals is included to showcase the audio quality post-demodulation.

The demodulation was done for different modulation indices. The plots corresponding to each index are shown below.

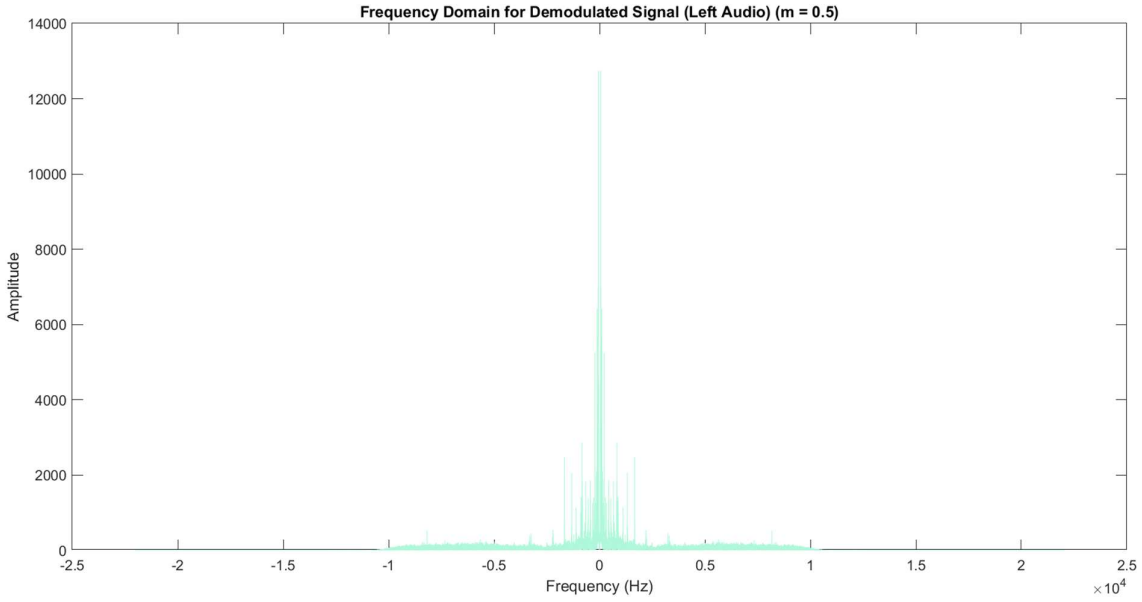
**m = 0.5:**

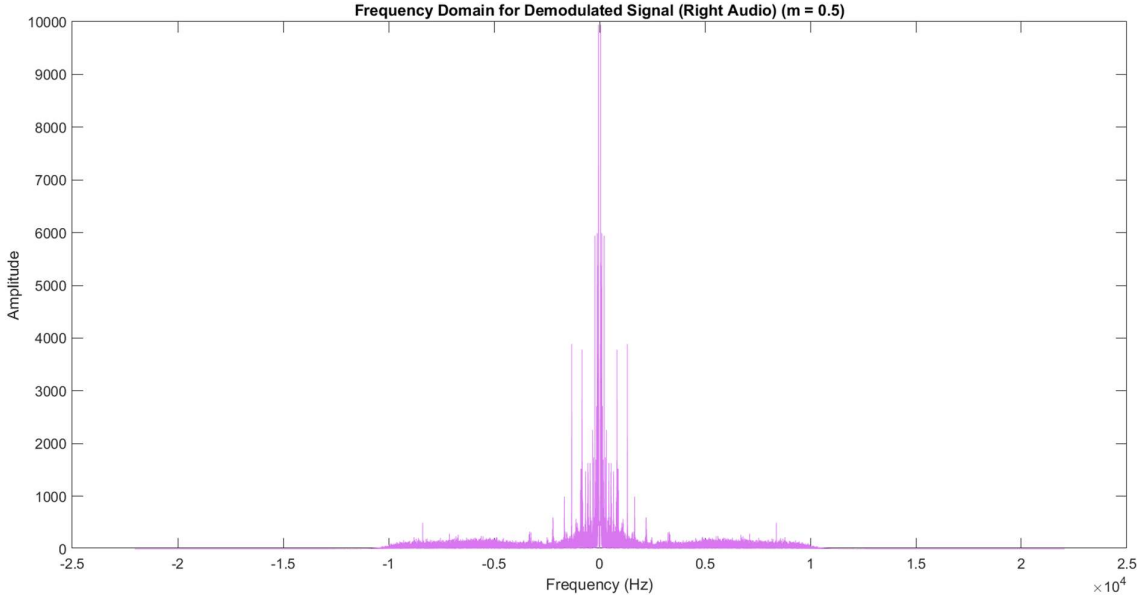
The demodulated signals in time domain are:



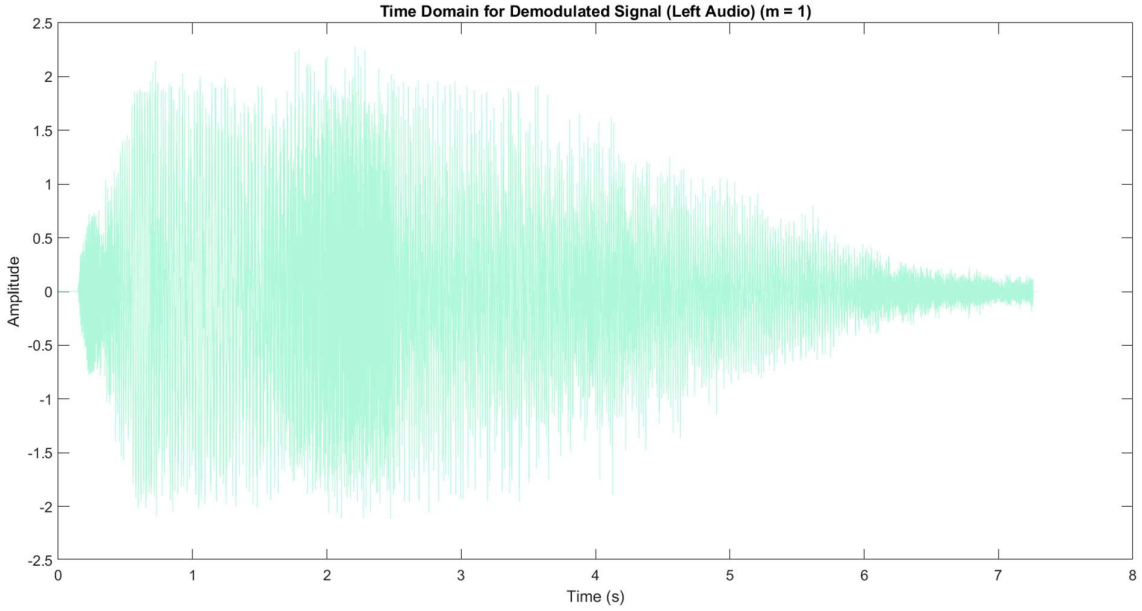
The frequency domain representation is:

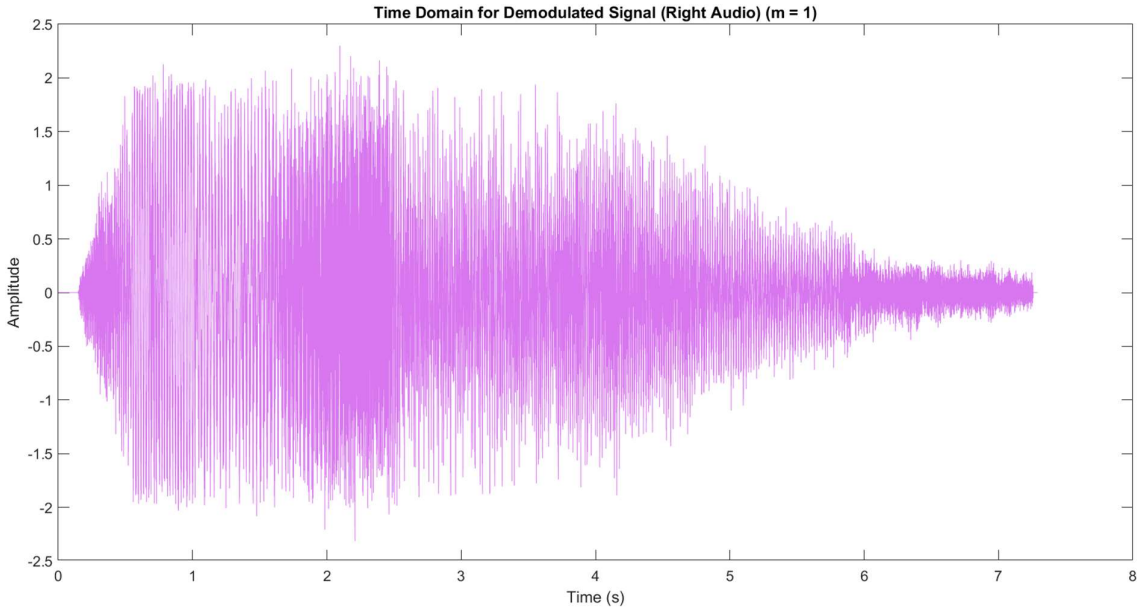


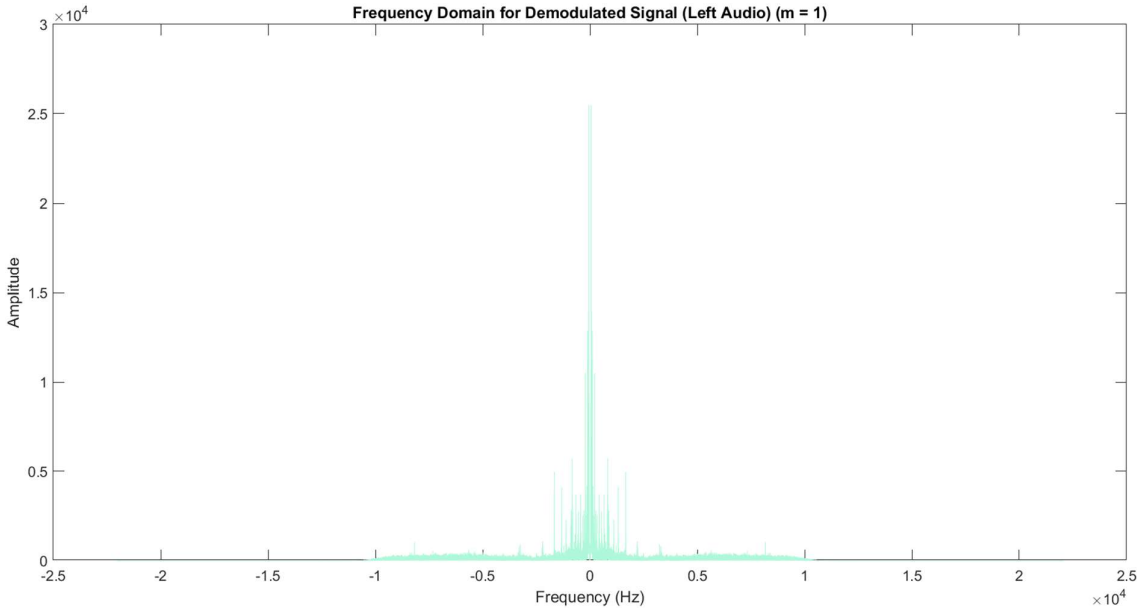
**m = 1:**

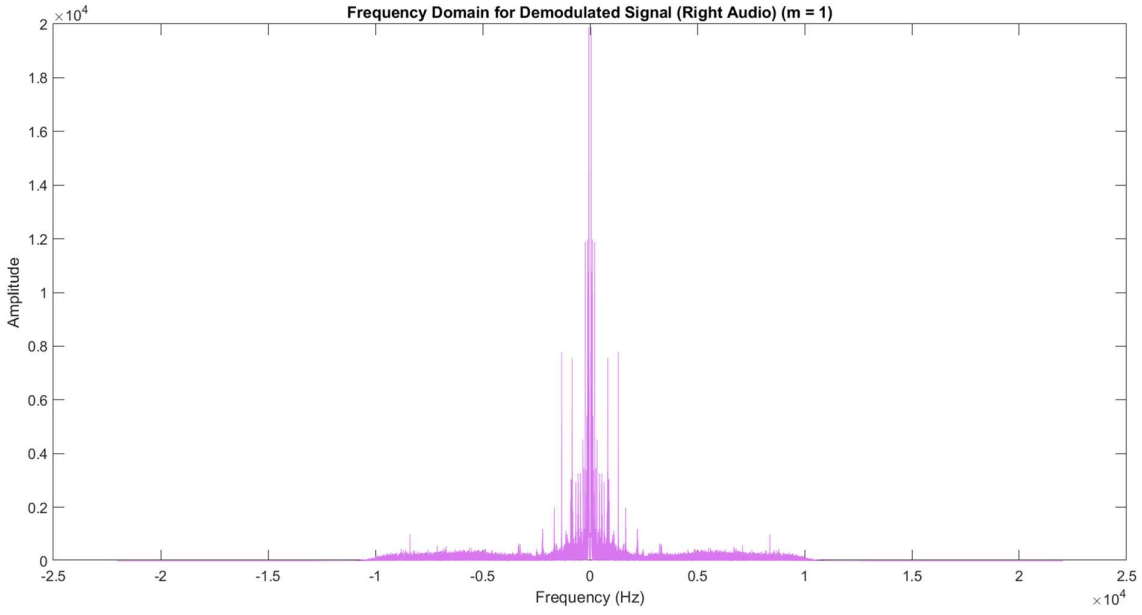
The time domain representation is:



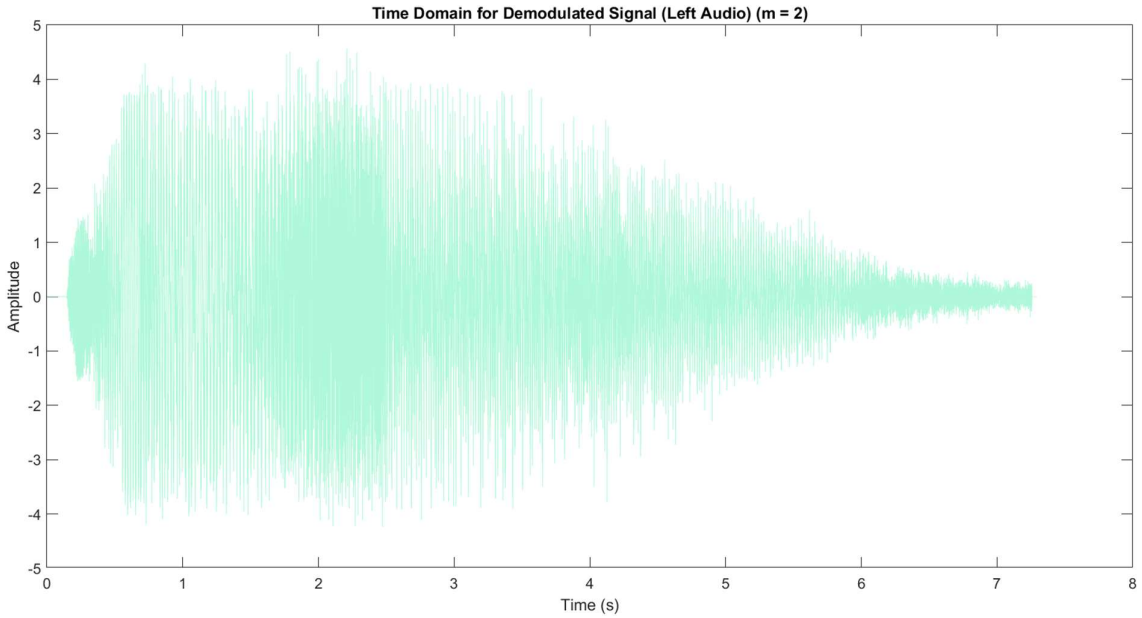
The frequency domain representation is:

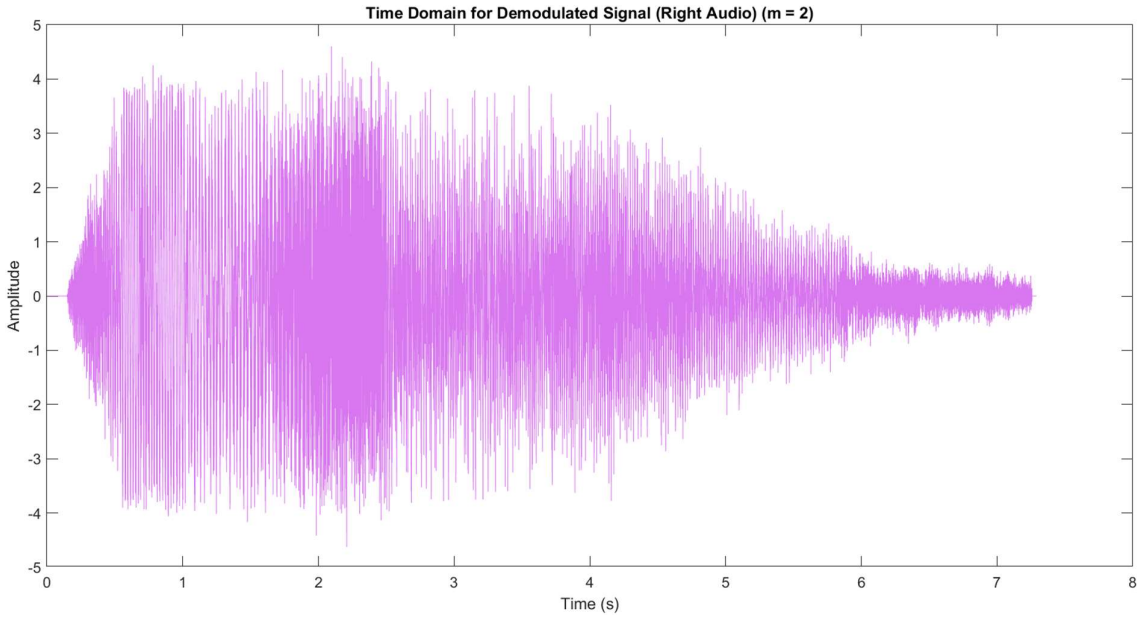


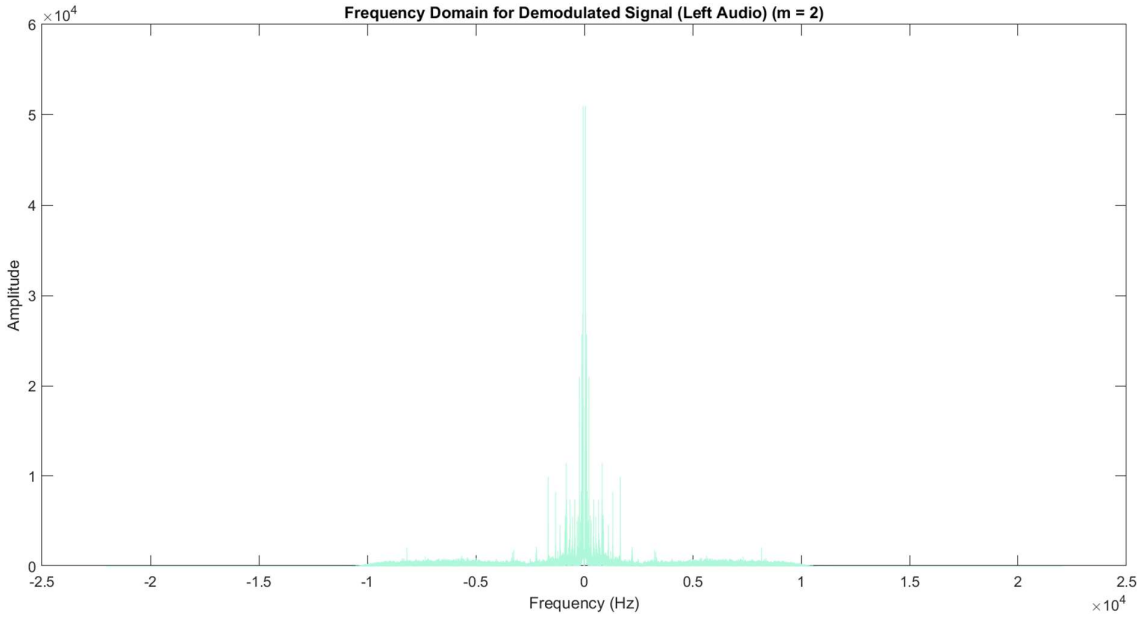
**m = 2:**

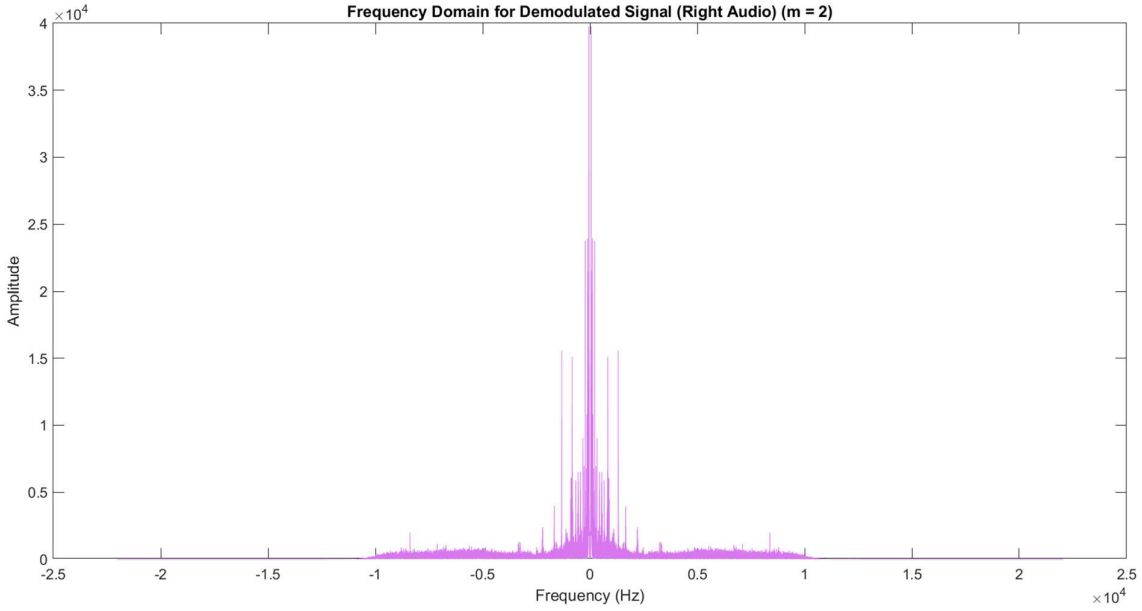
The time domain representation of the demodulated signals is:



The frequency domain representation is:



# Section 3: Amplitude Demodulation using Envelope Detector

In this section, we explore the process of amplitude demodulation using an envelope detector. The envelope detector is a crucial component in recovering the original message signal from an amplitude-modulated waveform.

## Code Description

The provided code focuses on the following key steps in amplitude demodulation using an envelope detector:

1. **Loading the Audio File:** We start by loading the audio file, "videoplayback.wav." The original audio signal is extracted, and the sampling frequency (fs) is determined.
2. **Signal Splitting:** The audio signal is split into left and right channels.
3. **Modulation Indices:** We define modulation indices for under, critically, and over modulation scenarios (mu).
4. **Carrier Signal Generation:** A carrier signal with a specified carrier frequency (fc) is generated. The carrier signal is reshaped to match the audio signals.
5. **Envelope Detector:** Incoherent demodulation is performed by first taking the envelope of the modulated signal using the Hilbert transform. The DC offset is removed from the demodulated signal to centre it around zero.
6. **Low-Pass Filtering:** To extract the message signal, a low-pass Butterworth filter is designed and applied to the demodulated signal.
7. **Analysis:** For each modulation index (mu), we analyse the original and demodulated signals in both the time and frequency domains to observe the impact of amplitude demodulation on the audio signals.

