Analog Communications Report

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MATLAB SIMULINK
R2023b
was used in this report!

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Introduction

In the field of communications engineering, both analog and digital transmission methods are fundamental in transmitting information across various mediums. While digital communication offers robustness and versatility, analog communication remains crucial, particularly in applications involving continuous signals like audio transmission and radio broadcasting.

This report explores the theoretical and practical aspects of analog communication and digital filtering. It delves into analog communication systems, discussing modulation techniques such as amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM), along with their applications and trade-offs.

Transitioning to digital filtering, the report examines the design and analysis of digital filters, essential for signal processing in both analog and digital communication systems. Through MATLAB's Simulink, demonstrates filter design, frequency response analysis, and noise reduction techniques.

Highlighting the synergy between analog communication and digital filtering, the report showcases how digital filters enhance analog communication systems' performance in signal conditioning, interference mitigation, and demodulation.

By offering insights into both analog communication principles and digital filtering techniques, this report equips readers with the knowledge to design efficient and robust communication systems, bridging the gap between analog and digital domains for modern communication applications.

Theoretical Background

1. Introduction to Digital Filtering

Digital filters are essential components in signal processing systems, employed to modify or extract desired components from input signals while attenuating unwanted frequencies. These filters play a critical role in various applications, including communications, audio processing, image processing, and biomedical signal analysis.

2. LP Digital Filter Design

Low-pass (LP) digital filters are designed to pass signals with frequencies lower than a certain cutoff frequency while attenuating signals with frequencies higher than the cutoff. The design process involves specifying filter parameters such as passband frequency, stopband frequency, passband ripple, and stopband ripple.

3. Filter Specifications

Passband Frequency (fp): The frequency range within which the filter allows signals to pass with minimal attenuation. In LP filters, this is the highest frequency of interest.

Stopband Frequency (fs): The frequency range beyond which the filter attenuates signals to achieve the desired rejection. In LP filters, this is typically higher than the passband frequency.

Passband Ripple (Rp): The maximum allowable variation in amplitude within the passband. It quantifies the filter's deviation from the ideal frequency response in the passband.

Stopband Ripple (Rs): The minimum level of attenuation required in the stopband. It indicates the filter's ability to suppress out-of-band frequencies.

4. Sampling Frequency

The sampling frequency determines the rate at which the analog input signal is sampled to produce discrete-time samples. It is crucial in digital filtering as it defines the resolution and frequency range of the digital signal

5. Frequency Response of Digital Filters

The frequency response characterizes how a filter affects the amplitude and phase of signals at different frequencies. It is commonly represented using magnitude and phase response plots, providing insights into the filter's behavior across the frequency spectrum.

6. Effect of Changing Signal Frequency

Altering the frequency of the input signal affects the filter's response and the resulting output.

When the signal frequency aligns with the passband frequency, minimal attenuation occurs, resulting in high output amplitudes.

As the signal frequency approaches the stopband frequency, the filter attenuates the signal more significantly, reducing output amplitudes.

The relationship between signal frequency and filter response demonstrates the filter's selectivity and ability to attenuate out-of-band frequencies while passing desired signal components.

7. Frequency Modulation (FM) and Demodulation

FM is a modulation technique where the frequency of a carrier signal varies in accordance with the amplitude of a modulating signal. FM demodulation involves recovering the original modulating signal from the FM-modulated signal using demodulation techniques such as frequency discrimination.

Theoretical background in digital filtering encompasses various key concepts and techniques crucial in signal processing systems. Digital filters, including low-pass (LP) filters, are instrumental in modifying or extracting desired signal components while attenuating unwanted frequencies across applications such as communications and audio processing. LP filter design entails specifying parameters like passband and stopband frequencies, and passband and stopband ripple, crucial for achieving desired filter characteristics. Sampling frequency plays a pivotal role, in determining signal resolution and frequency range in digital filtering. Understanding the frequency response of digital filters, represented through magnitude and phase response plots, provides insights into their behavior across the frequency spectrum. Moreover, altering signal frequency affects the filter's response, showcasing its selectivity and attenuation capabilities. Furthermore, frequency modulation (FM) and demodulation techniques are fundamental, enabling the modulation and subsequent recovery of modulating signals from FM-modulated signals using demodulation techniques like frequency discrimination.