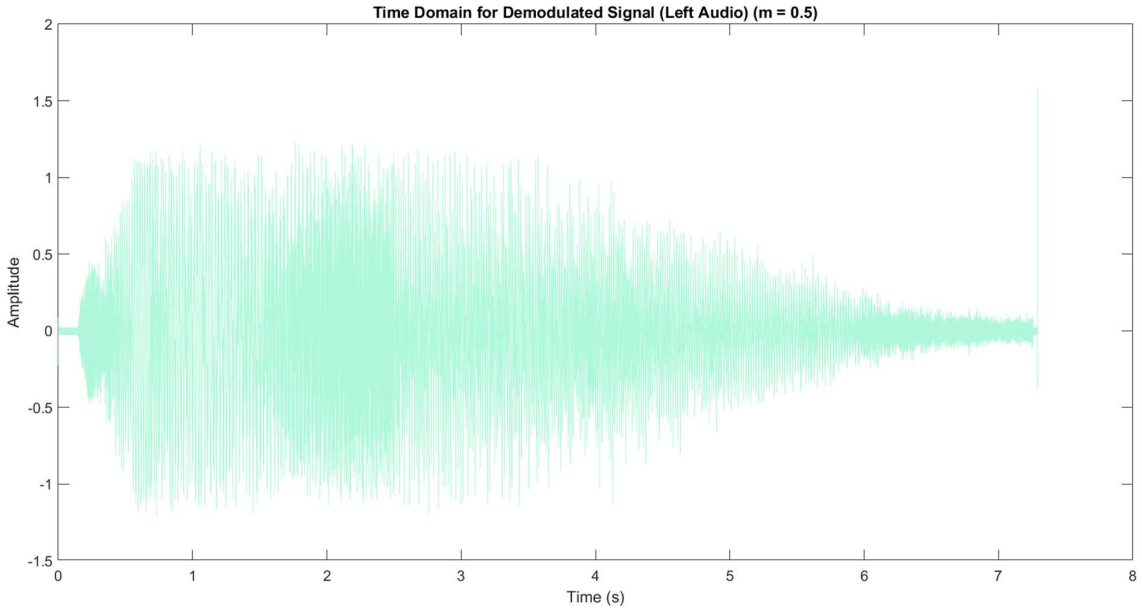
## Results

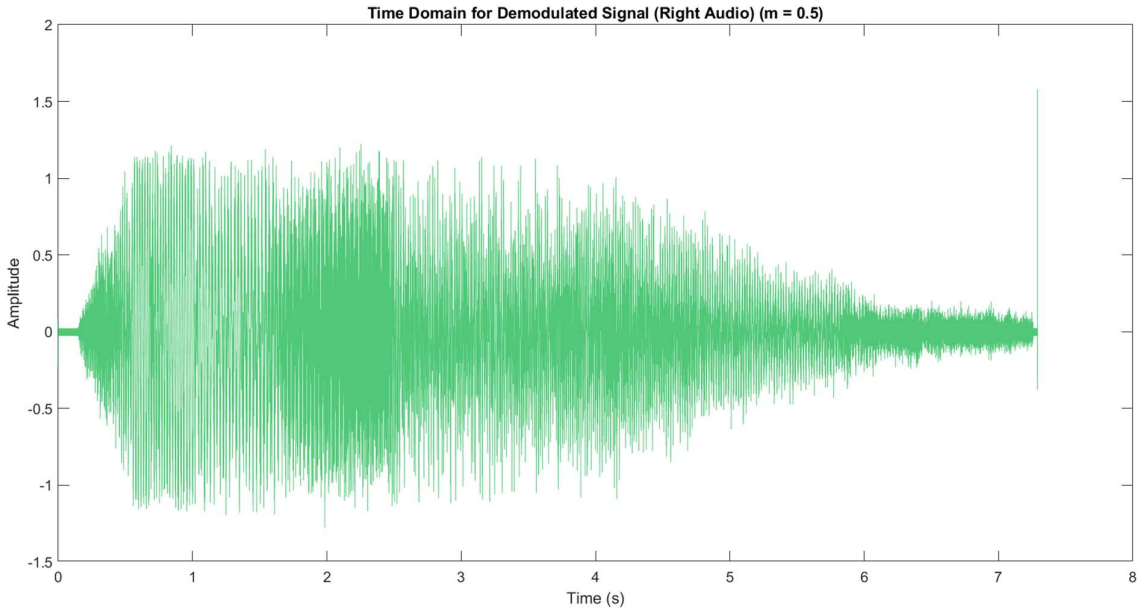
The code generates various figures and provides auditory feedback to illustrate the results of amplitude demodulation using an envelope detector. Figures display the frequency domain representations and the time domain signals of both the original and demodulated audio for different modulation indices.

The plots for various modulation indices are added below:

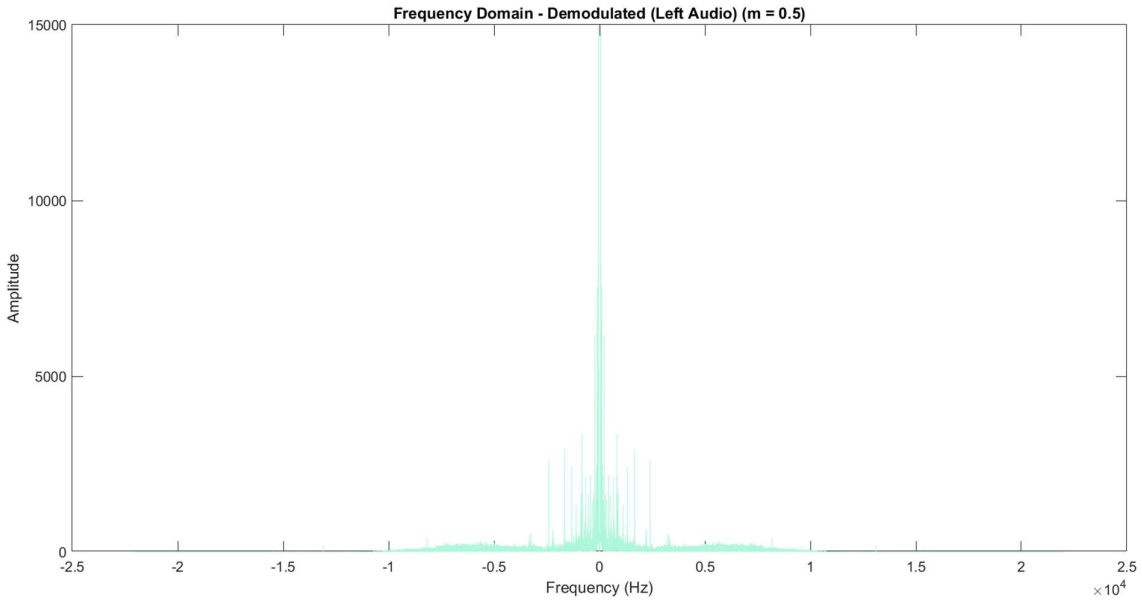
**m = 0.5:**

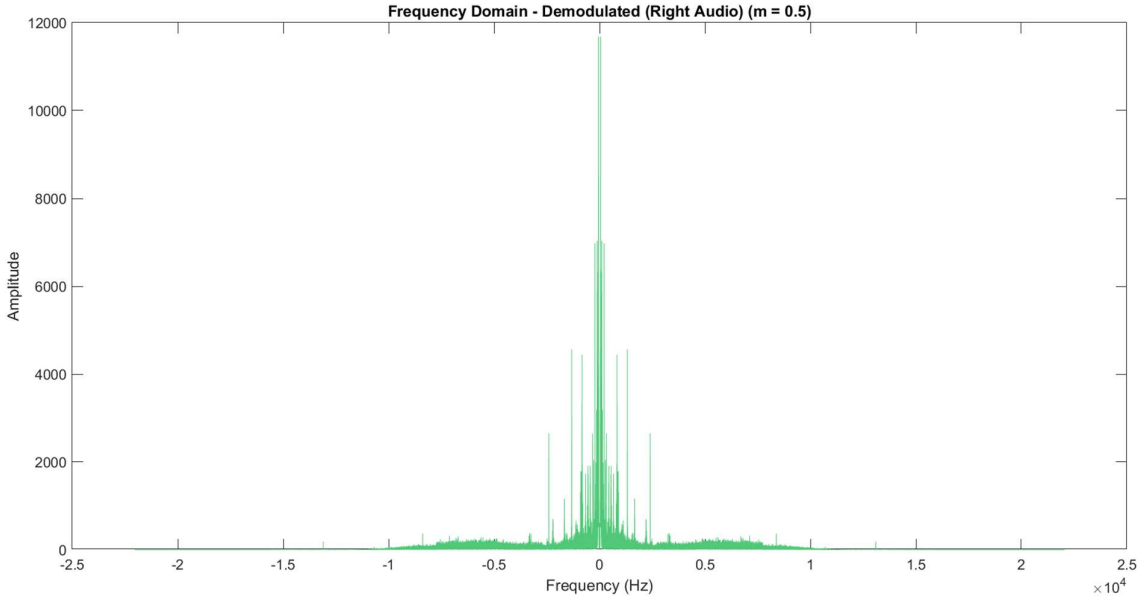
Time domain representation:



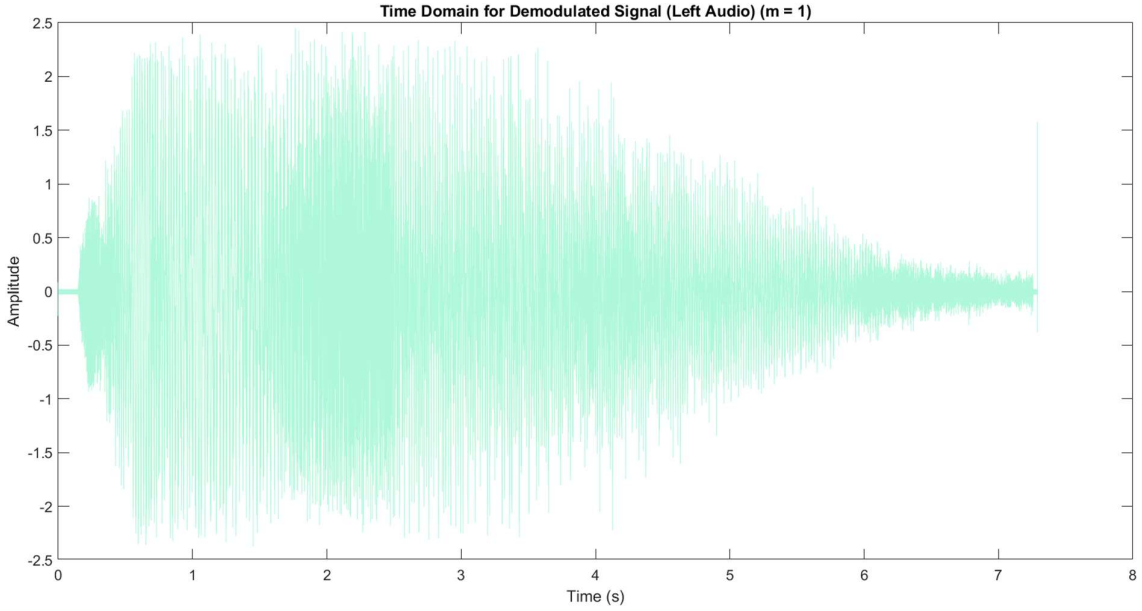
Frequency domain representation:

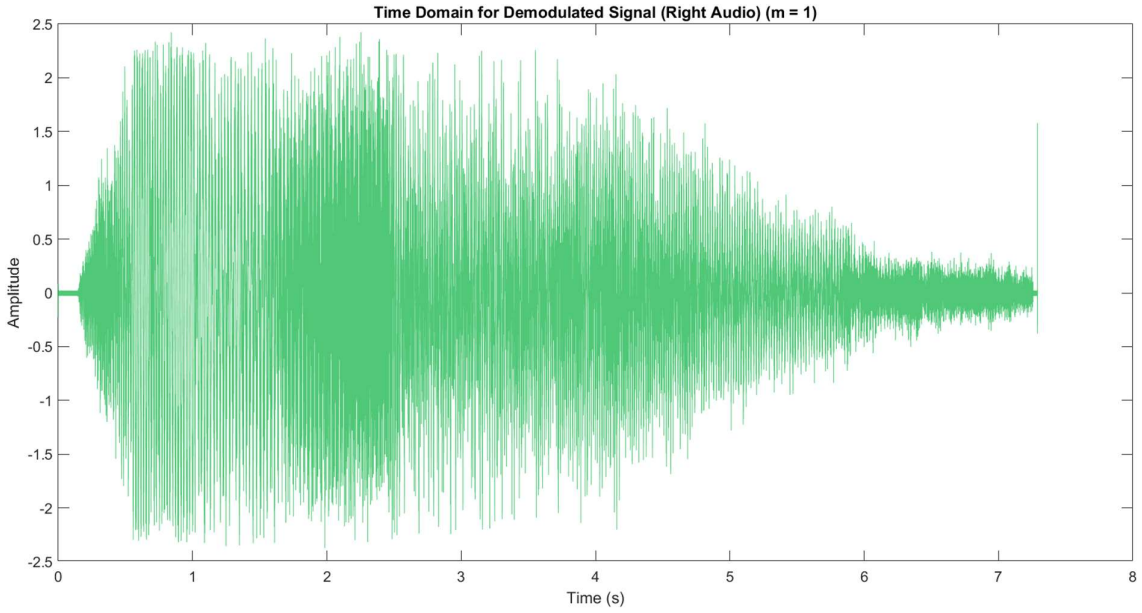


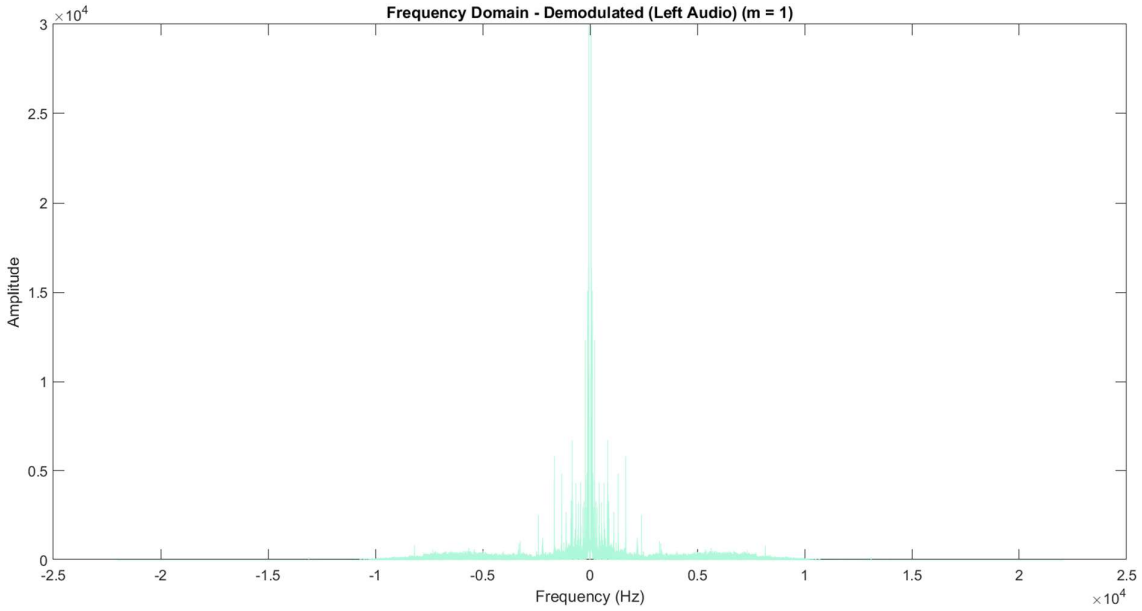
**m = 1:**

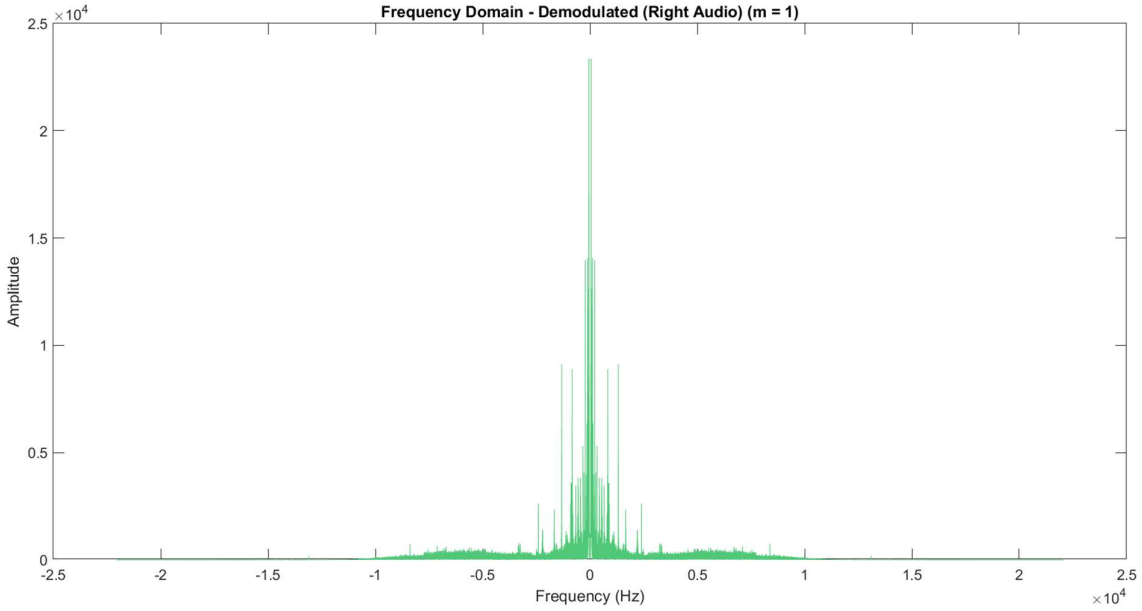
Time domain representation:



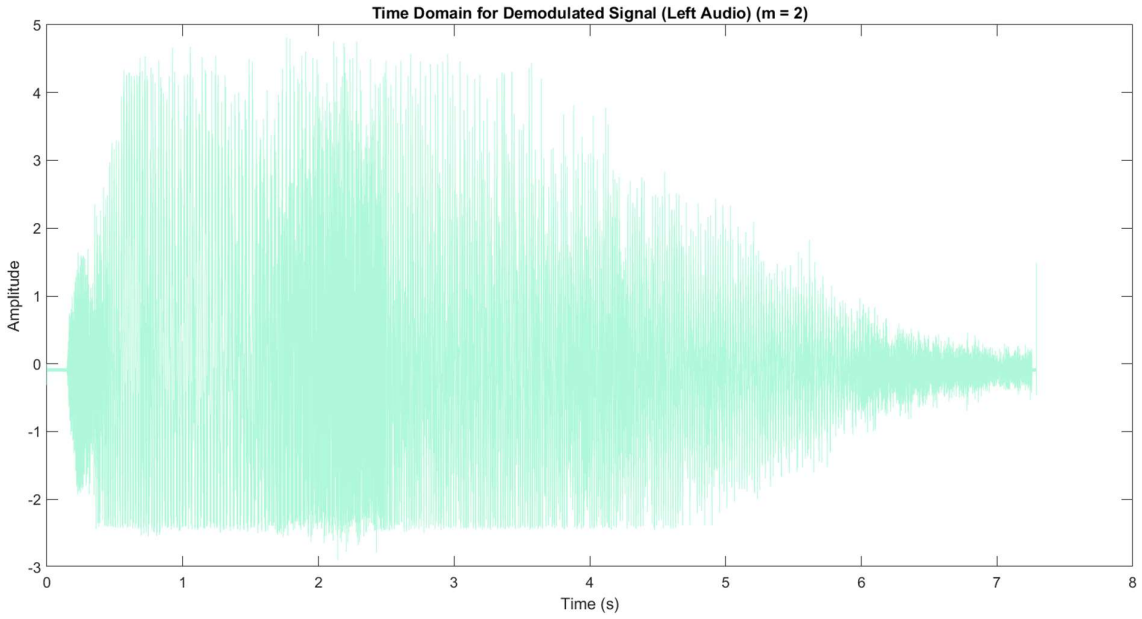
Frequency domain representation:

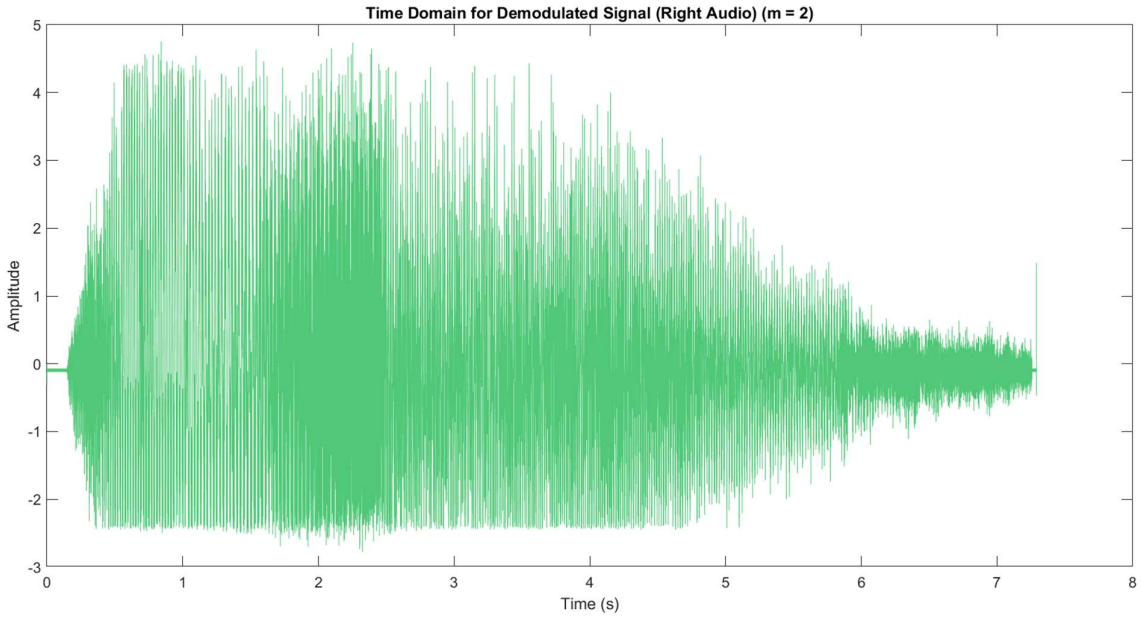


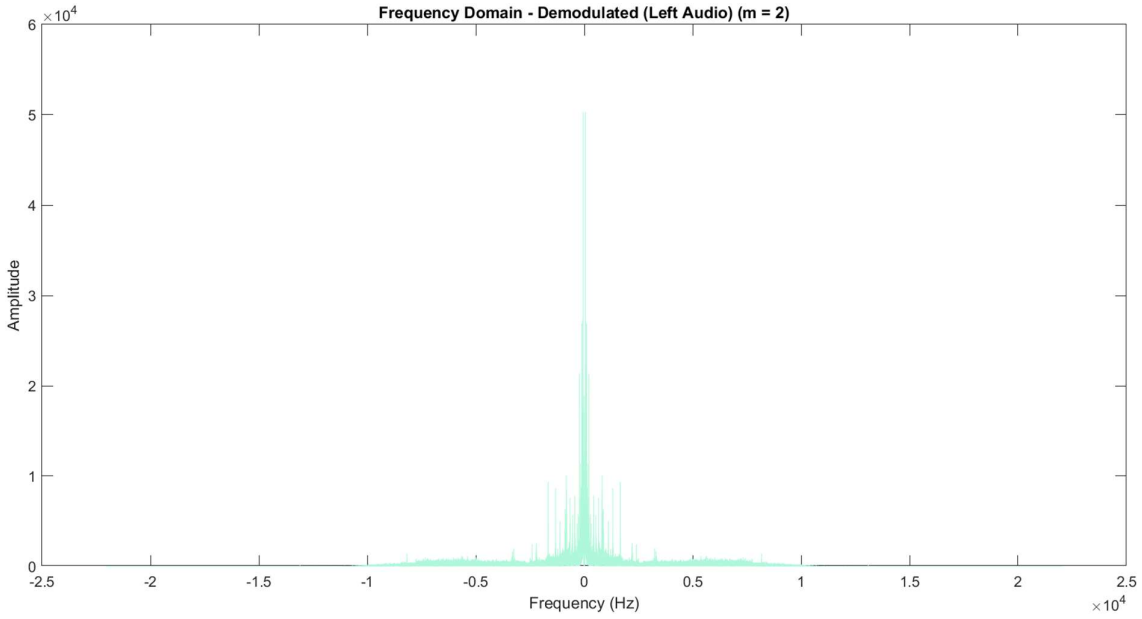
**M = 2:**

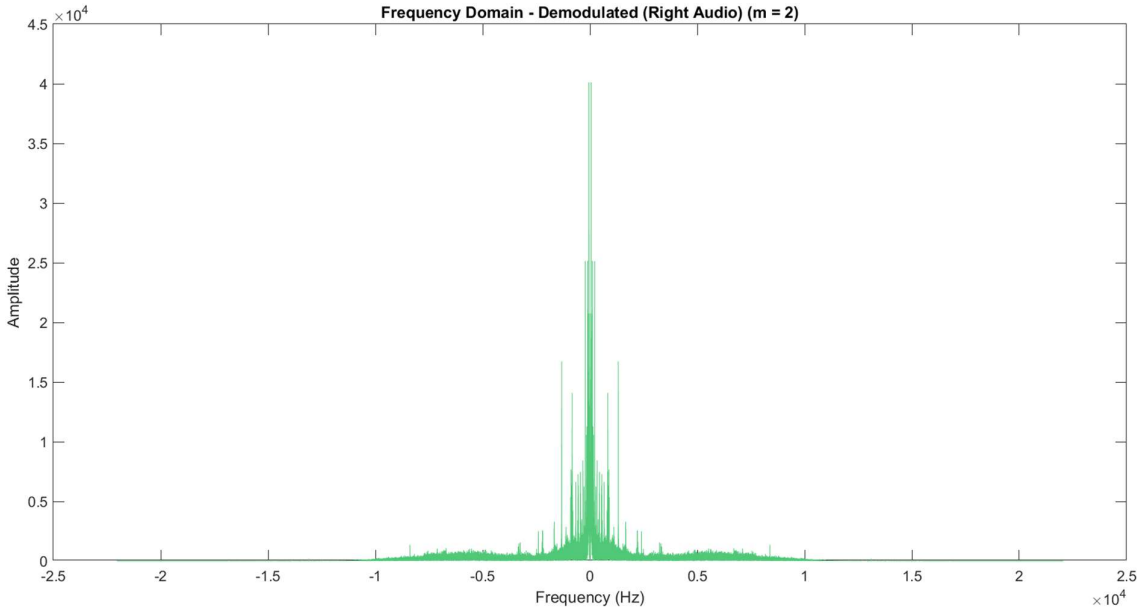
Time domain representation:



Frequency domain representation:




As we can see, the demodulation for m = 2 is not proper. This is because of overmodulation.

# Section 4: Frequency Modulation (FM)

In this section, we delve into the fascinating world of Frequency Modulation (FM). FM is a widely-used modulation technique for transmitting information via radio and other communication mediums. Unlike Amplitude Modulation (AM), FM varies the carrier signal's frequency to convey data. We will explore the principles and effects of FM modulation on audio signals.

## Introduction to Frequency Modulation

Frequency Modulation (FM) is a modulation technique used in various communication systems. In FM, the frequency of the carrier signal varies in proportion to the instantaneous amplitude of the modulating signal. This variation in frequency allows for the transmission of audio signals, making FM a popular choice in broadcasting, particularly in FM radio.

## Code Description

The provided code illustrates FM modulation using the following key steps:

1. **Loading the Audio File:** We begin by loading the audio file, "videoplayback.wav." This audio file will serve as our source signal for FM modulation.
2. **Signal Splitting:** The audio signal is separated into left and right channels.
3. **Time and Frequency Domain Analysis (Original Signal):** We first analyse the original audio signals in both the time and frequency domains. This step allows us to understand the characteristics of the audio signals before modulation.
4. **FM Modulation:** The code generates FM-modulated signals for the left and right audio channels. We explore different modulation indices (mu) of 0.5, 1, and 2. The modulated signals are obtained by cumulatively integrating the modulating audio signals.
5. **Time and Frequency Domain Analysis (FM Signals):** The FM-modulated signals are analysed in both the time and frequency domains. These analyses reveal the effects of FM modulation on the audio signals and provide insights into how varying modulation indices influence the modulated signals.

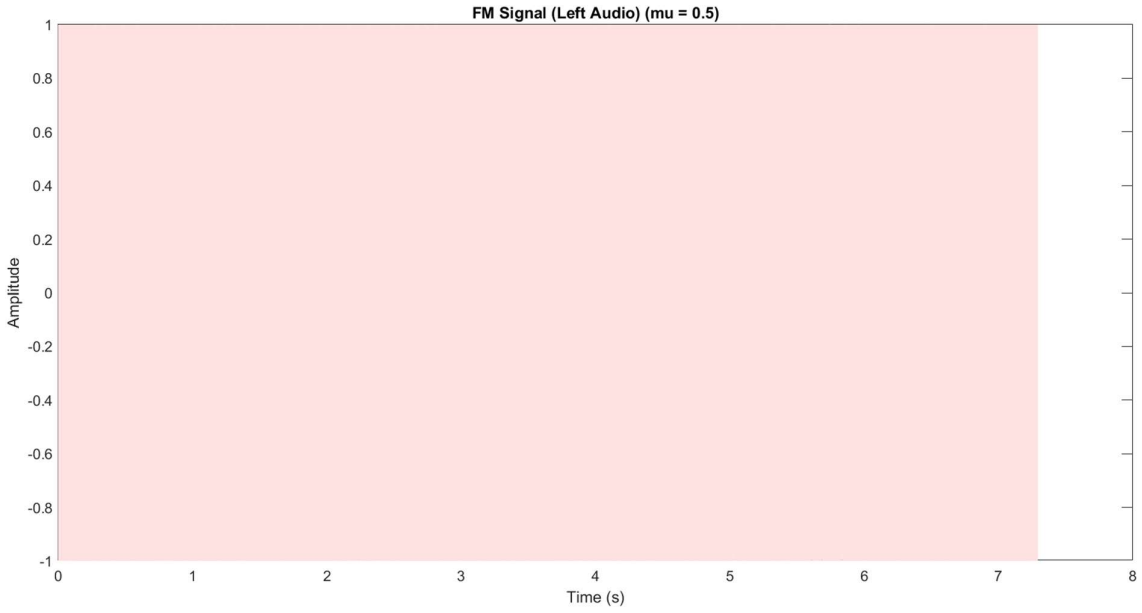
## Results

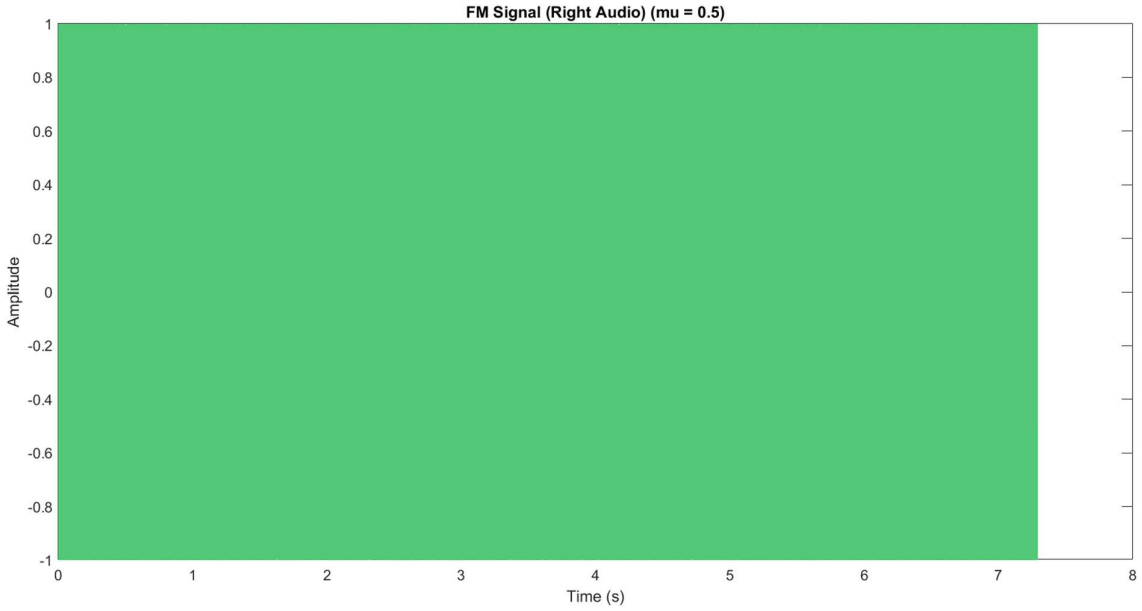
The code generates several figures showcasing the original and FM-modulated signals in both the time and frequency domains. These figures help us visualize the impact of FM modulation on audio signals and understand how different modulation indices affect the modulation process.

The plots corresponding to the different modulation indices are shown below.

**M = 0.5:**

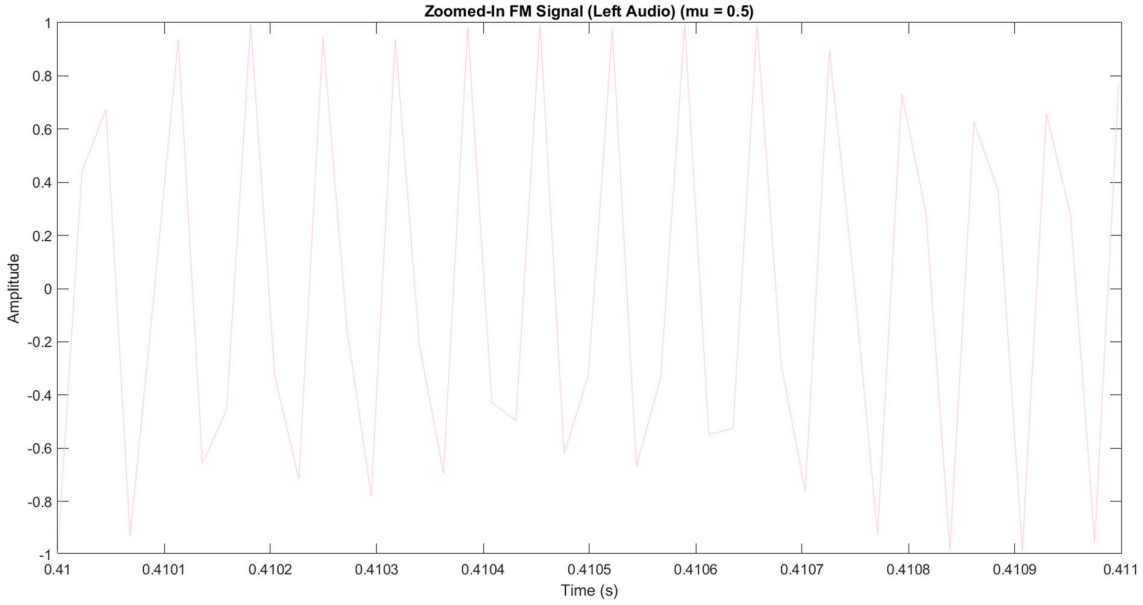
Time domain representation:

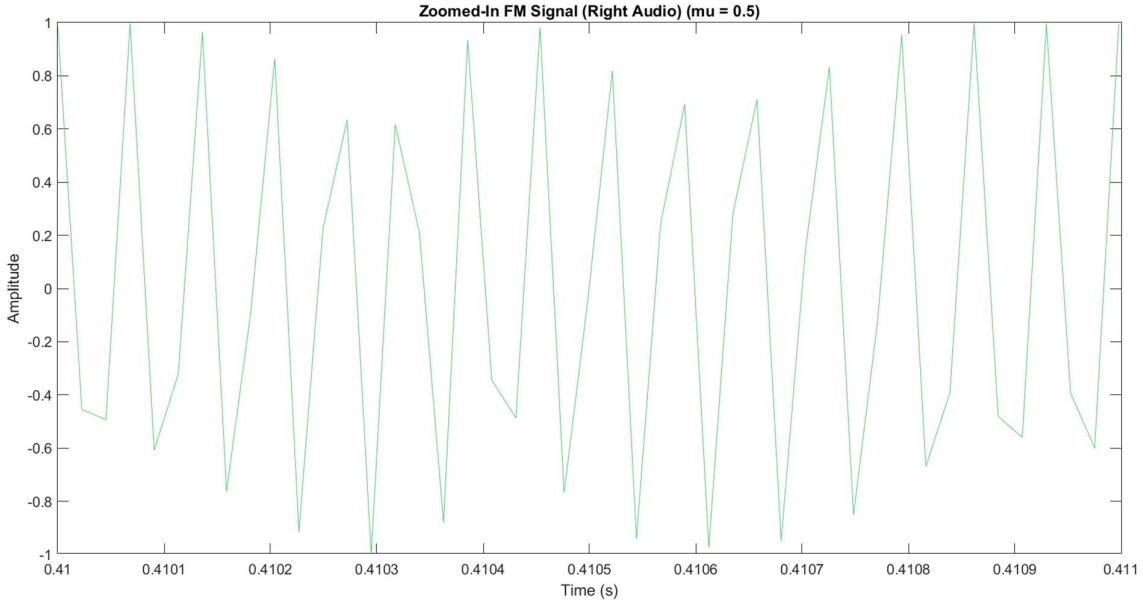


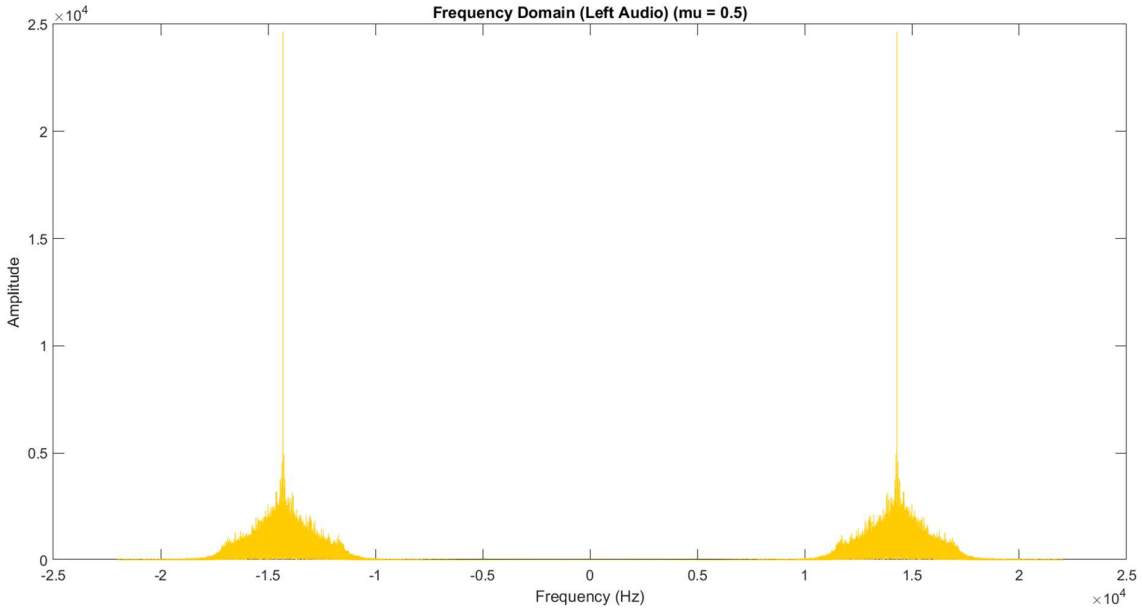

Since the carrier frequency is very high, to understand the signal, we have to take a look at the zoomed in signal.

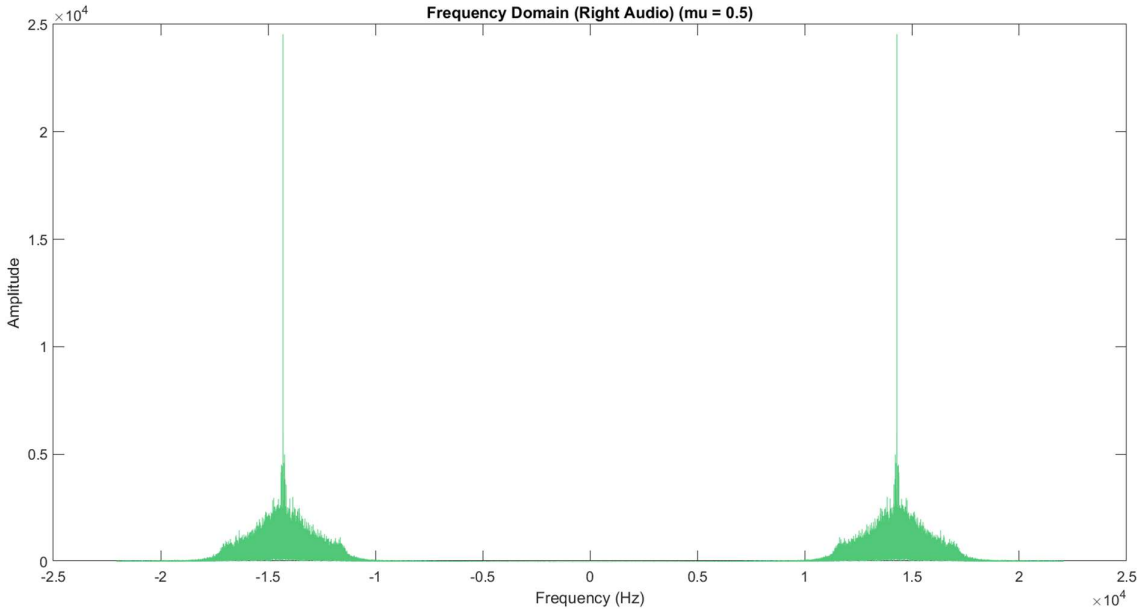
Zoomed in time domain representation:



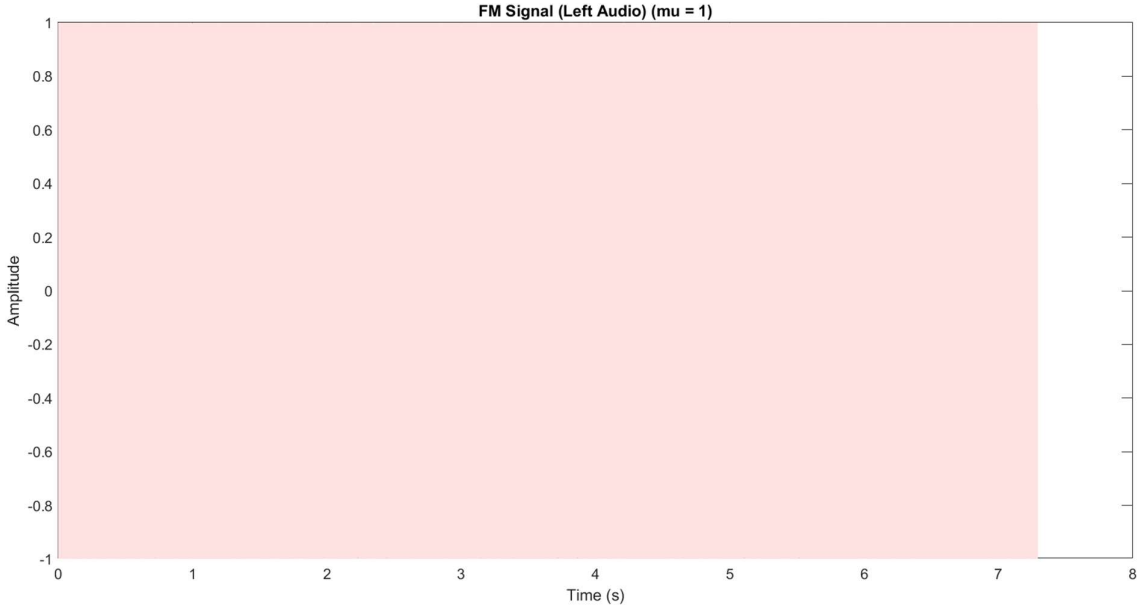
Frequency domain representation:

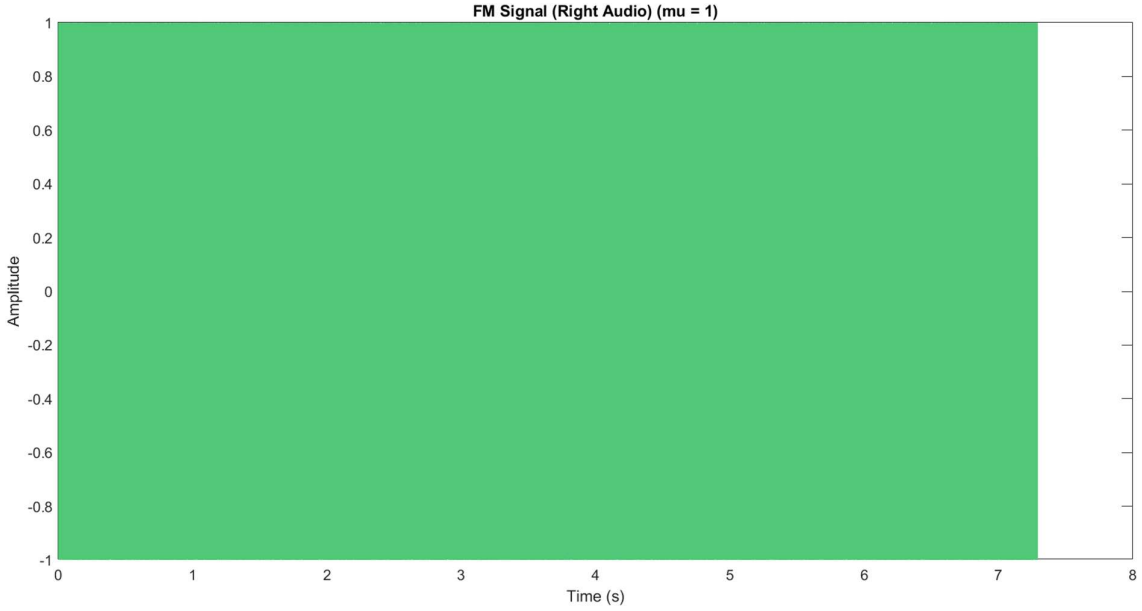


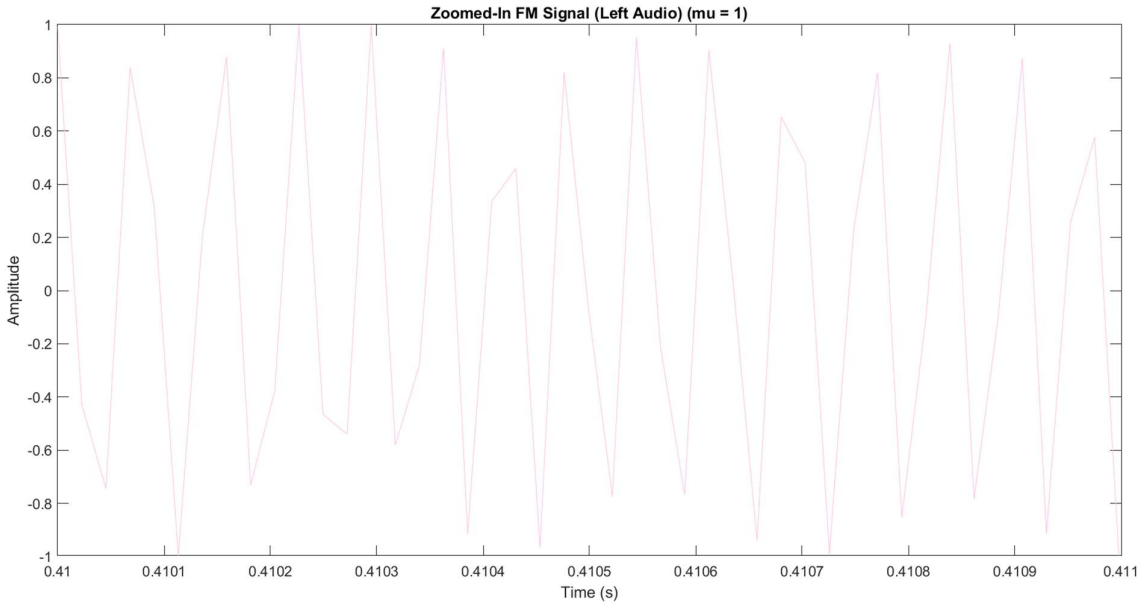
## M = 1:

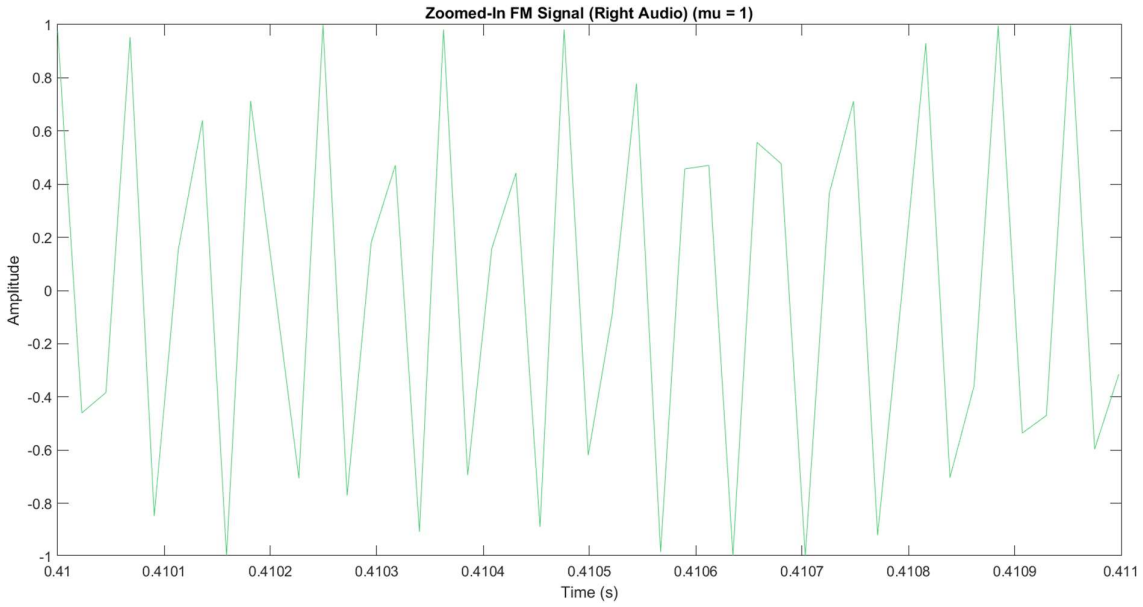
Time domain representation:



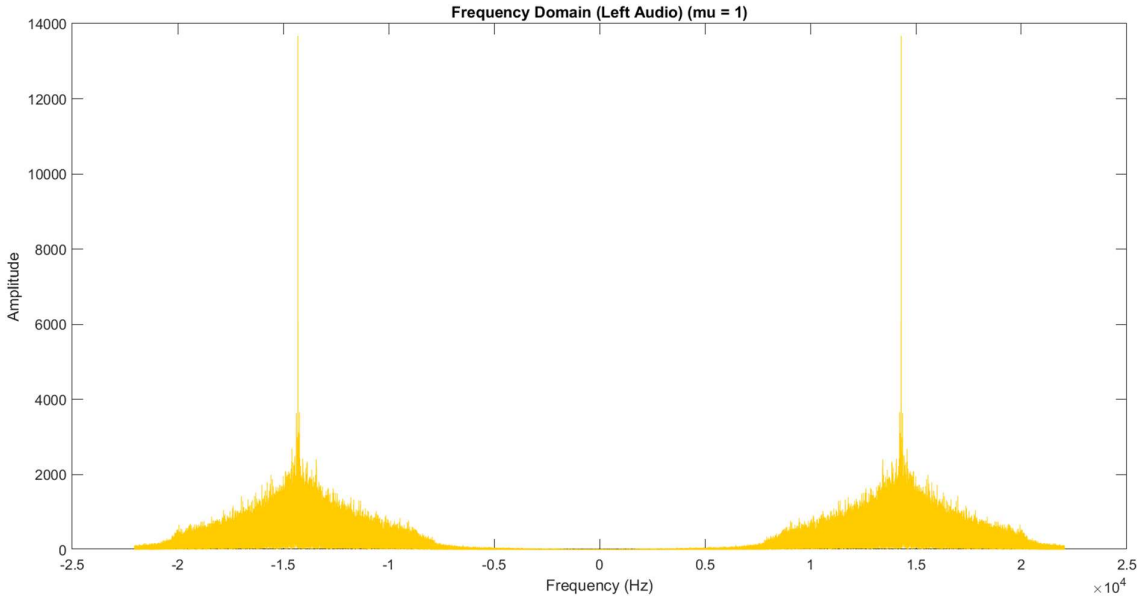



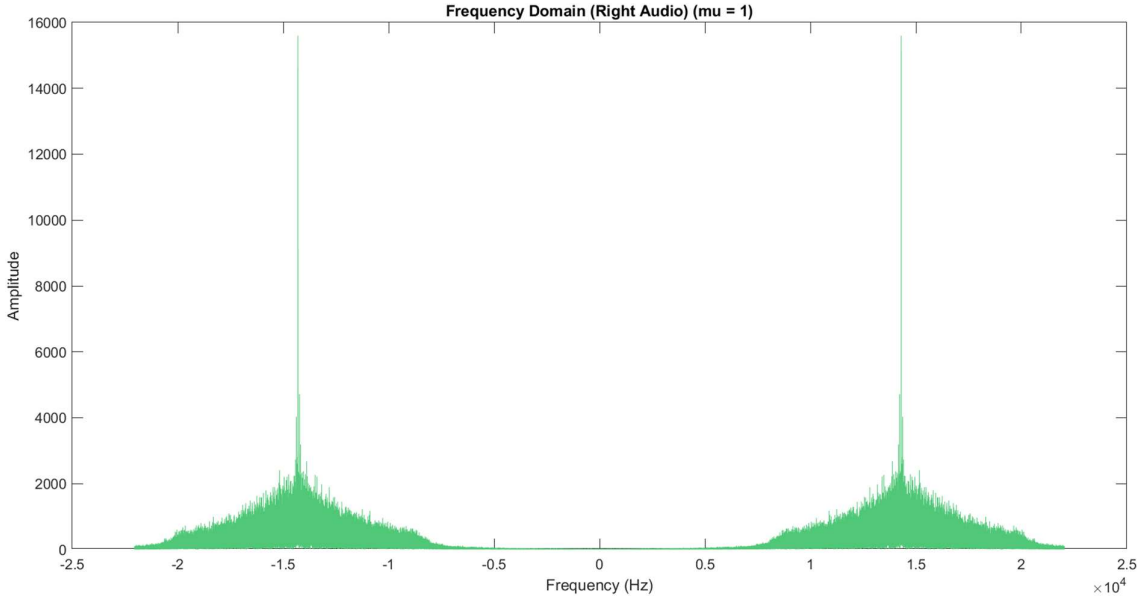
Zoomed in signals:



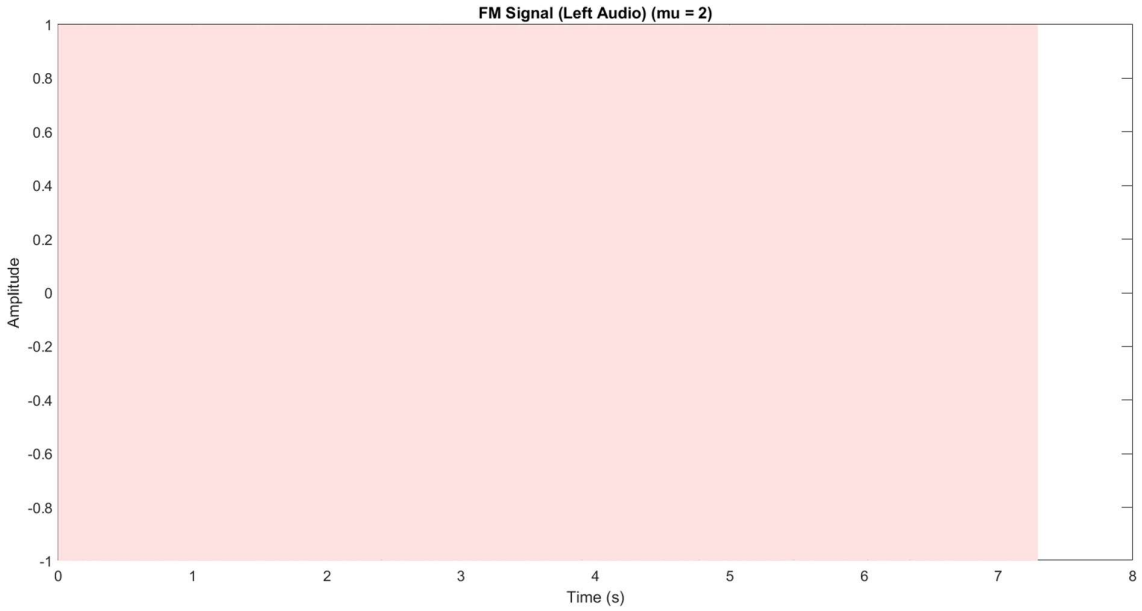
Frequency domain representation:

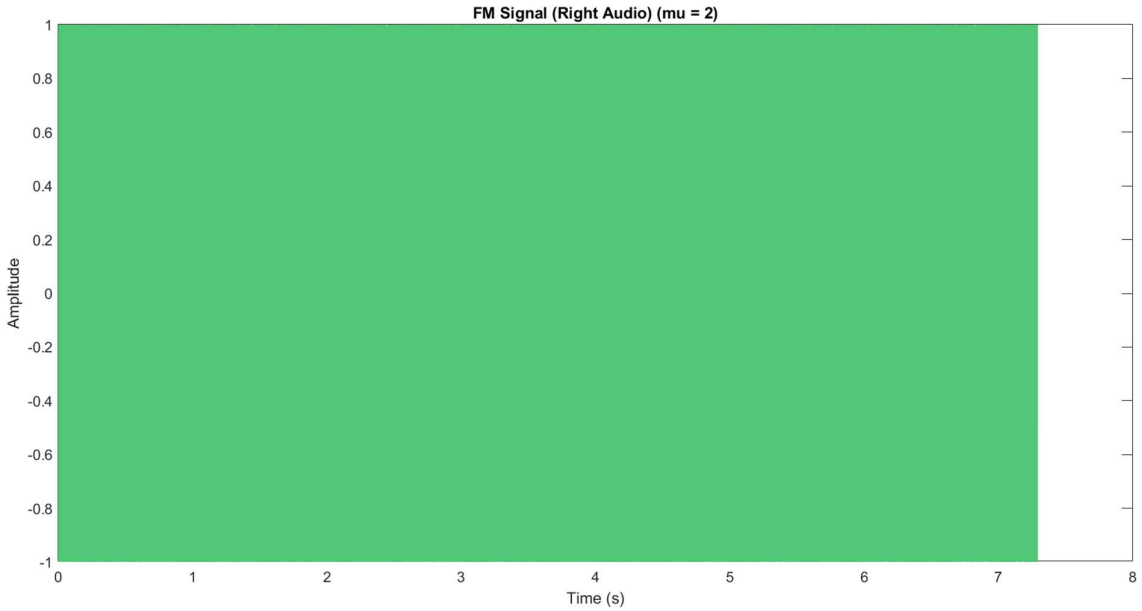


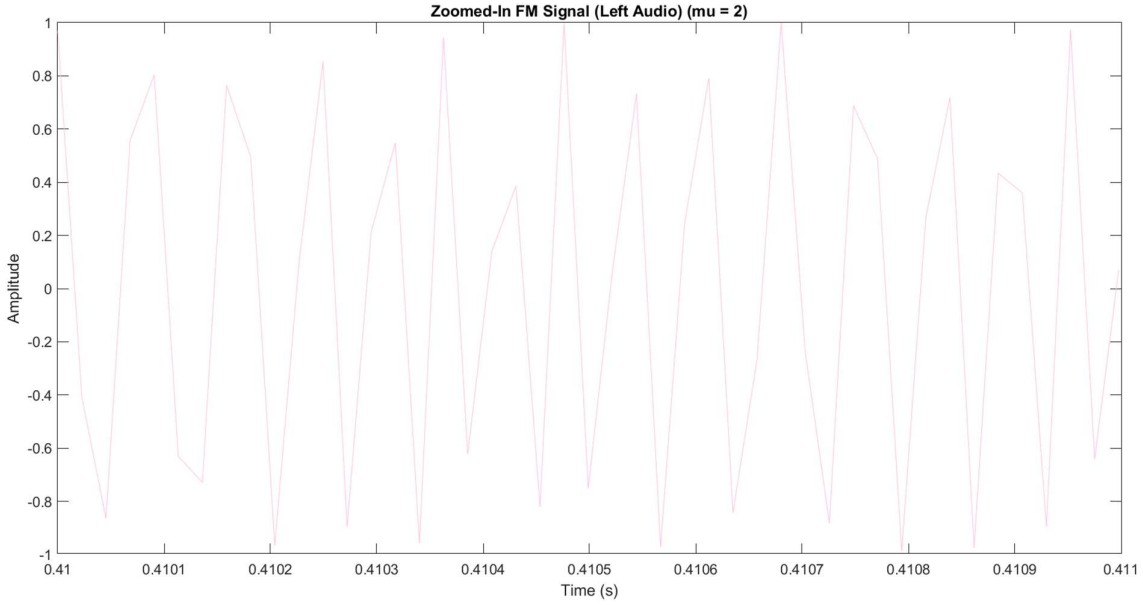
**M = 2:**

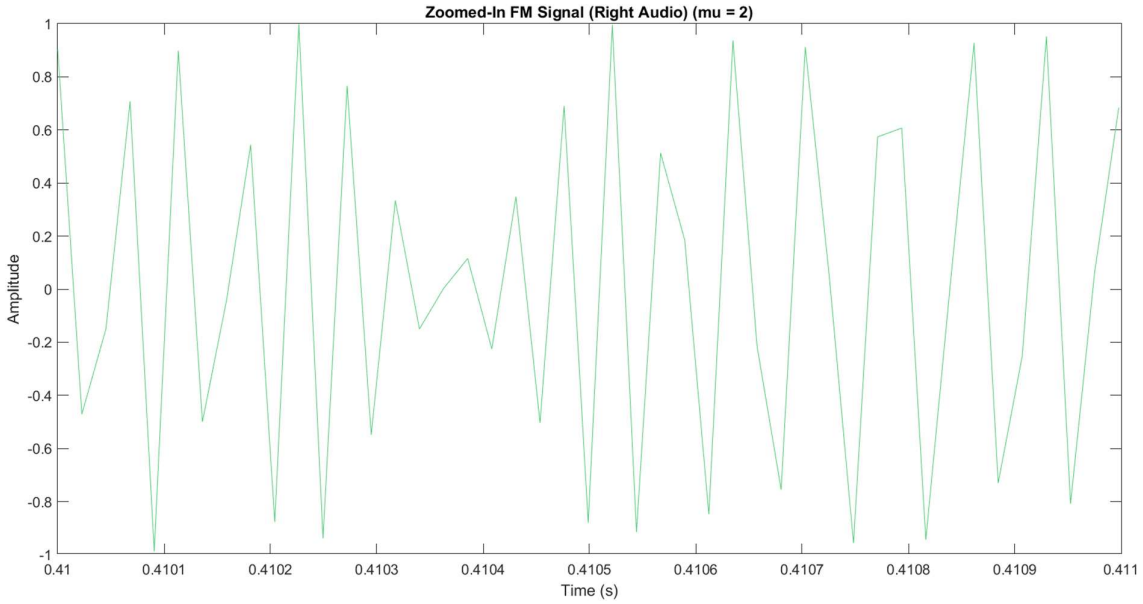
Time domain representation:



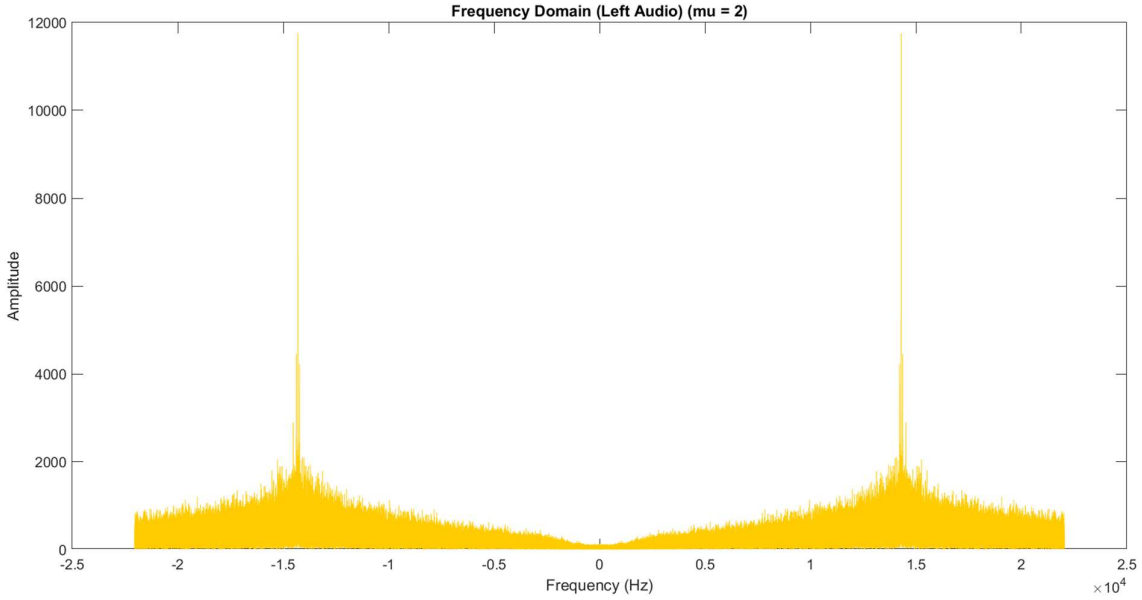



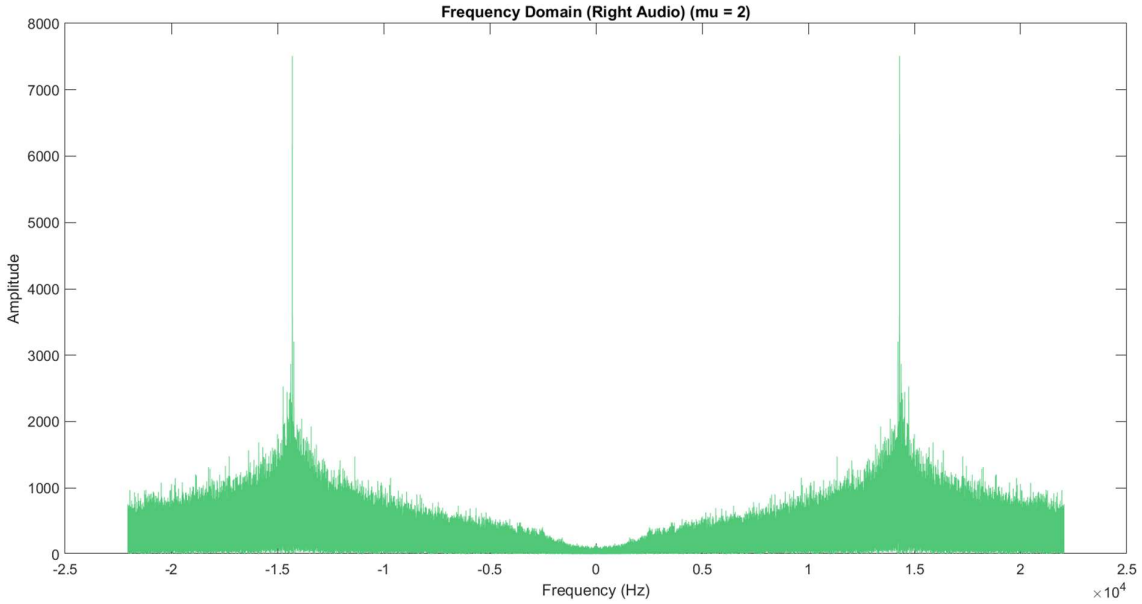
Zoomed in signals:



Frequency domain representation:



# Section 5: Frequency Demodulation using Differentiator and Envelope Detection

In this section, we explore the process of frequency demodulation using the methods of differentiator and envelope detection. This technique is essential for extracting the original audio signal from a frequency-modulated carrier.

## Introduction to Frequency Demodulation

Frequency Modulation (FM) is a modulation technique in which the frequency of the carrier signal varies according to the instantaneous amplitude of the modulating signal. To recover the original audio signal from an FM-modulated carrier, we require demodulation. The provided code showcases a demodulation technique involving differentiation and envelope detection.

## Code Description

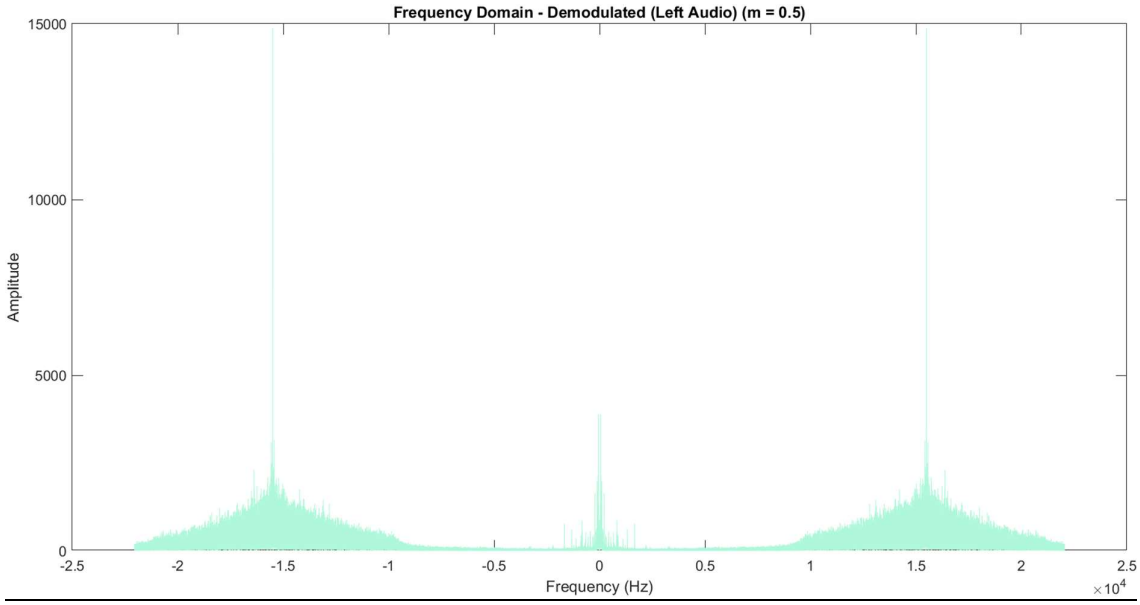
The code performs the following steps:

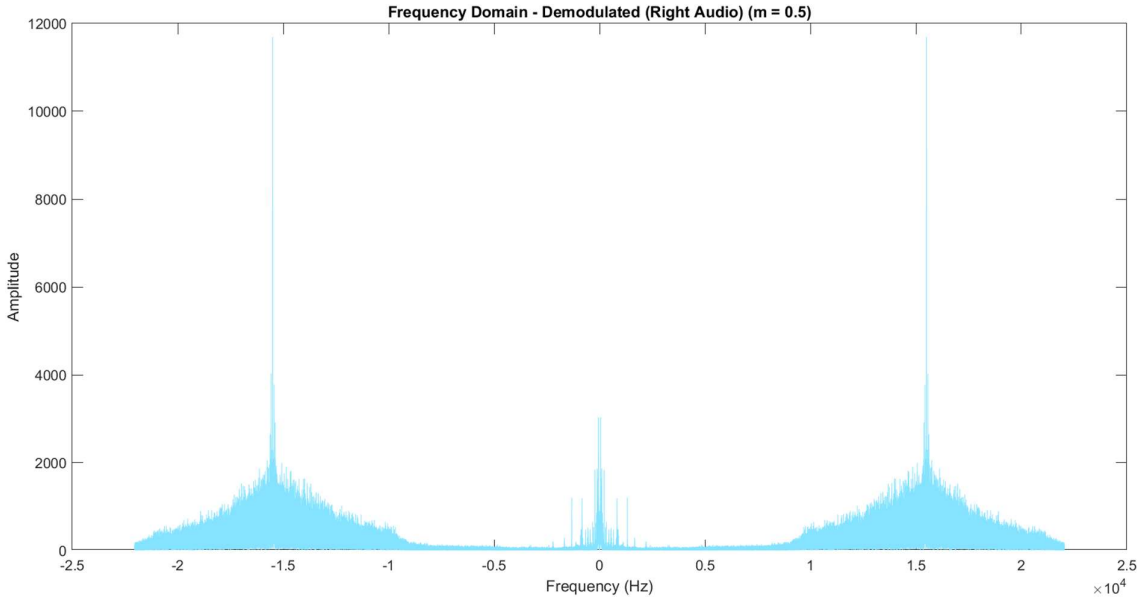
1. **Loading the Audio File:** We start by loading the audio file, "videoplayback.wav." This file serves as our source for FM demodulation.
2. **Signal Splitting:** The audio signal is split into left and right channels.
3. **Frequency Domain Analysis (Original Signal):** The code analyses the frequency domain of the original audio signals, allowing us to understand the characteristics of the FM-modulated signals.
4. **FM Demodulation:** Demodulation is carried out for different modulation indices (0.5, 1, and 2) for both the left and right audio channels. The process involves differentiation, envelope detection, and low-pass filtering. The signal is also scaled appropriately to try to ensure that proper information is passed. The modulation index variation helps us visualize the impact of modulation depth on the demodulation process.
5. **Time and Frequency Domain Analysis (Demodulated Signal):** We analyse the demodulated signals in both the time and frequency domains. Additionally, the code scales the frequency components in a certain range for the left audio channel to emphasize specific frequency bands.

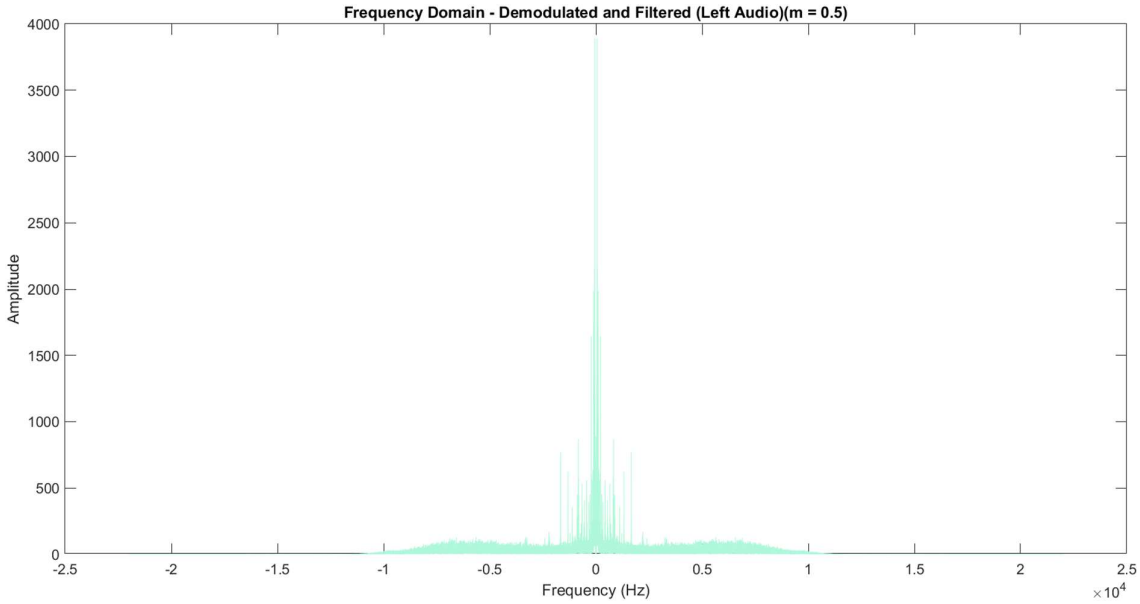
## Results

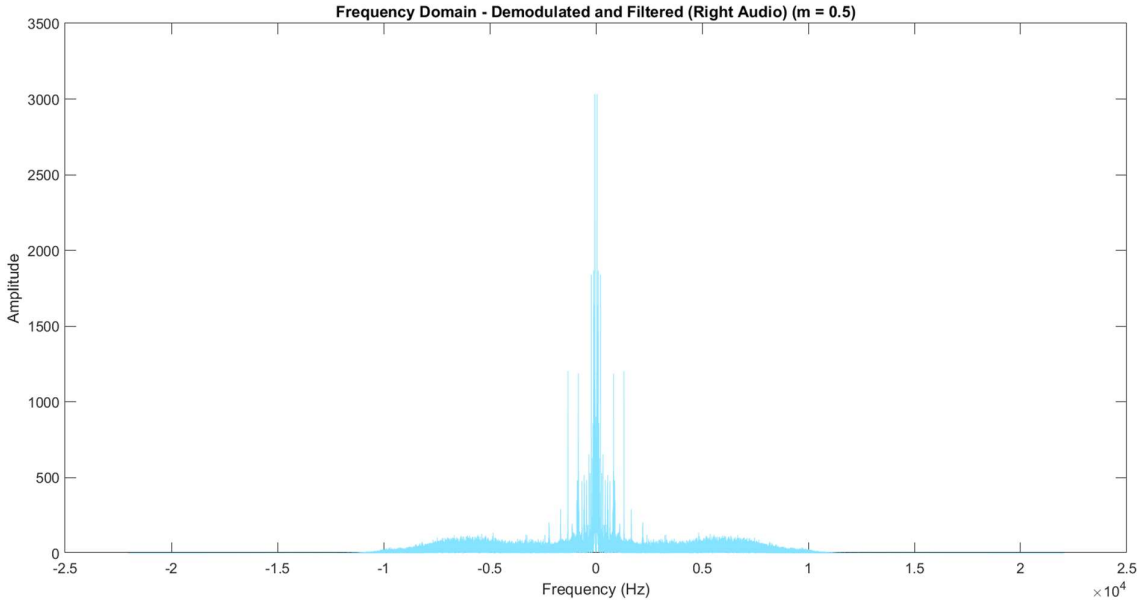
The code generates multiple figures illustrating the frequency demodulation process, both in the time and frequency domains. These figures help us visualize the impact of modulation indices on the demodulated audio signals.