Results of SIMULINK

LAB ONE

1. **Sine Wave's blocks and scope with frequency of 0.1 Hz:**

Figure 1: Sine wave block design

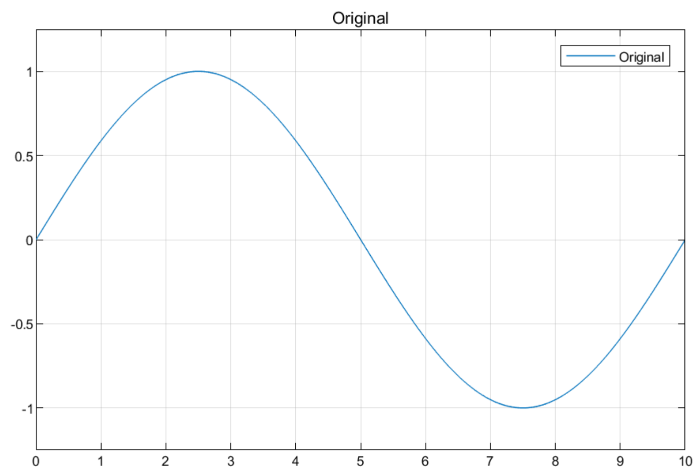

Figure 2: Sine wave's scope

2. **Changing the sample time to 0.01 seconds and 5 volts peak:**

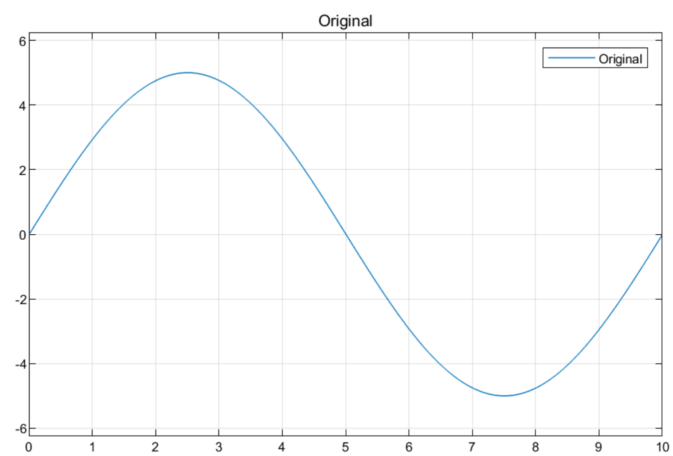

Figure 3: Sine wave's scope with 5V Peak

3. Changing the frequency of the Sine wave to 0.5 Hz instead of 0.1 Hz:

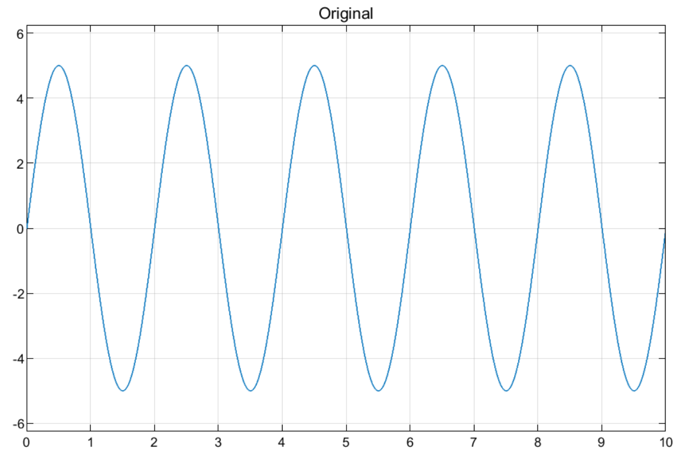

Figure 4: Sine wave's scope with changed frequency

The amplitude output of the filter is 4.9675 volts. (4.967422025)
To calculate the filter gain in decibels (dB):

Gain (dB)=$20\log_{10}(V_{out}/V_{in})$. After substituting V_{out} with 4.9675V, and V_{in} with 5V, the gain in dB would be equal around to −0.0988dB.