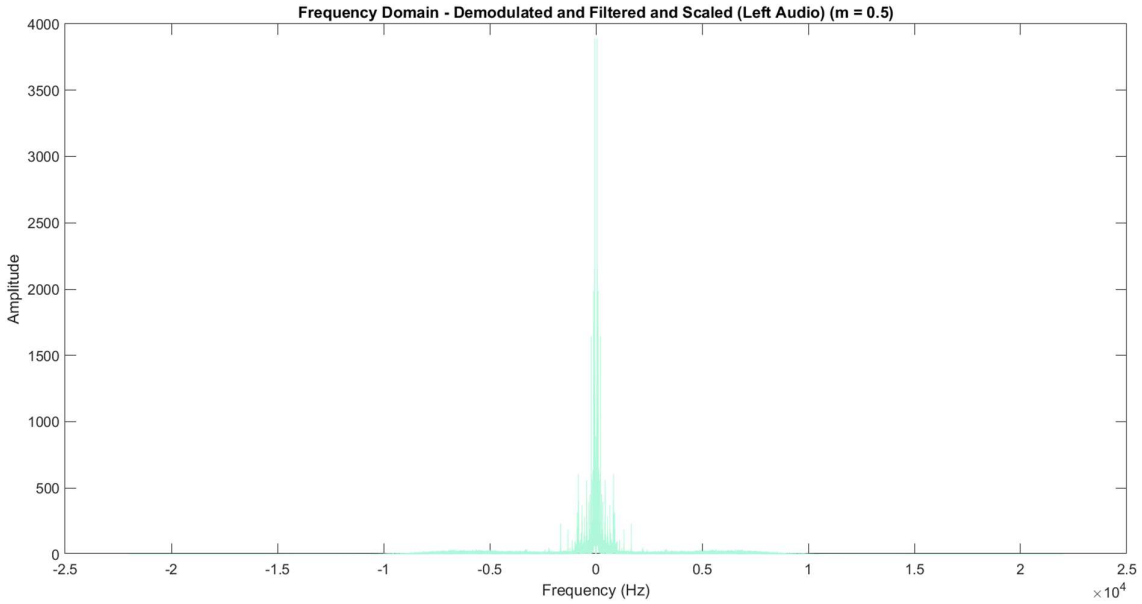
The plots for various modulation indices are added below.

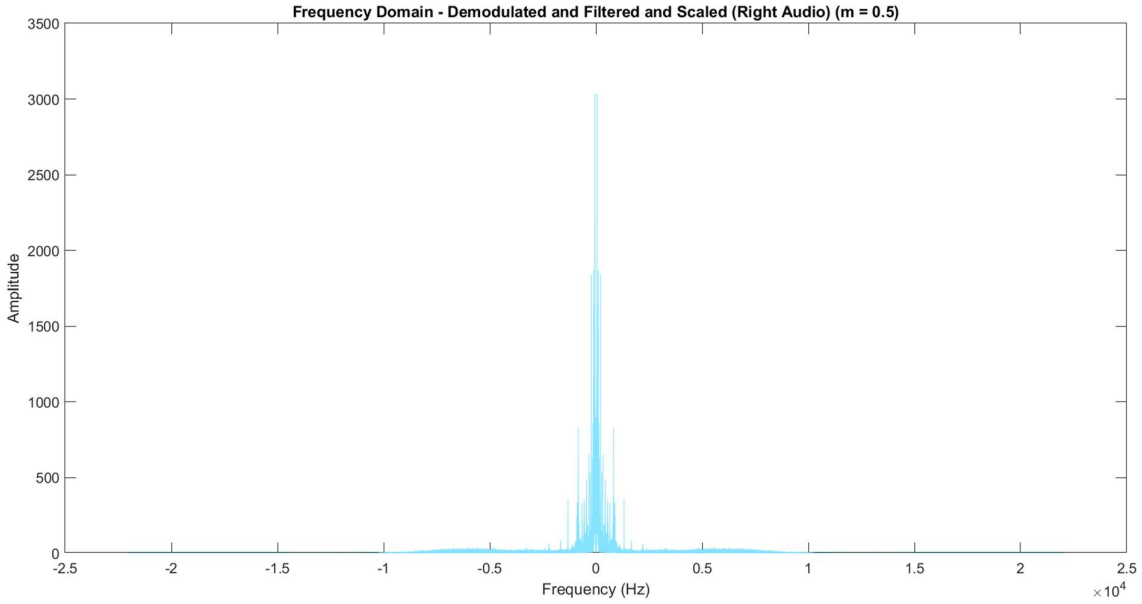

Frequency Domain - Demodulated (Left Audio) (m = 0.5)
15000
10000
5000
0
Amplitude
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Frequency (Hz)
×10^4

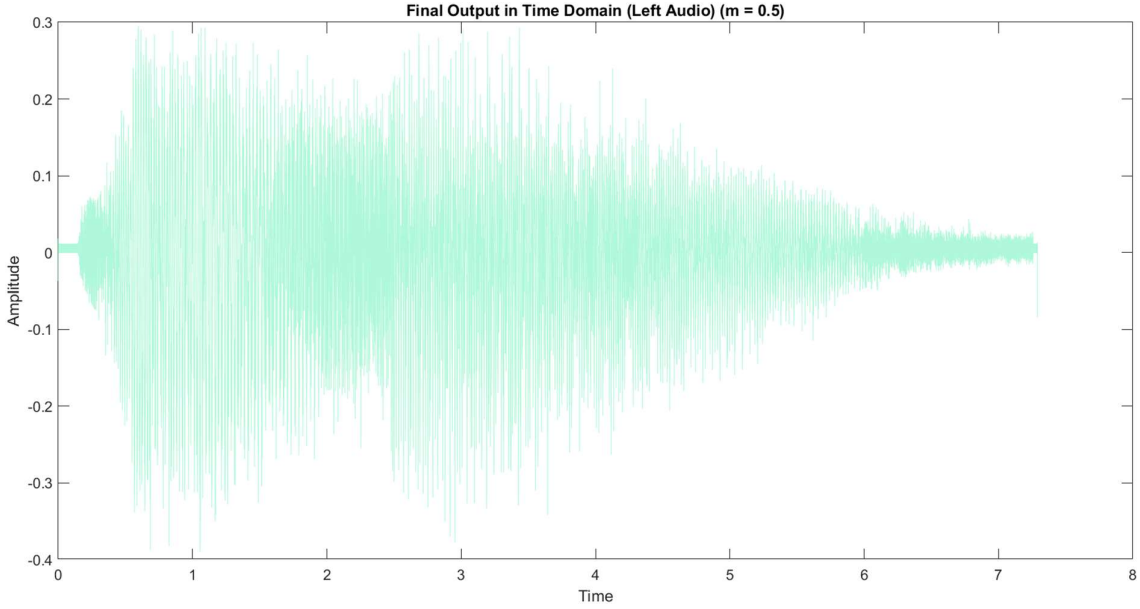

Frequency Domain - Demodulated (Right Audio) (m = 0.5)
12000
10000
8000
6000
4000
2000
0
Amplitude
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Frequency (Hz)
×10^4

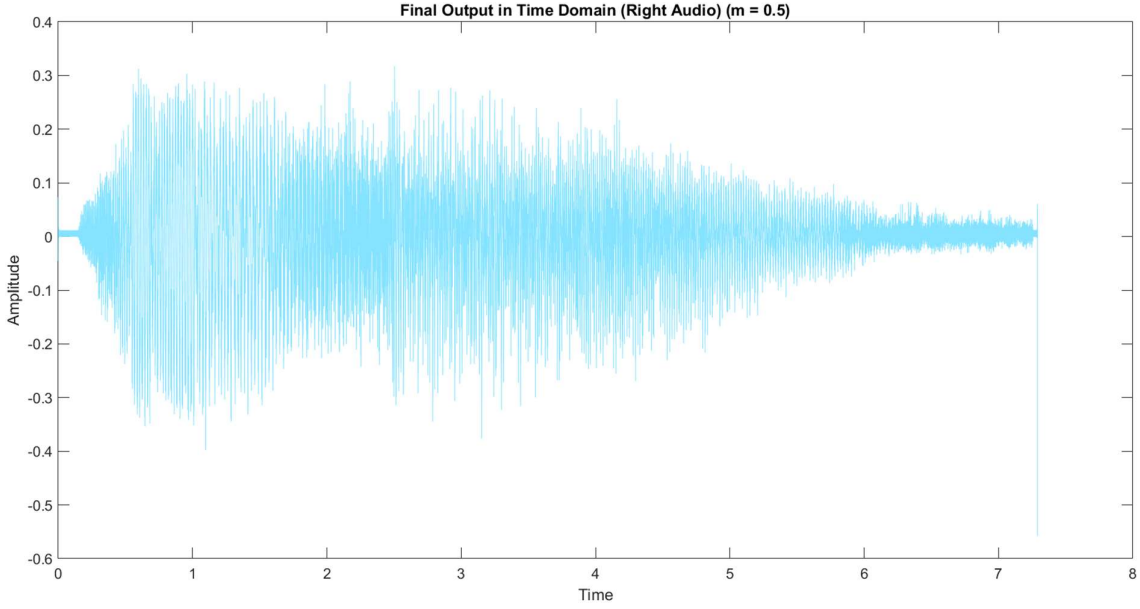

Frequency Domain - Demodulated and Filtered (Left Audio)(m = 0.5)
Amplitude
Frequency (Hz)
×10^4

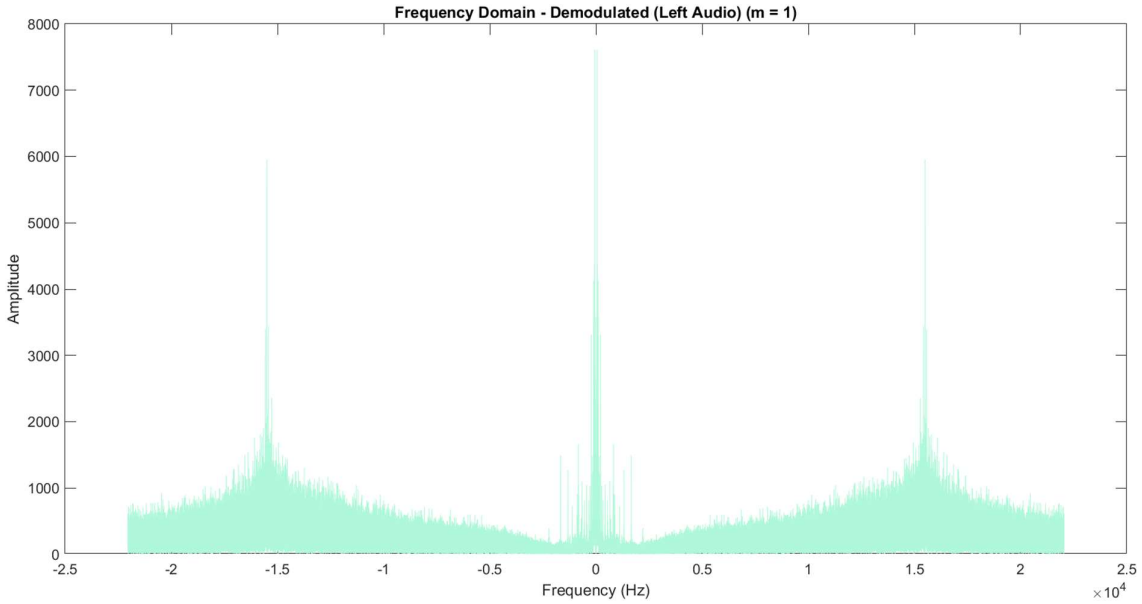

Frequency Domain - Demodulated and Filtered (Right Audio) (m = 0.5)
Amplitude
Frequency (Hz)
×10^4

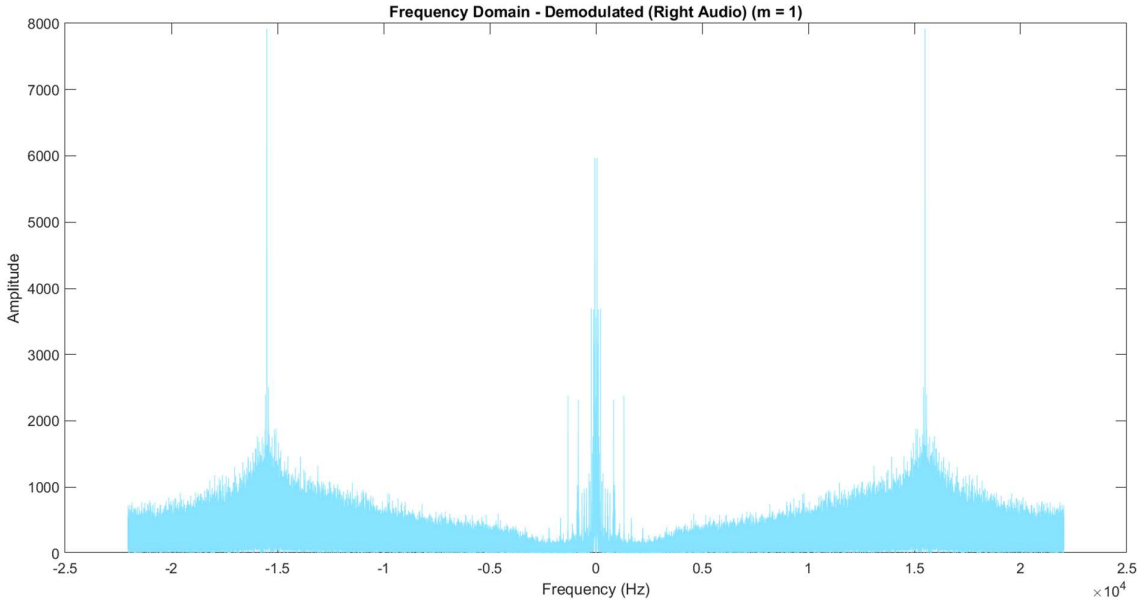

Frequency Domain - Demodulated and Filtered and Scaled (Left Audio) (m = 0.5)
Amplitude
Frequency (Hz)
×10^4

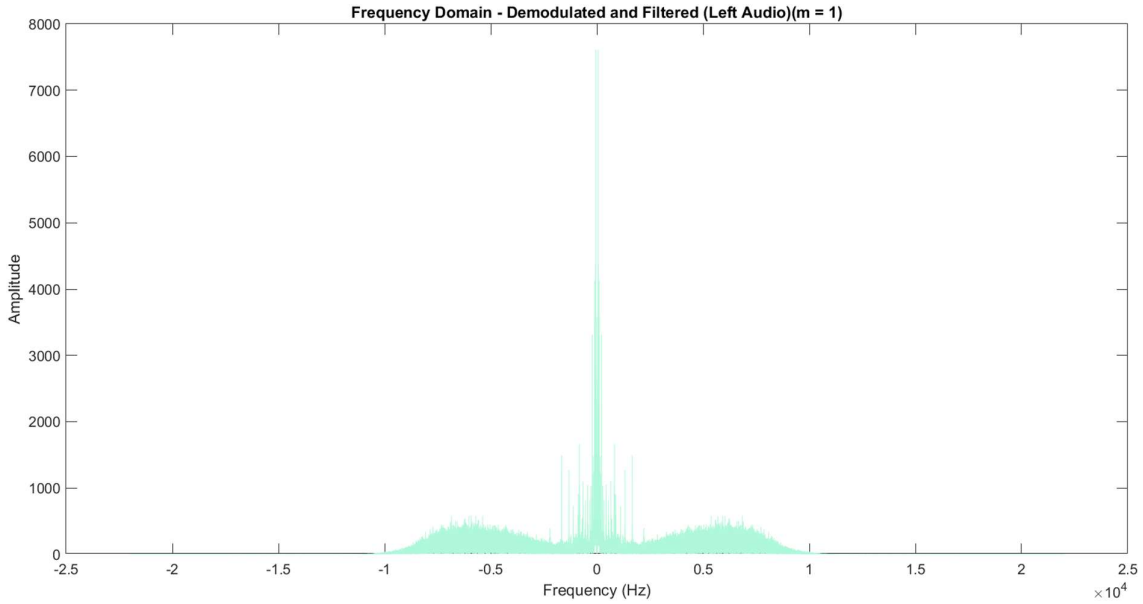

Frequency Domain - Demodulated and Filtered and Scaled (Right Audio) (m = 0.5)
Amplitude
Frequency (Hz)
×10^4

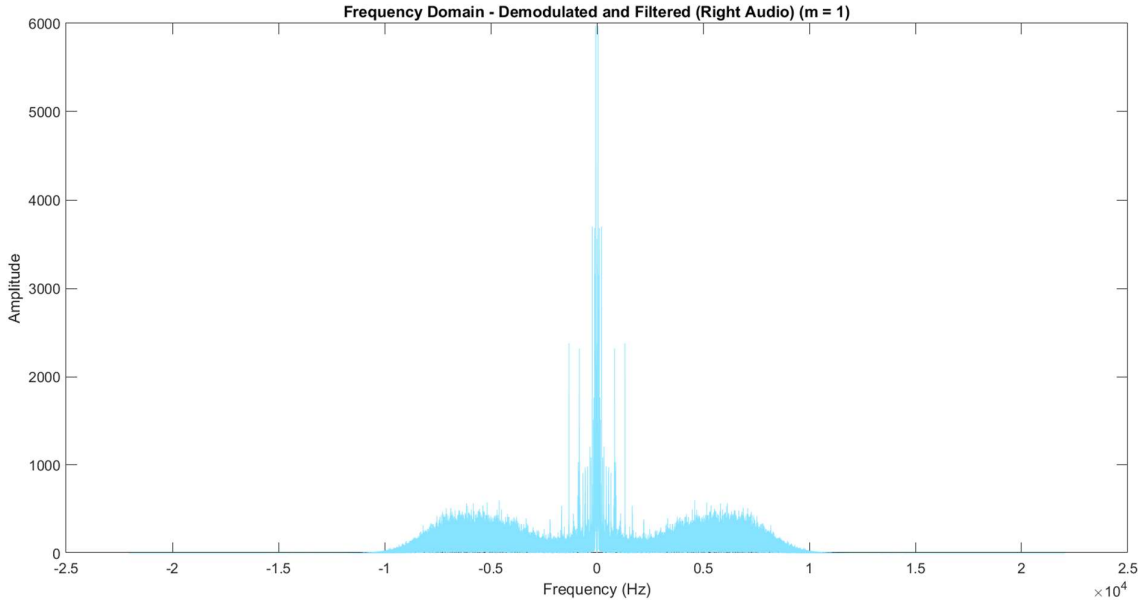

Final Output in Time Domain (Left Audio) (m = 0.5)
Amplitude
Time
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
1
2
3
4
5
6
7
8

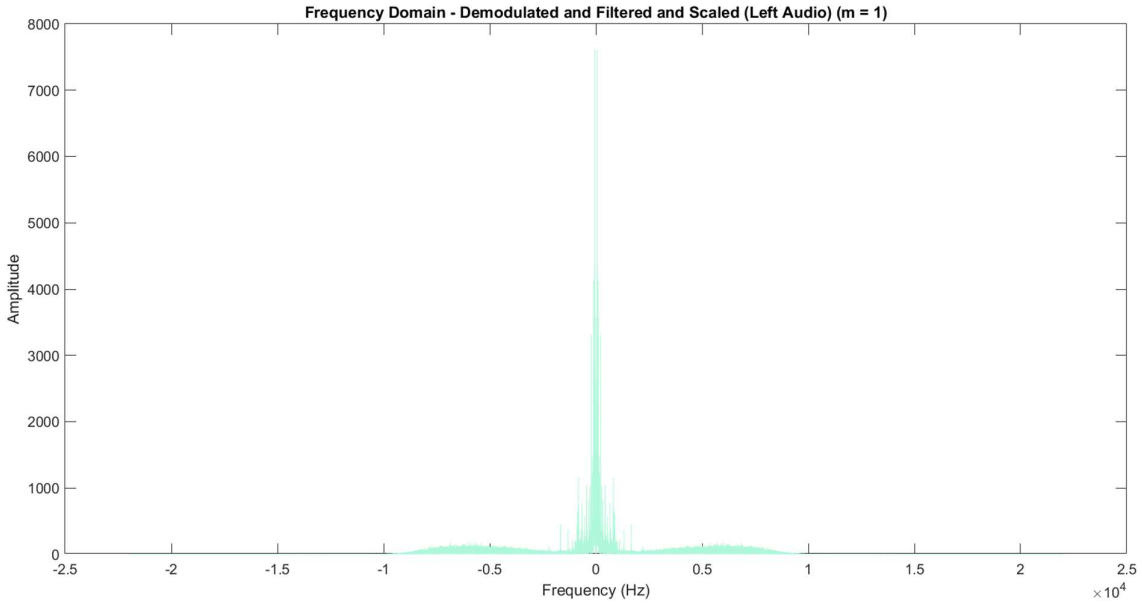

Final Output in Time Domain (Right Audio) (m = 0.5)
Amplitude
Time
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
1
2
3
4
5
6
7
8

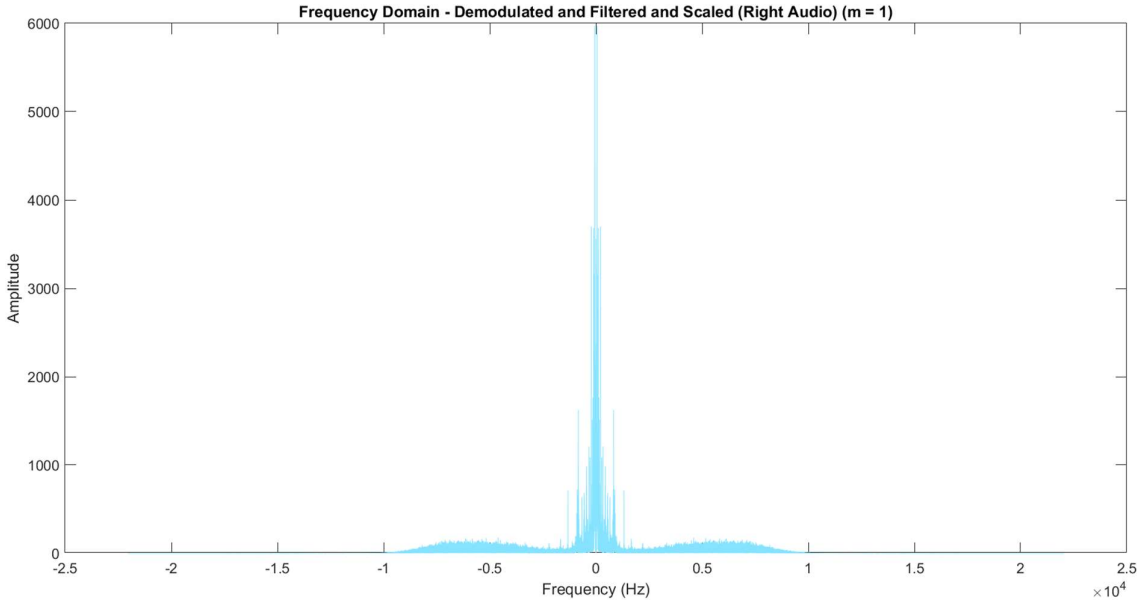

Frequency Domain - Demodulated (Left Audio) (m = 1)
Amplitude
Frequency (Hz)
×10^4

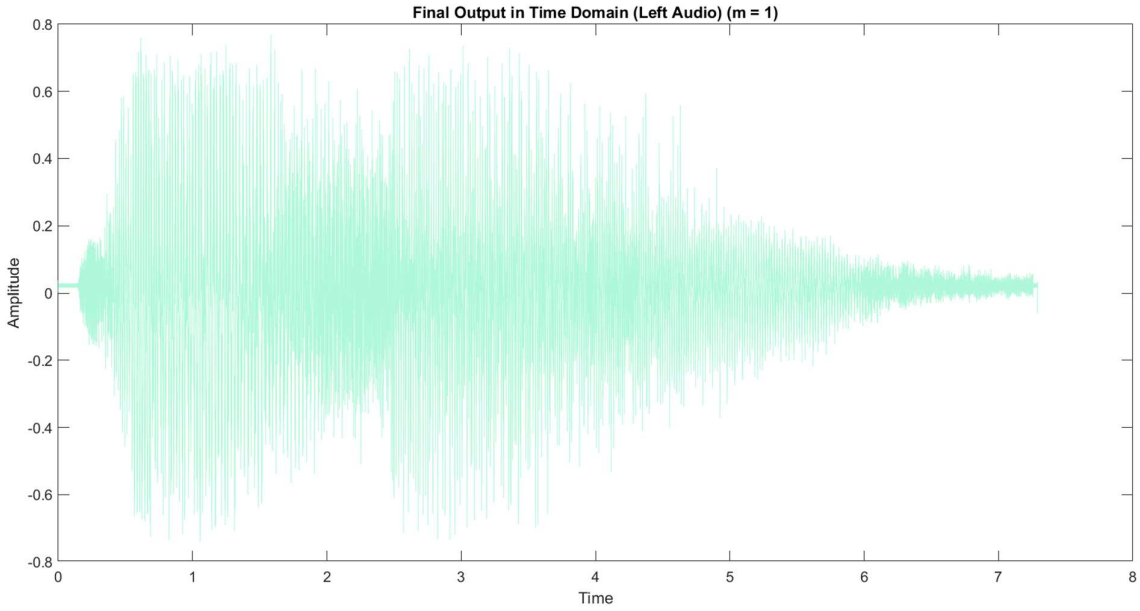

Frequency Domain - Demodulated (Right Audio) (m = 1)
Amplitude
Frequency (Hz)
×10^4

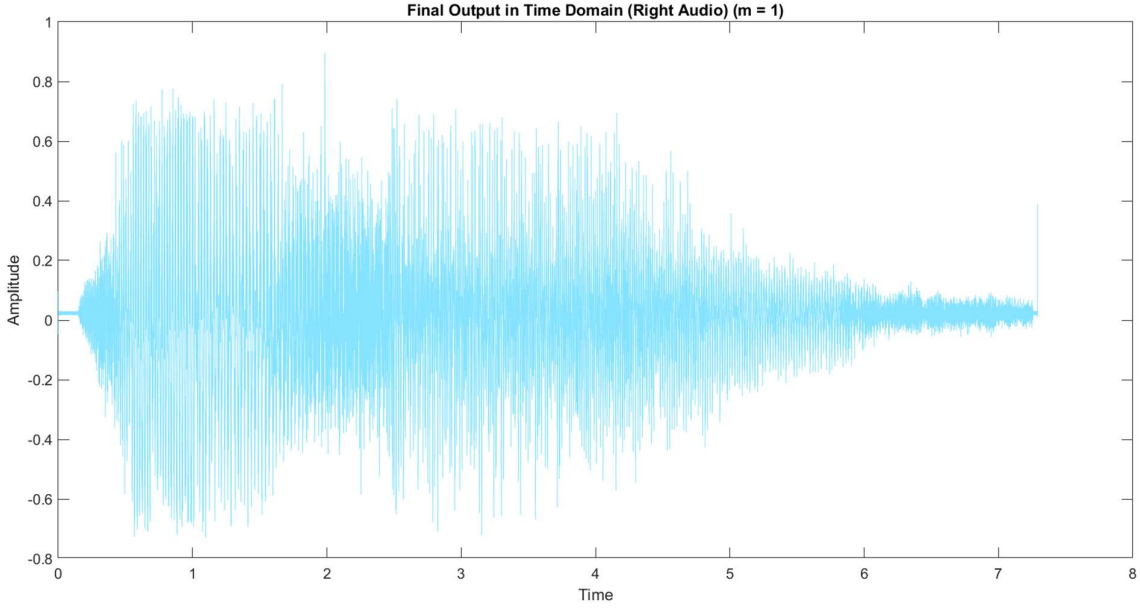

Frequency Domain - Demodulated and Filtered (Left Audio)(m = 1)
Amplitude
Frequency (Hz)
×10^4