5. Adding the Random Source using a Random Number Block that contains a Gaussian random source.

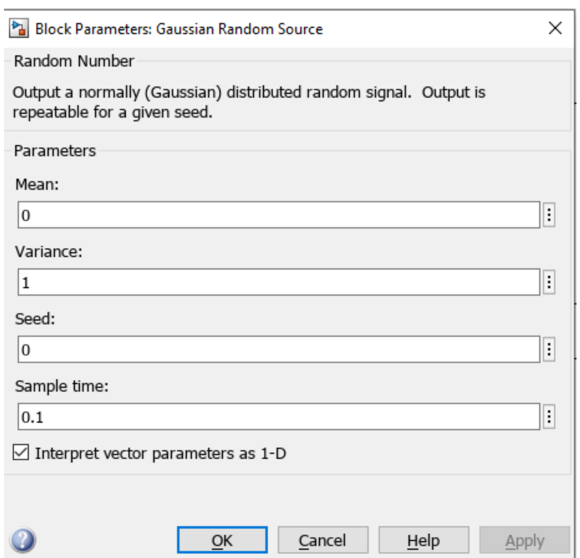

Figure 5: Block parameters for Gaussian Random Source

6. Changing the Sine wave (the message signal) to a frequency of 1 Hz and adding it to the Random Source Block:

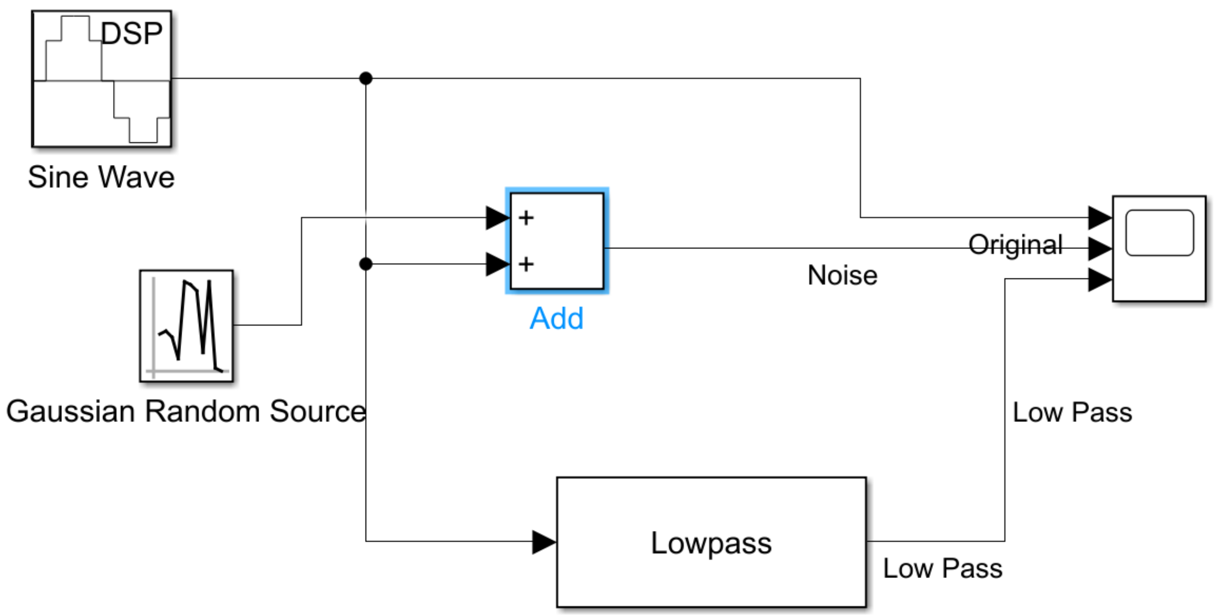

Figure 6: Lab one diagram

7. Drawing the 2 signals of the noise and the low pass while also keeping the original in the graph:

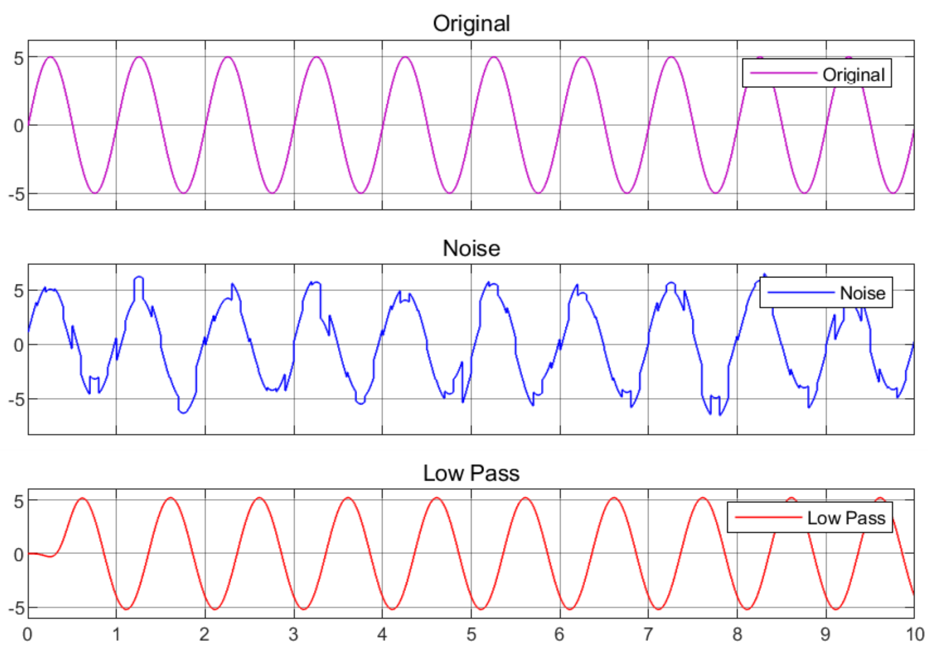

Figure 7: The graph of the signals

8. Changing the frequency by 0.5 Hz up words and down words:

The 0.5 Hz:

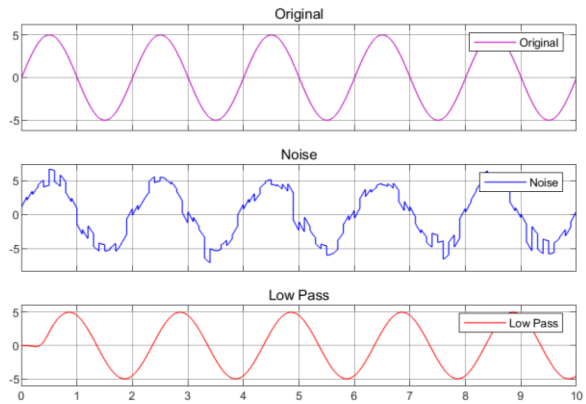

Figure 8: The 0.5 Hz message Plot

The 1.5 Hz:

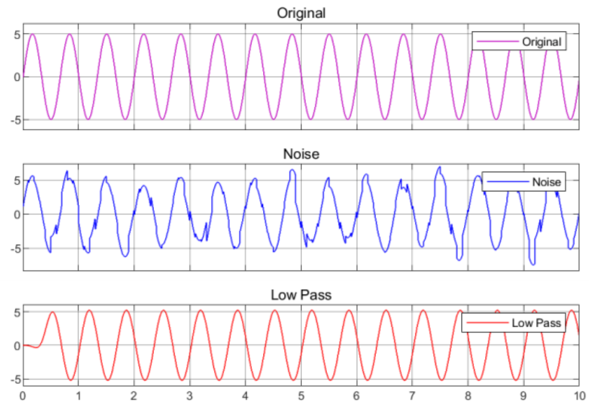

Figure 9: The 1.5 Hz message Plot

9. So here are the comments:

Frequency Increase: When you increase the frequency of the message signal by 0.5 Hz, you'll observe a corresponding increase in the frequency of the combined signal. This increase might lead to a change in the perceived pitch or tone of the signal. Additionally, aliasing may occur if the frequency increase approaches the Nyquist frequency (half the sampling frequency).

Frequency Decrease: Conversely, when you decrease the frequency of the message signal by 0.5 Hz, the frequency of the combined signal will decrease accordingly. This decrease may result in a lower pitch or tone in the signal. However, if the frequency decreases too much, the signal may become indistinguishable from the noise, especially if the noise has a wide frequency spectrum.

When the frequency of the message signal is varied upwards and downwards by 0.5 Hz increments, noticeable changes occur in the output of the filter. As the frequency approaches the passband frequency of 2 Hz, the filter allows the signal to pass through with minimal attenuation, resulting in a relatively high amplitude output. Conversely, as the frequency moves away from the passband towards the stopband frequency of 5 Hz, the filter begins to attenuate the signal more significantly, leading to a decrease in the output amplitude.

However, beyond the stopband frequency of 5 Hz, the attenuation capabilities of the digital low-pass filter become more pronounced. Surpassing the stopband frequency results in a drastic reduction in the output amplitude as the filter actively suppresses frequencies beyond the specified stopband limit. Additionally, surpassing the stopband frequency may introduce effects such as spectral leakage or aliasing, which can distort the output signal and impact its fidelity.