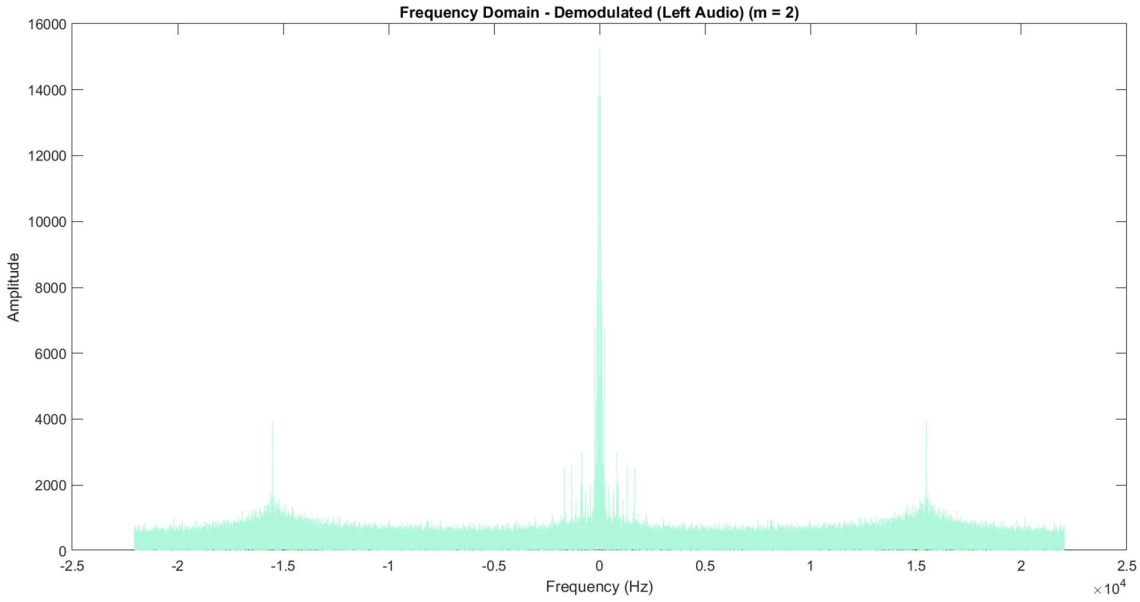

Frequency Domain - Demodulated and Filtered (Right Audio) (m = 1)
Amplitude
Frequency (Hz)
×10^4

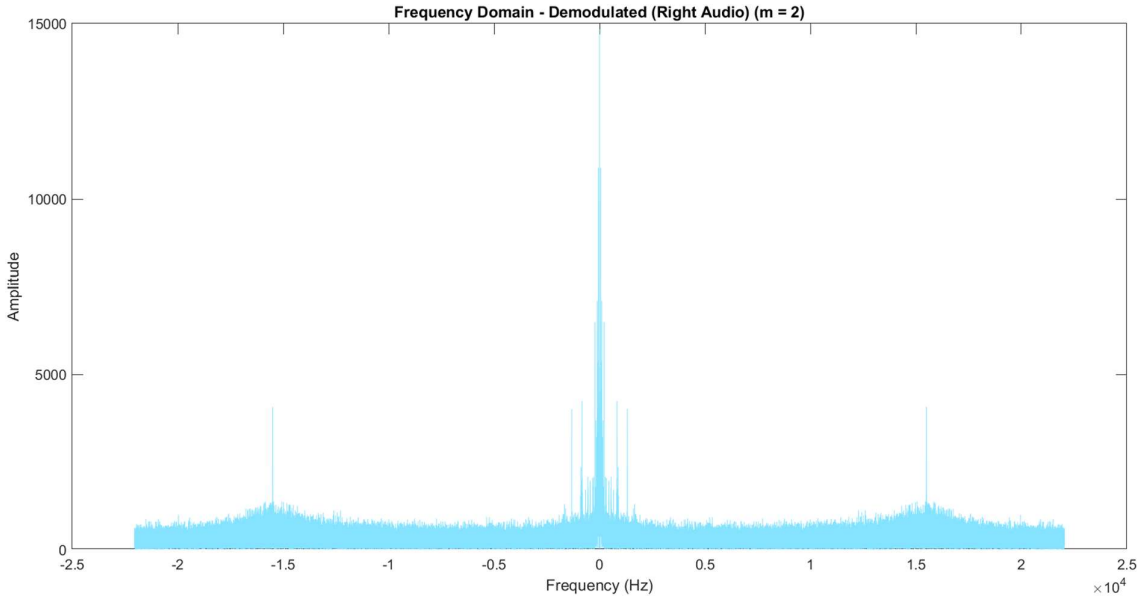

Frequency Domain - Demodulated and Filtered and Scaled (Left Audio) (m = 1)
Amplitude
Frequency (Hz)
×10^4

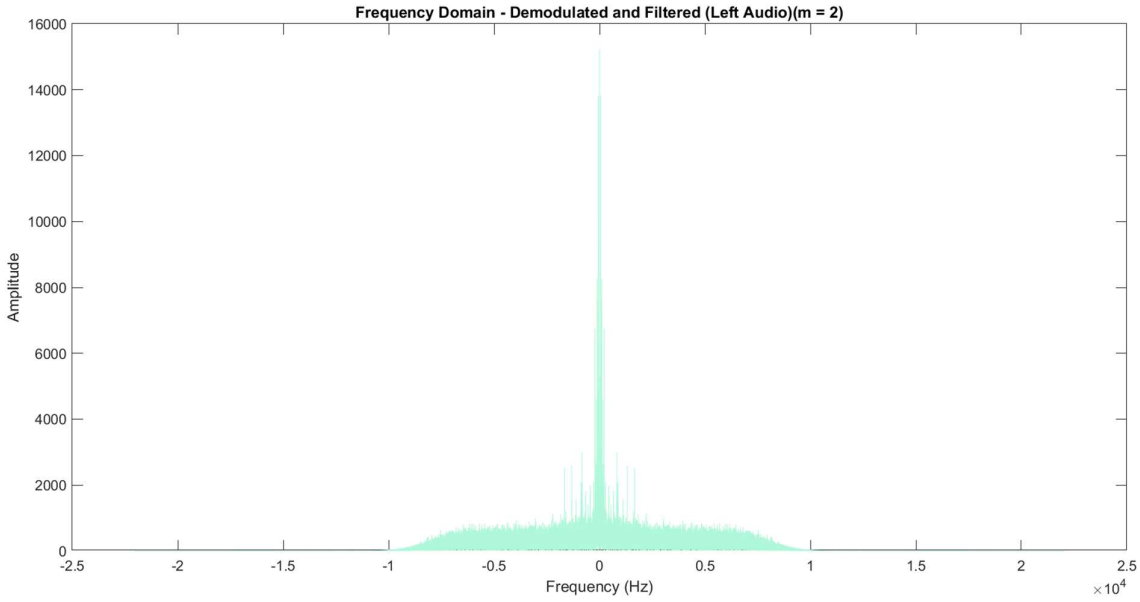

Frequency Domain - Demodulated and Filtered and Scaled (Right Audio) (m = 1)
Amplitude
Frequency (Hz)
×10^4

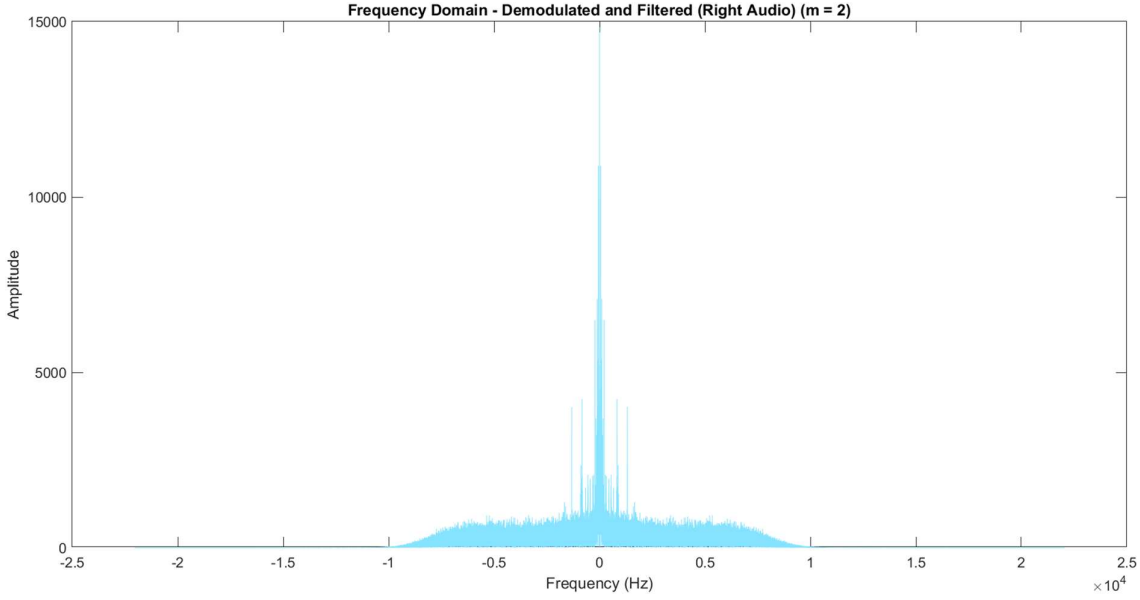

Final Output in Time Domain (Left Audio) (m = 1)
Amplitude
Time
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1
2
3
4
5
6
7
8

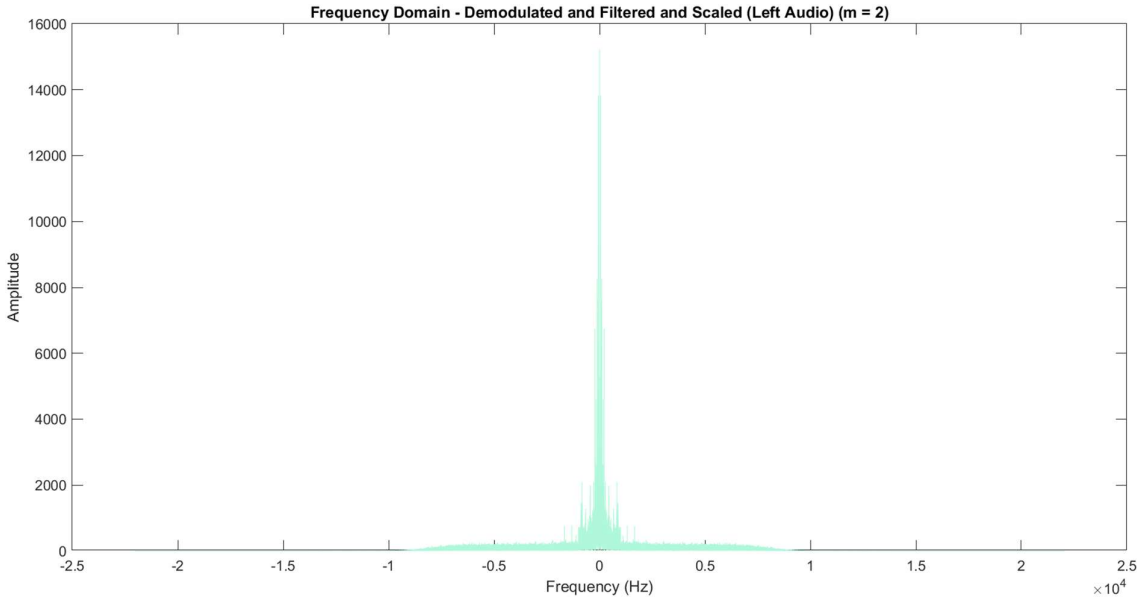

Final Output in Time Domain (Right Audio) (m = 1)
Amplitude
Time
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1
2
3
4
5
6
7
8

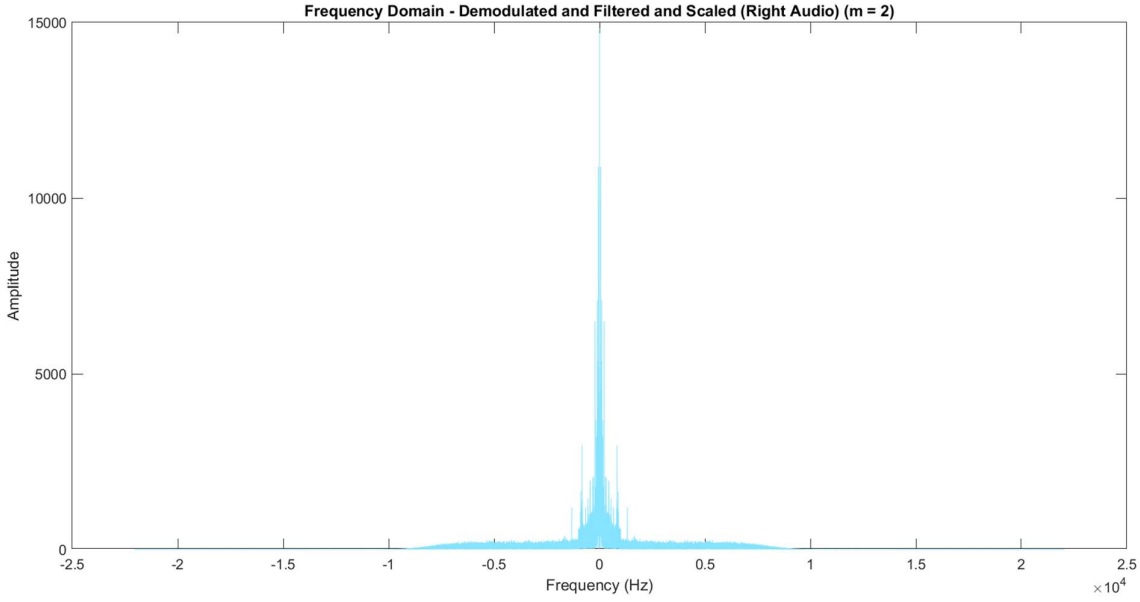

Frequency Domain - Demodulated (Left Audio) (m = 2)
Amplitude
Frequency (Hz)
×10^4

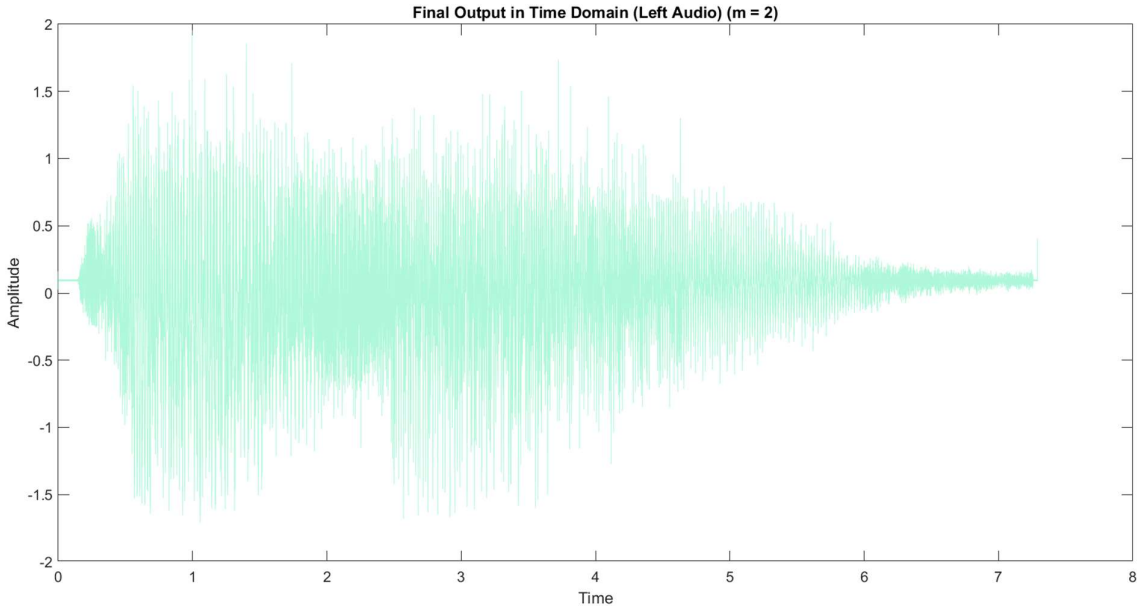

Frequency Domain - Demodulated (Right Audio) (m = 2)
Amplitude
Frequency (Hz)
×10^4

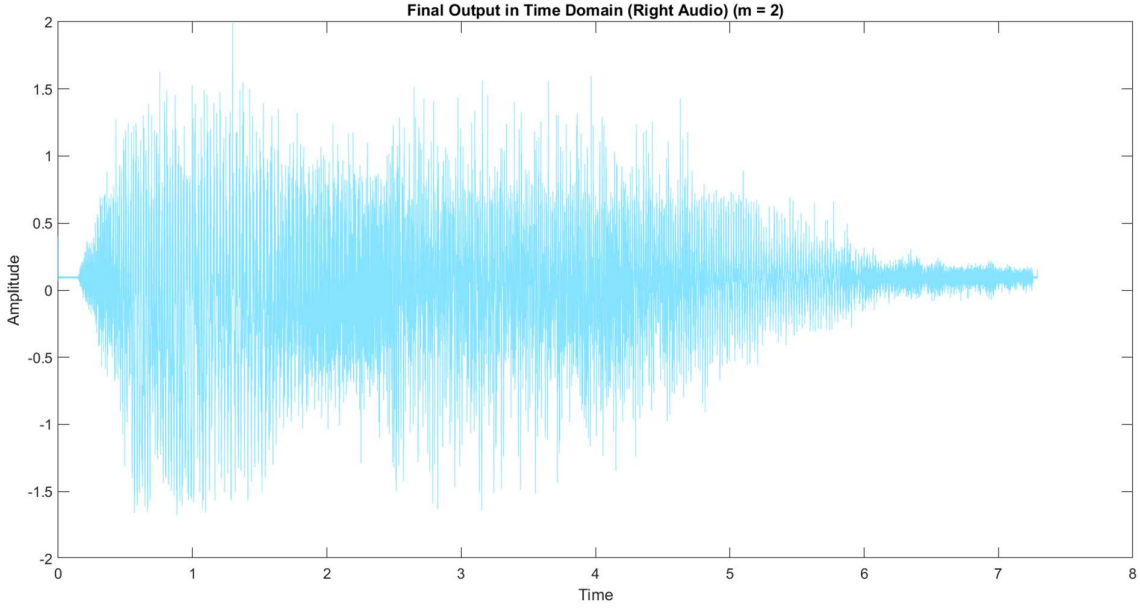

Frequency Domain - Demodulated and Filtered (Left Audio)(m = 2)
Amplitude
Frequency (Hz)
×10^4


Frequency Domain - Demodulated and Filtered (Right Audio) (m = 2)
Amplitude
Frequency (Hz)
×10^4


Frequency Domain - Demodulated and Filtered and Scaled (Left Audio) (m = 2)
Amplitude
Frequency (Hz)
×10^4
16000
14000
12000
10000
8000
6000
4000
2000
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5


Frequency Domain - Demodulated and Filtered and Scaled (Right Audio) (m = 2)
Amplitude
Frequency (Hz)
×10^4
15000
10000
5000
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5


Final Output in Time Domain (Left Audio) (m = 2)
Amplitude
Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6
7
8


Final Output in Time Domain (Right Audio) (m = 2)
Amplitude
Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6
7
8

# Section 6: Phase Modulation and Demodulation

In this section, we explore the process of phase modulation and demodulation. Phase modulation is a modulation technique in which the phase of the carrier signal is varied in proportion to the message signal. Phase demodulation is the process of extracting the original message signal from the phase-modulated carrier.

## Introduction to Phase Modulation and Demodulation

Phase modulation (PM) is a modulation technique that represents information by varying the phase of a carrier signal. To retrieve the original audio signal from a phase-modulated carrier, we need phase demodulation. This section demonstrates the phase demodulation process.

## Code Description

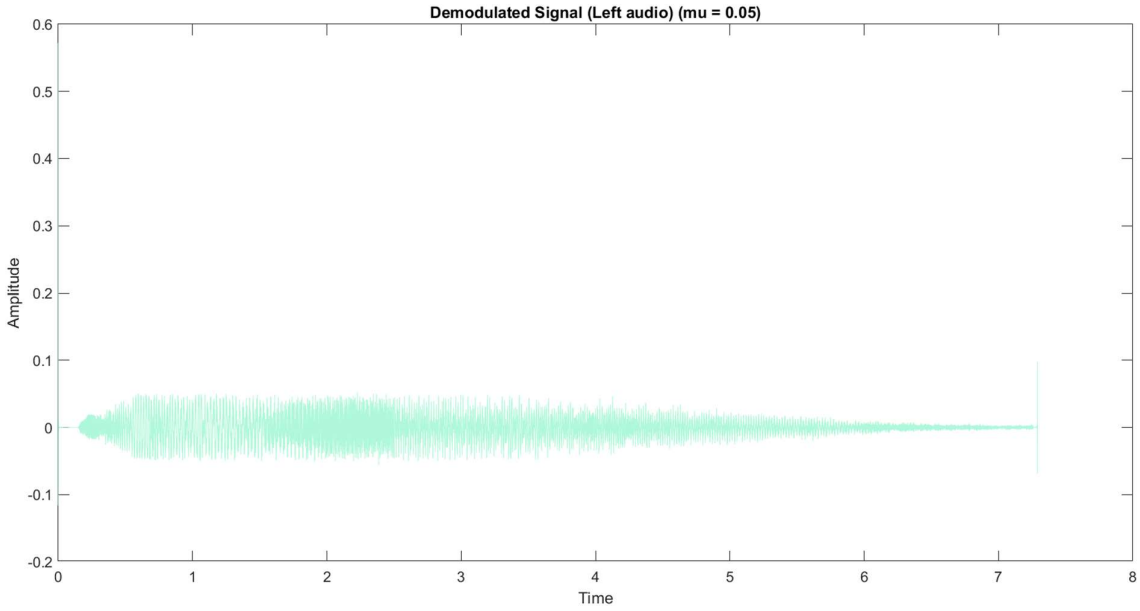
The provided code performs the following steps:

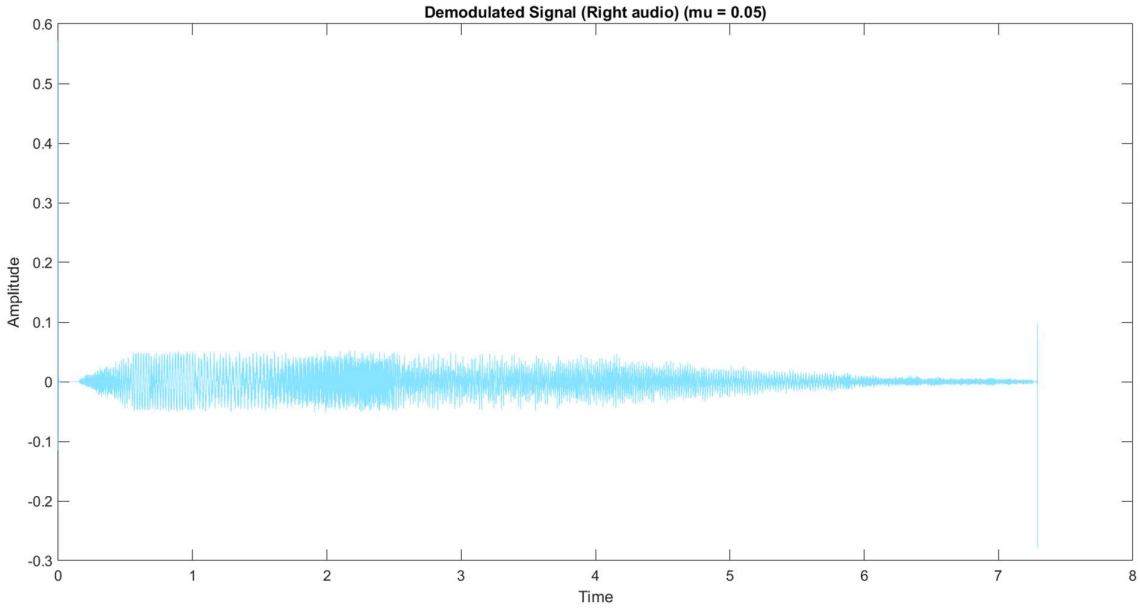
1. **Loading the Audio File:** The code begins by loading the audio file "videoplayback.wav" for the phase demodulation process.
2. **Signal Splitting:** The audio signal is separated into left and right channels.
3. **Frequency Domain Analysis (Original Signal):** The code analyses the frequency domain of the original audio signals, allowing us to understand the characteristics of the phase-modulated signals.
4. **Phase Modulation and Demodulation:** The phase modulation and demodulation process is performed for various modulation indices (0.05, 0.1, 0.5, 0.75, 1, 2) on both the left and right audio channels.
5. **Time and Frequency Domain Analysis (Demodulated Signal):** The demodulated signals are analysed in both the time and frequency domains. The code provides visual representations of the demodulated signals.

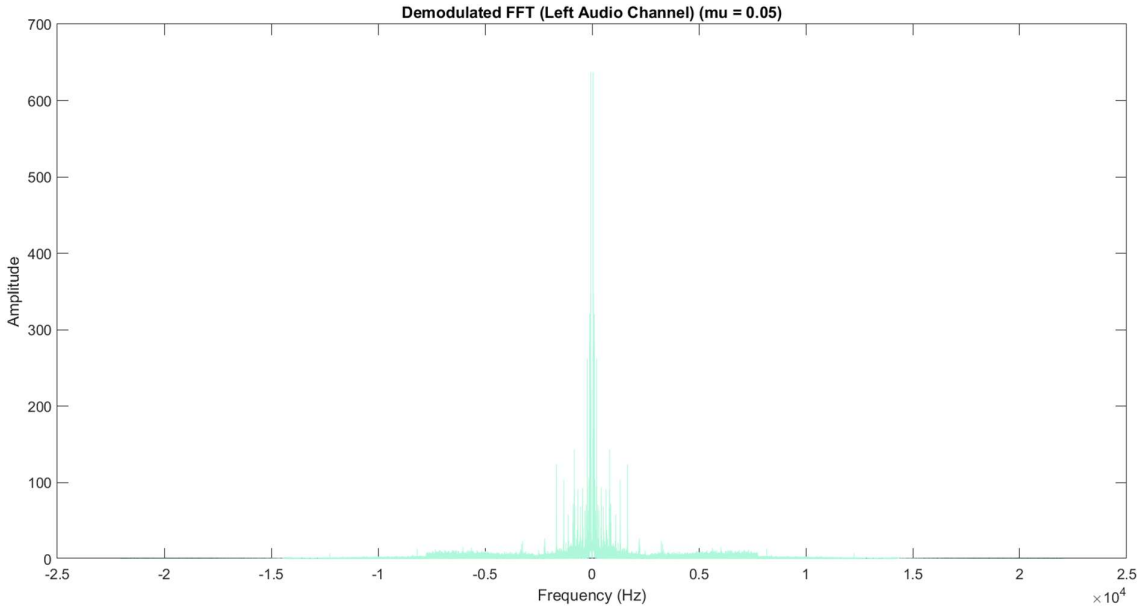
## Results

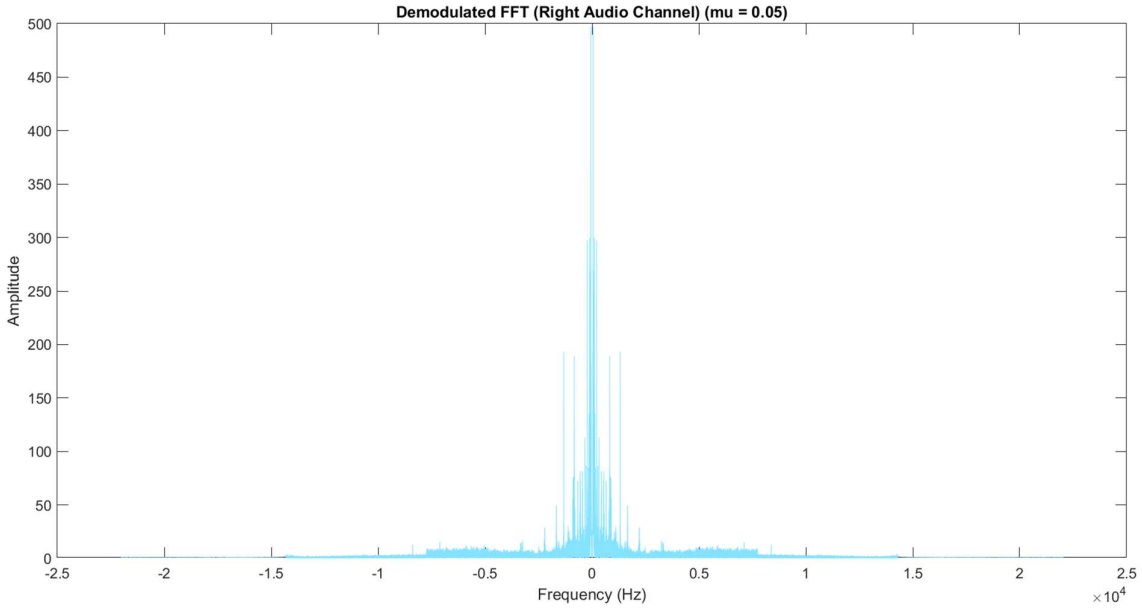
The code generates multiple figures illustrating the phase modulation and demodulation process, both in the time and frequency domains. The figures help us understand how the modulation index affects the demodulated audio signals and their characteristics.

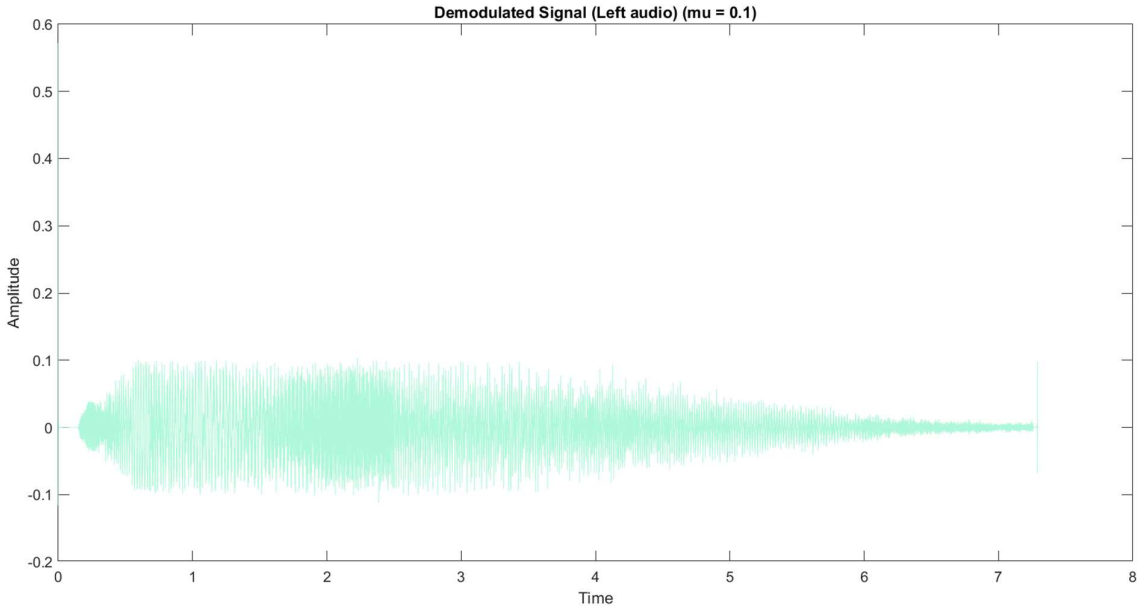
The various plots generated for the different modulation indices are added below:

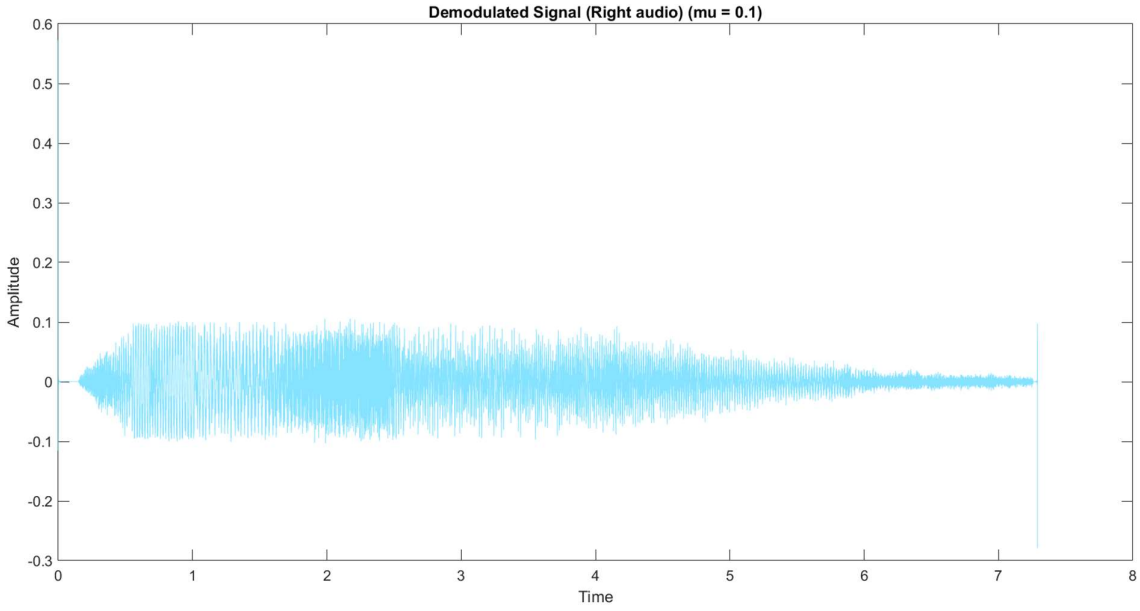

Demodulated Signal (Left audio) (mu = 0.05)
Amplitude
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
1
2
3
4
5
6
7
8

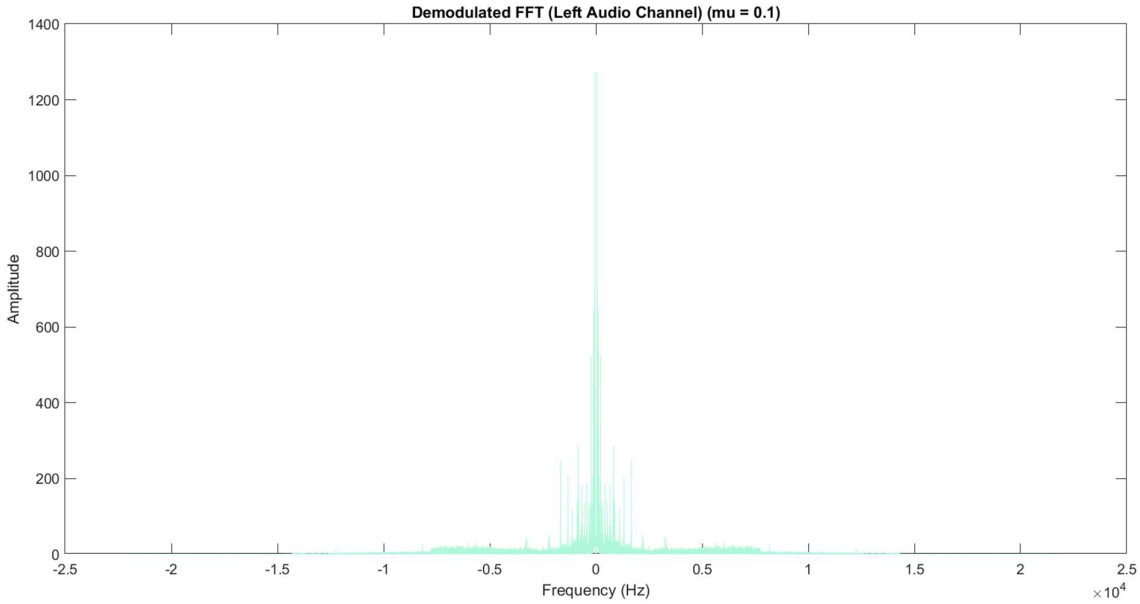

Demodulated Signal (Right audio) (mu = 0.05)
Amplitude
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
1
2
3
4
5
6
7
8

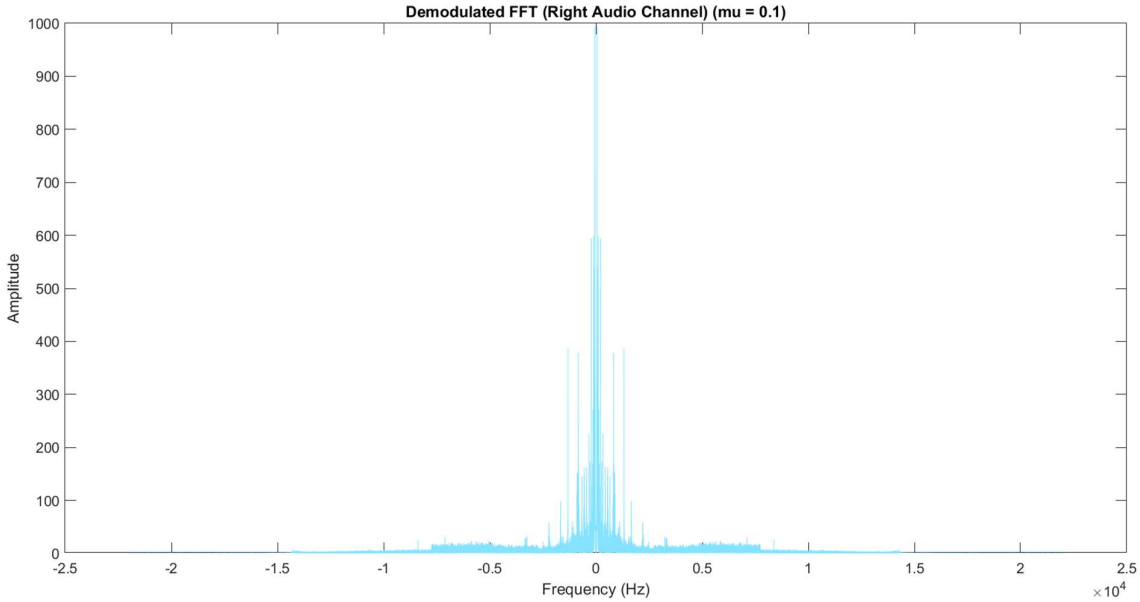

Demodulated FFT (Left Audio Channel) (mu = 0.05)
Amplitude
Frequency (Hz)
×10^4

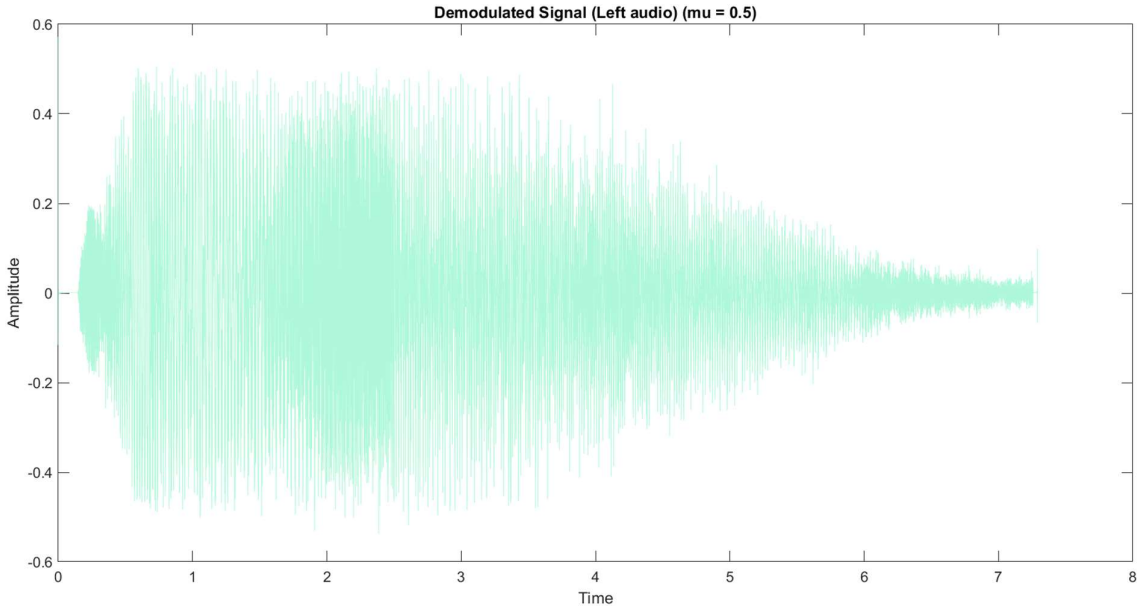

Demodulated FFT (Right Audio Channel) (mu = 0.05)
Amplitude
Frequency (Hz)
×10^4

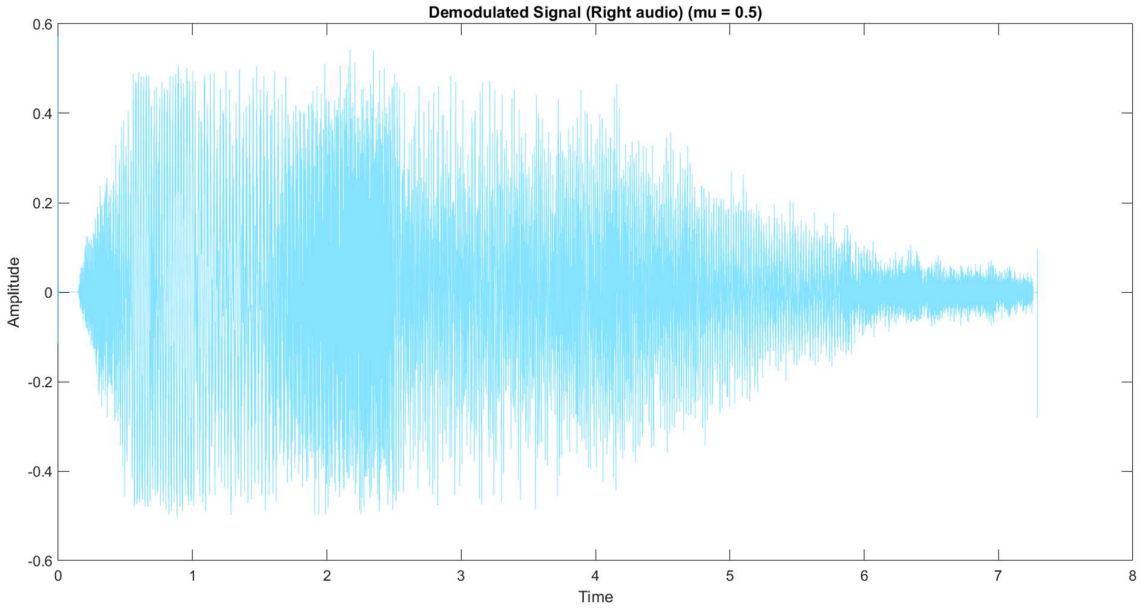

Demodulated Signal (Left audio) (mu = 0.1)
Amplitude
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
1
2
3
4
5
6
7
8

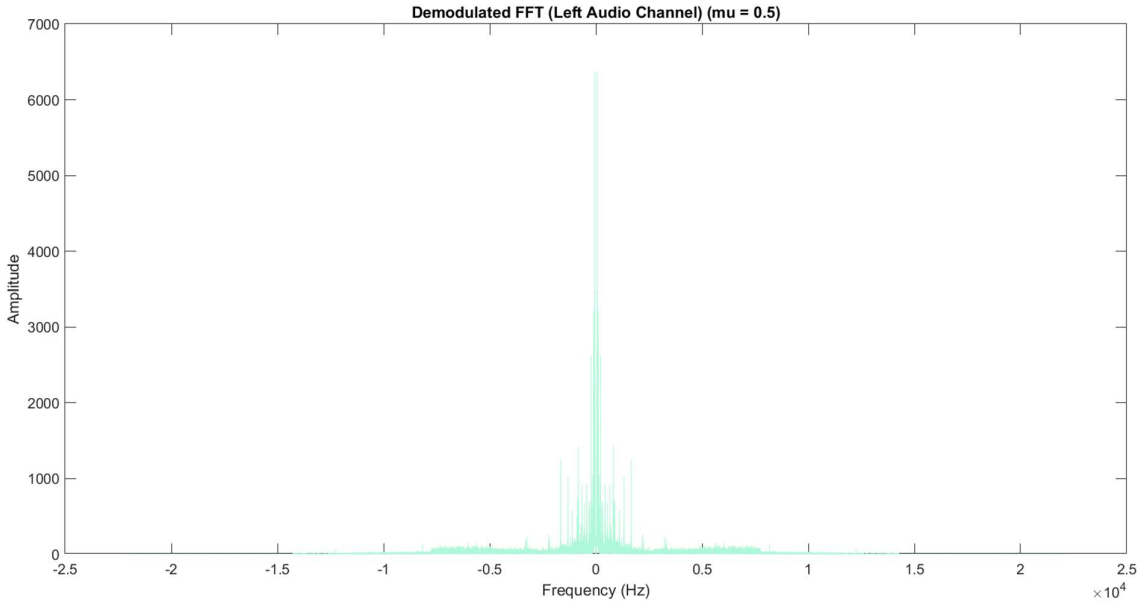

Demodulated Signal (Right audio) (mu = 0.1)
Amplitude
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
1
2
3
4
5
6
7
8

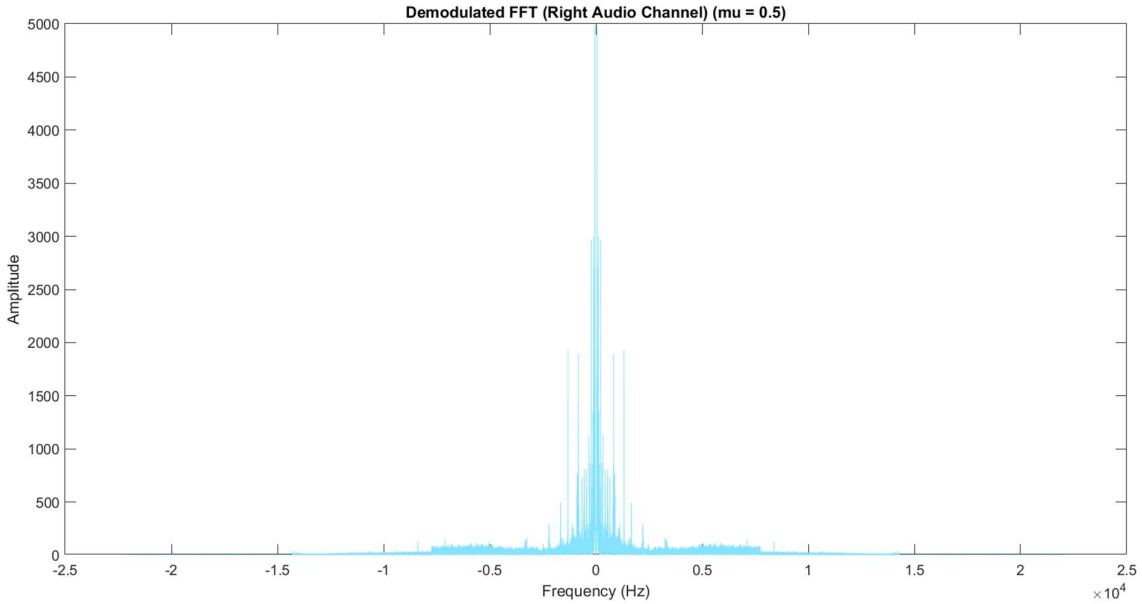

Demodulated FFT (Left Audio Channel) (mu = 0.1)
Amplitude
Frequency (Hz)
×10^4

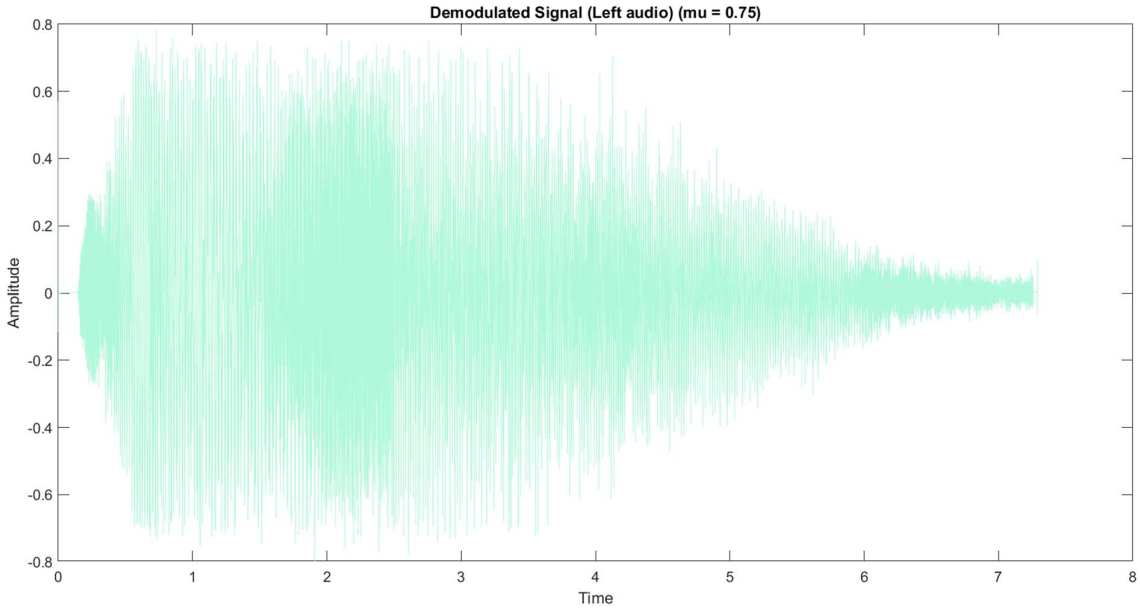

Demodulated FFT (Right Audio Channel) (mu = 0.1)
Amplitude
Frequency (Hz)
×10^4

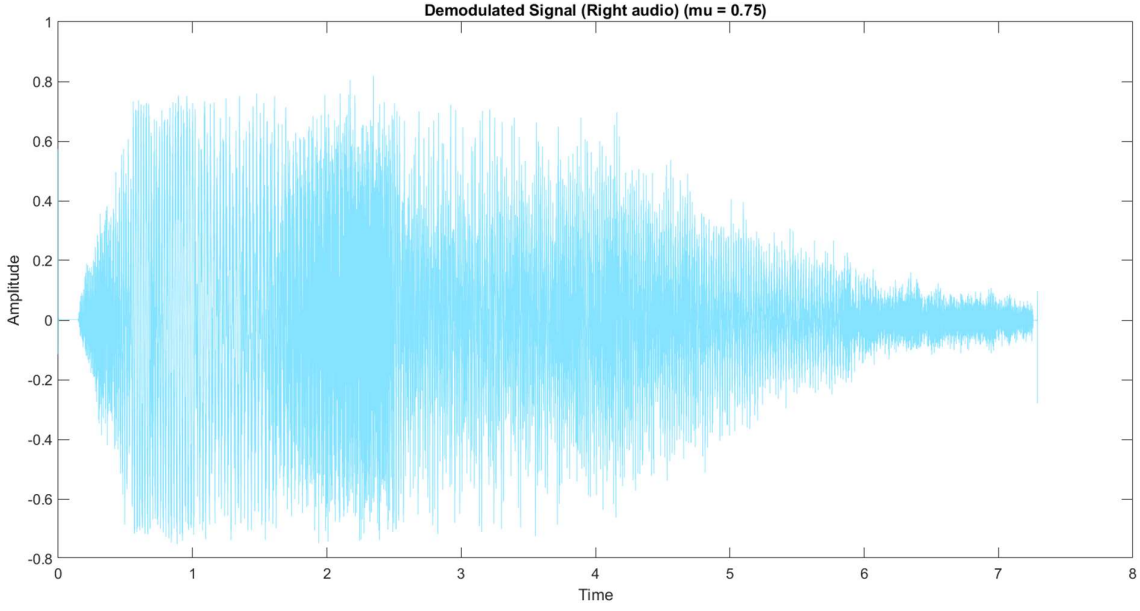

Demodulated Signal (Left audio) (mu = 0.5)
Amplitude
Time
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
1
2
3
4
5
6
7
8

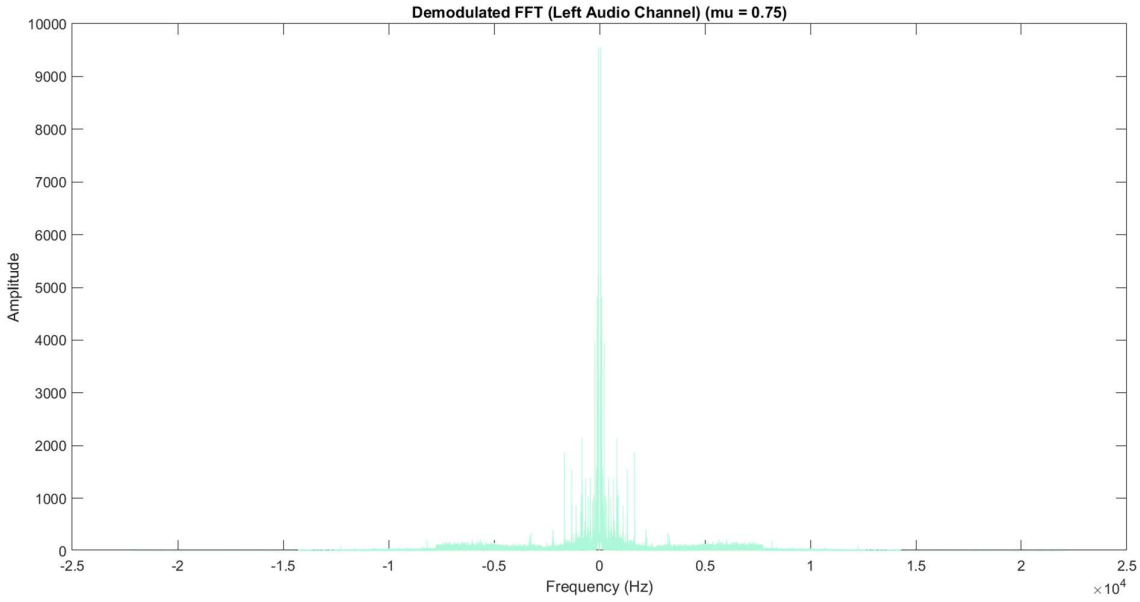

Demodulated Signal (Right audio) (mu = 0.5)
Amplitude
Time
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
1
2
3
4
5
6
7
8

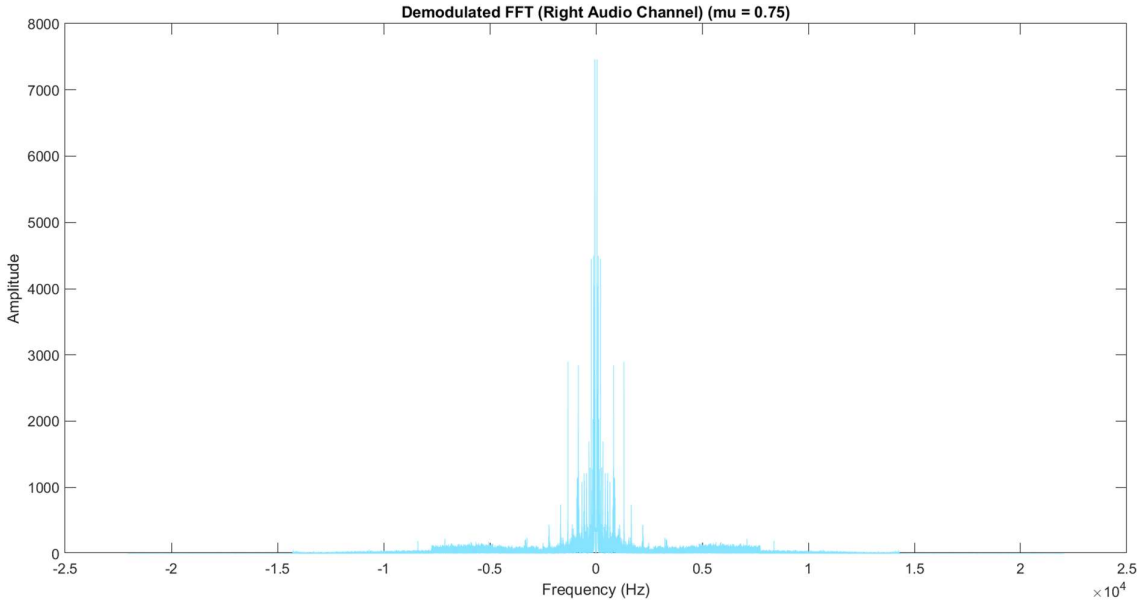

Demodulated FFT (Left Audio Channel) (mu = 0.5)
Amplitude
Frequency (Hz)
×10^4

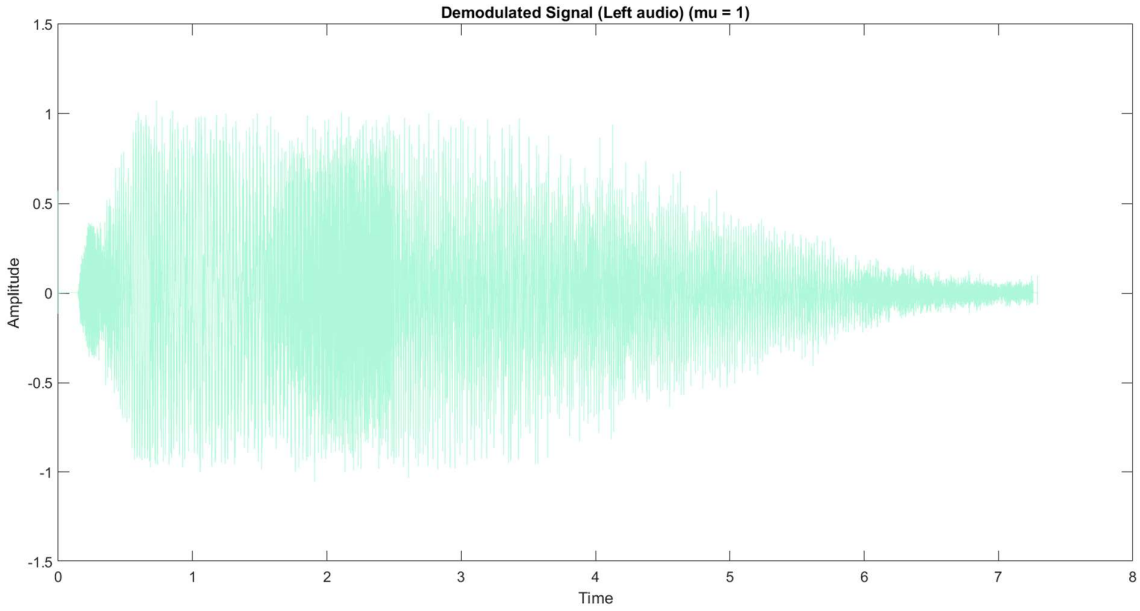

Demodulated FFT (Right Audio Channel) (mu = 0.5)
Amplitude
Frequency (Hz)
×10^4

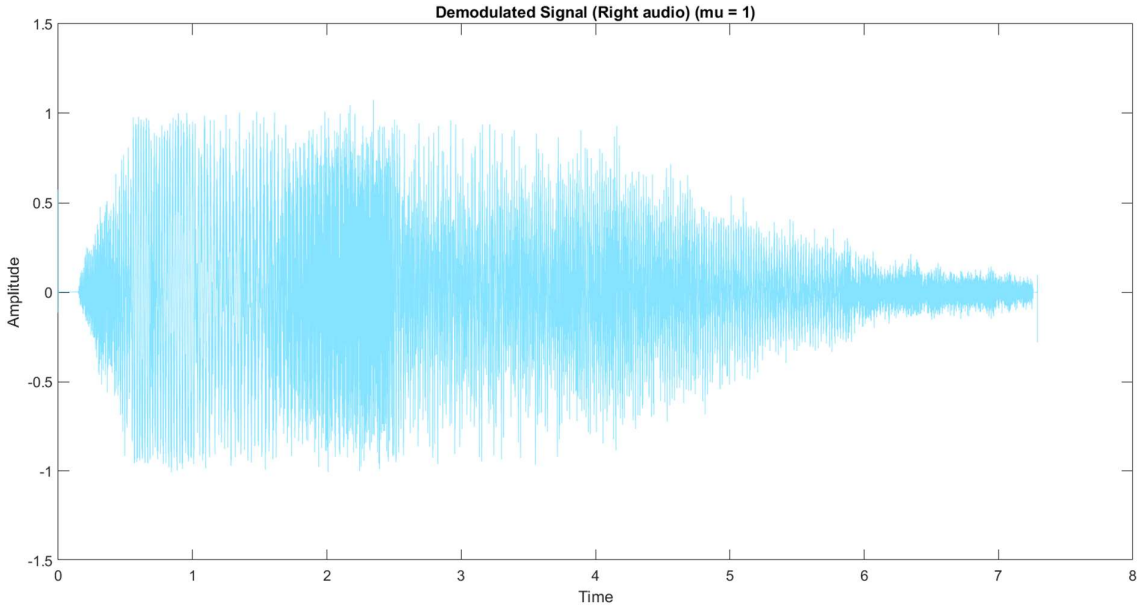

Demodulated Signal (Left audio) (mu = 0.75)
Amplitude
Time
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1
2
3
4
5
6
7
8

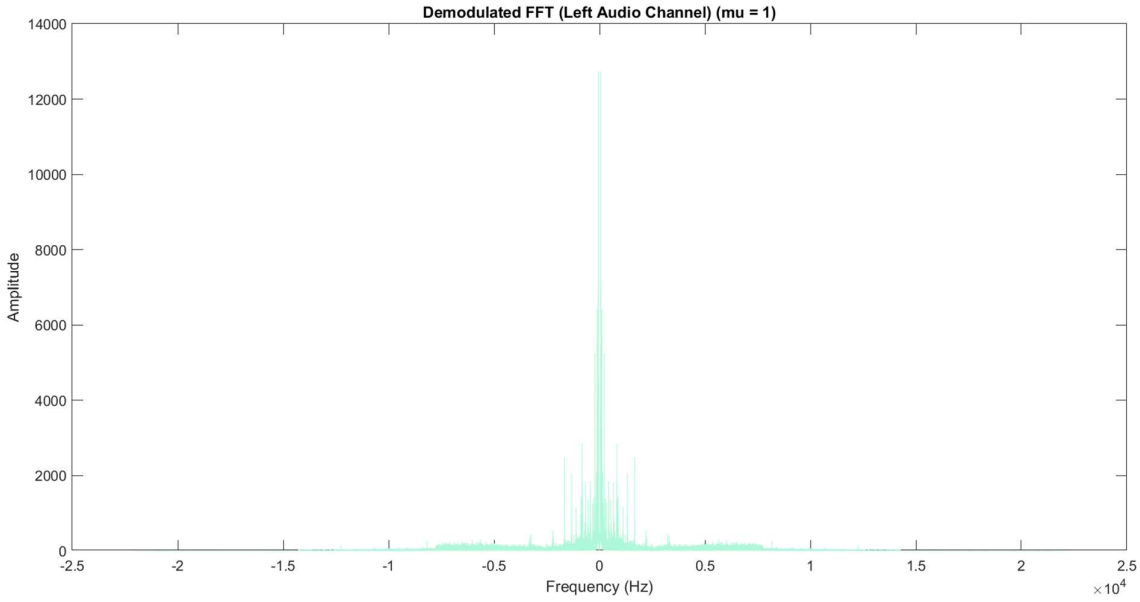

Demodulated Signal (Right audio) (mu = 0.75)
Amplitude
Time
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1
2
3
4
5
6
7
8

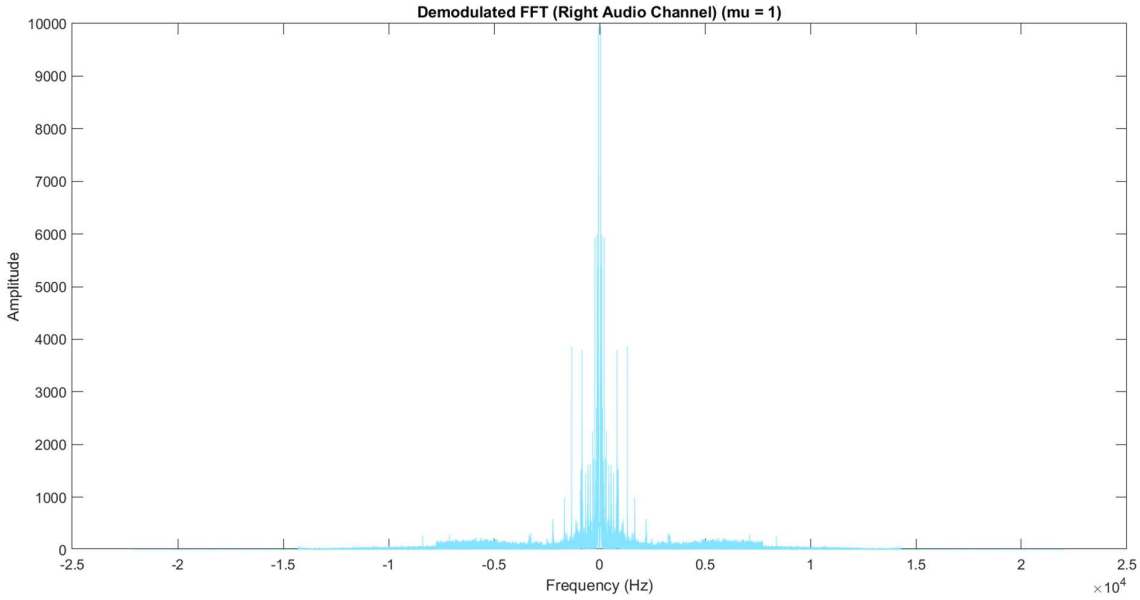

Demodulated FFT (Left Audio Channel) (mu = 0.75)
Amplitude
Frequency (Hz)
×10^4

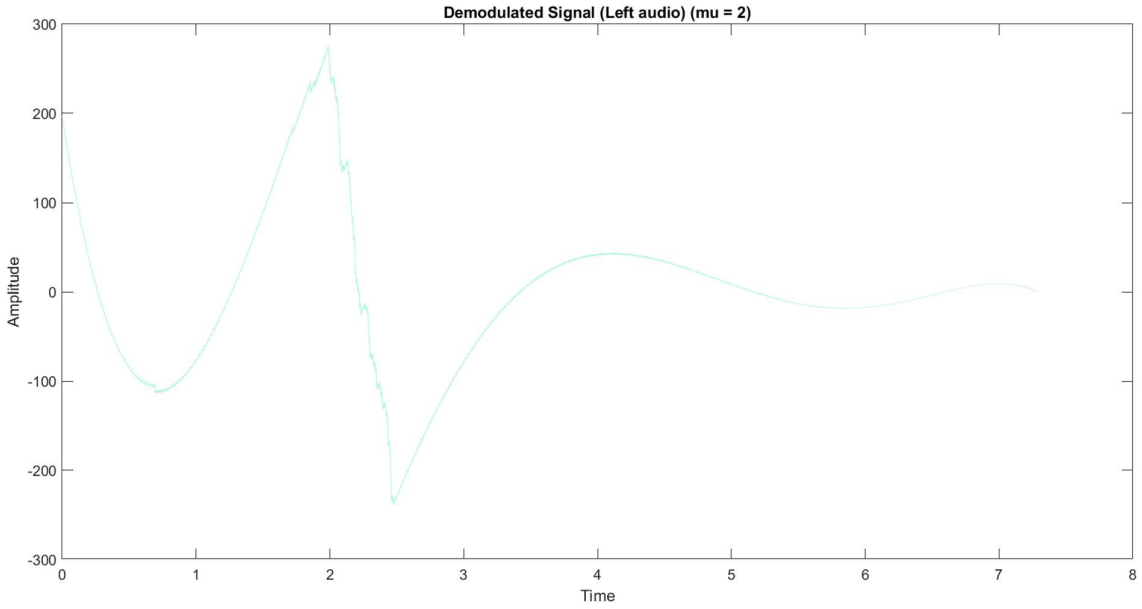

Demodulated FFT (Right Audio Channel) (mu = 0.75)
Amplitude
Frequency (Hz)
×10^4

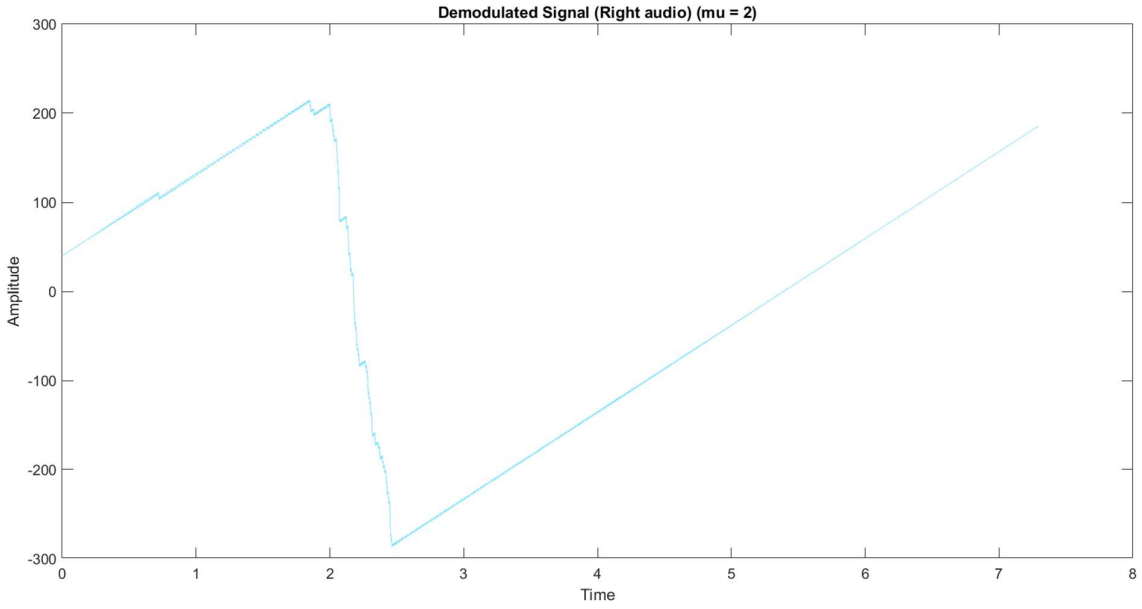

Demodulated Signal (Left audio) (mu = 1)
Amplitude
Time
1.5
1
0.5
0
-0.5
-1
-1.5
0
1
2
3
4
5
6
7
8

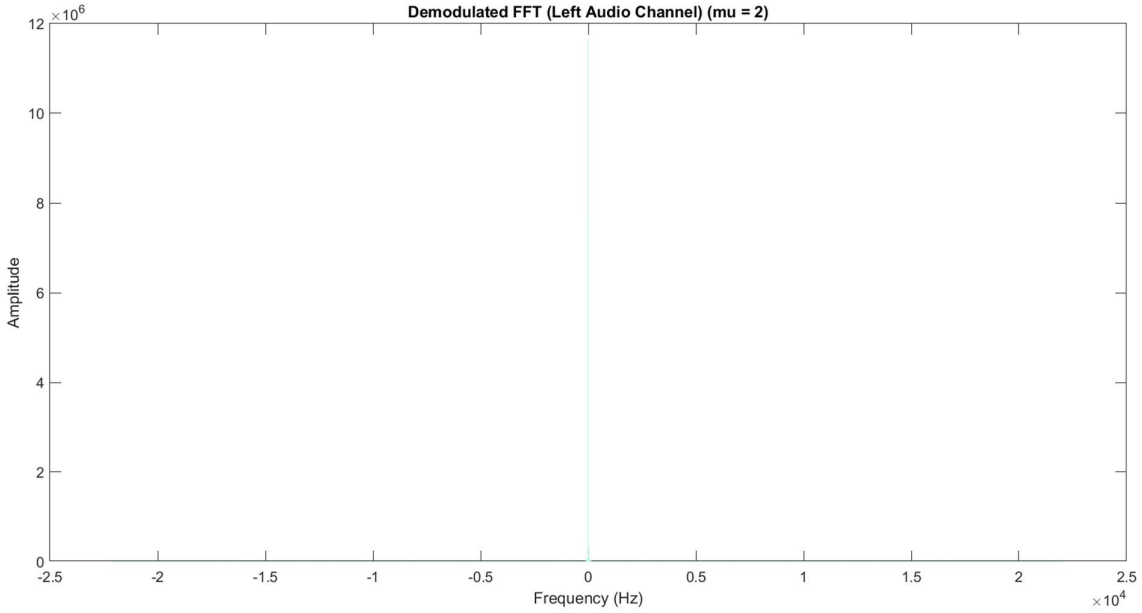

Demodulated Signal (Right audio) (mu = 1)
Amplitude
Time
1.5
1
0.5
0
-0.5
-1
-1.5
0
1
2
3
4
5
6
7
8

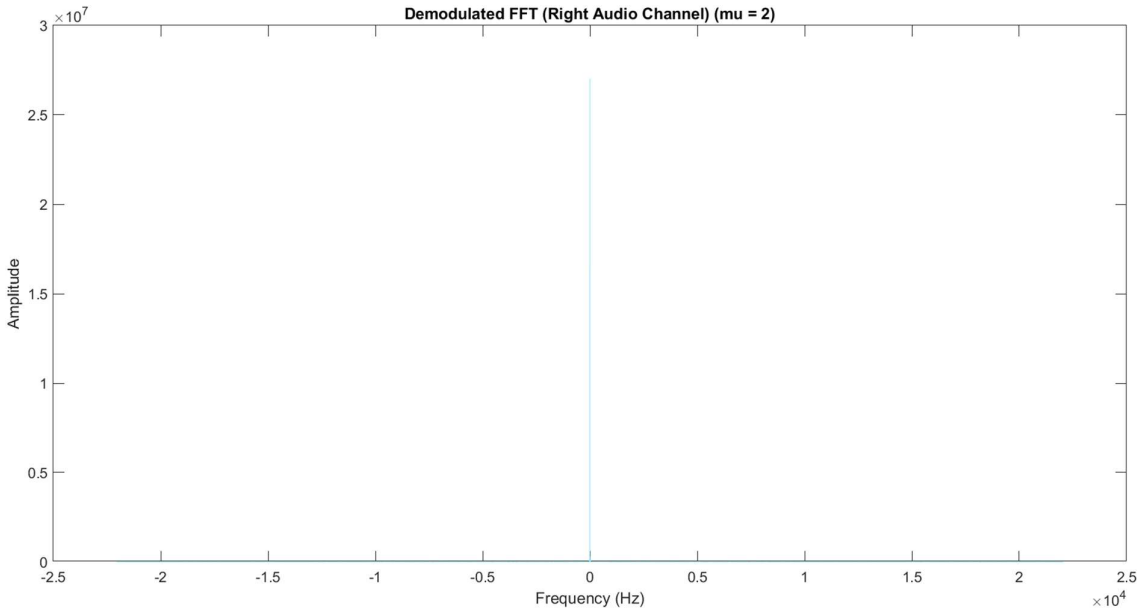

Demodulated FFT (Left Audio Channel) (mu = 1)
Amplitude
Frequency (Hz)
×10^4


Demodulated FFT (Right Audio Channel) (mu = 1)
Amplitude
Frequency (Hz)
×10^4


Demodulated Signal (Left audio) (mu = 2)
300
200
100
0
-100
-200
-300
Amplitude
0
1
2
3
4
5
6
7
8
Time


Demodulated Signal (Right audio) (mu = 2)
300
200
100
0
-100
-200
-300
Amplitude
0
1
2
3
4
5
6
7
8
Time




Here, we see that for too low modulation indices, the amplitude of the demodulated signal is very small and the SNR is quite high. When the modulation index is very low, it means that the phase of the carrier signal changes significantly due to the modulation. In this case, it can be challenging to accurately recover the modulating signal because the instantaneous phase can wrap around, leading to ambiguity in the demodulated signal.

On the other hand, when the modulation index was very high (m = 2), we got no signal after demodulation. When the modulation index is very high, it means that the phase of the carrier signal changes very little as it carries the information. In this case, the phase demodulation may not be very effective because the phase variations are too small to reliably extract the modulating signal.

## Conclusion:

In this assignment, we have journeyed through various modulation and demodulation techniques to understand how audio signals are transformed and then brought back to their original form. These methods, like Amplitude Modulation and Phase Modulation, play a crucial role in communication systems. By decoding the signals, we can enjoy the music, speech, and sounds that make up our world. Learning about these techniques helps us appreciate the technology that makes our audio experiences possible.