LAB TWO

Task 1:

Section ONE

1. Here are the block parameters of the signal generator for the carrier:

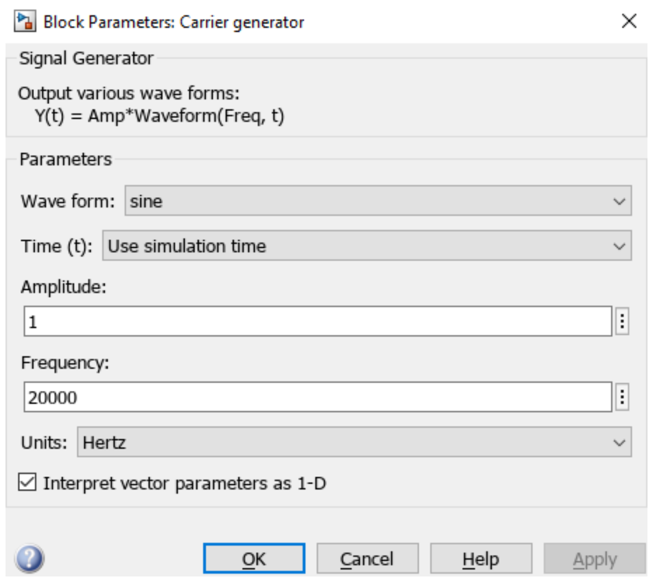

Figure 10: Carrier generator parameters

2. Here are the block parameters of the signal generator for the carrier:

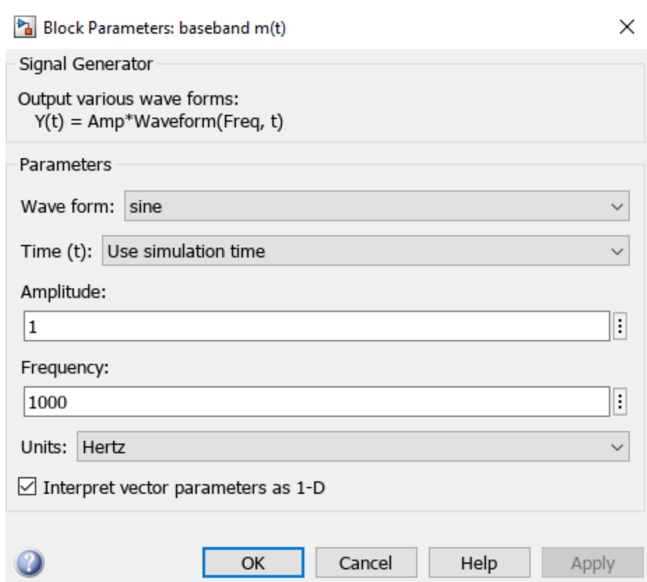

Figure 11: Baseband generator parameters

3. Used the product block to modulate the baseband with the carrier signals.

4. (and 5) Here are the inputs of the baseband and carrier signals and their respective modulated output:

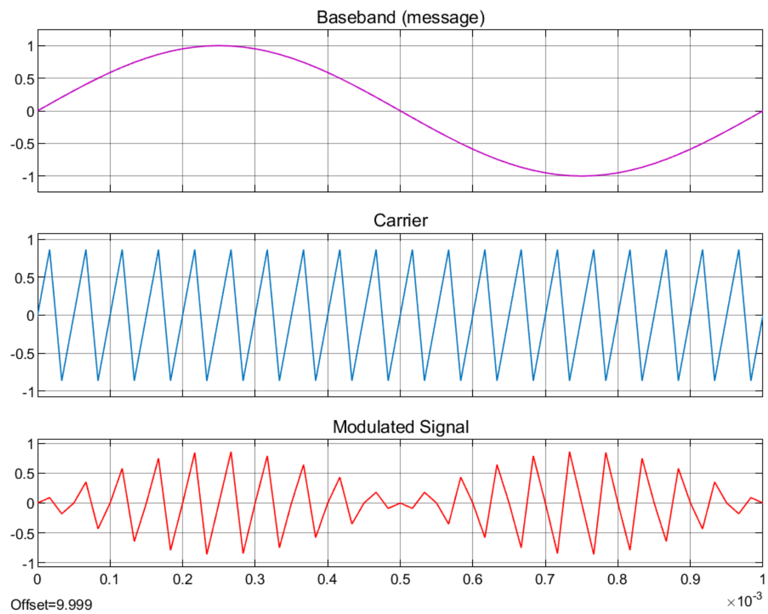

Figure 12: The default Plot

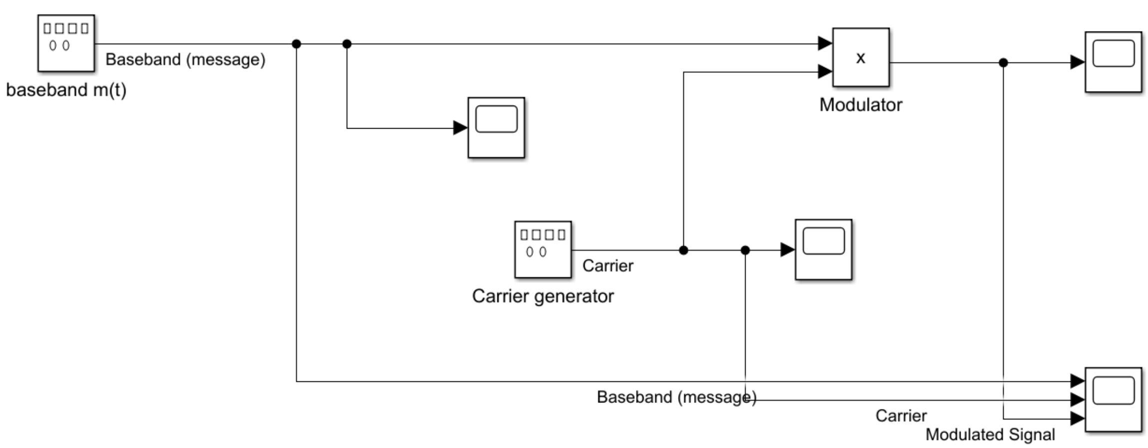

Figure 13: Lab Two Section One Diagram

6. **Changing the amplitude of the baseband signal to 0.5 and 2 volts respectively while also changing the frequencies to 100, 500, 1500, and 2000 Hz:**

The 0.5 V with 100 Hz:

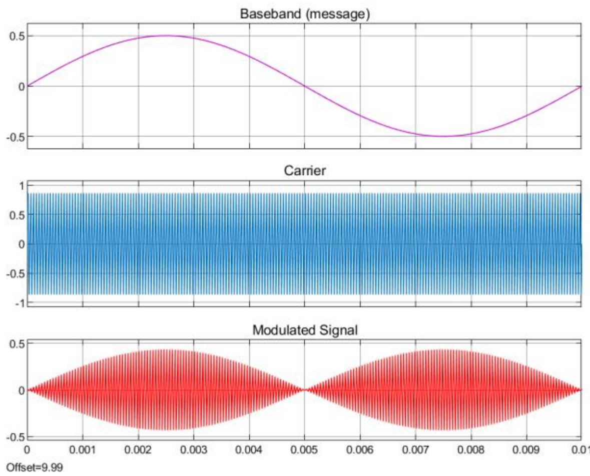

Figure 14: The 0.5V Baseband, 100Hz Plot

The 2 V with 100 Hz:

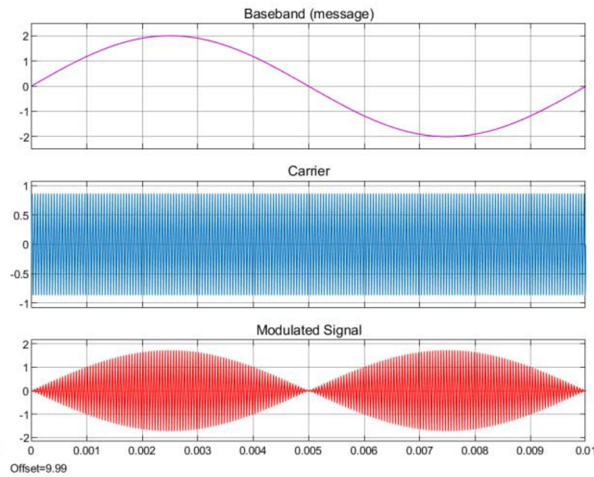

Figure 15: The 2V Baseband, 100Hz Plot

The 0.5 V with 500 Hz:

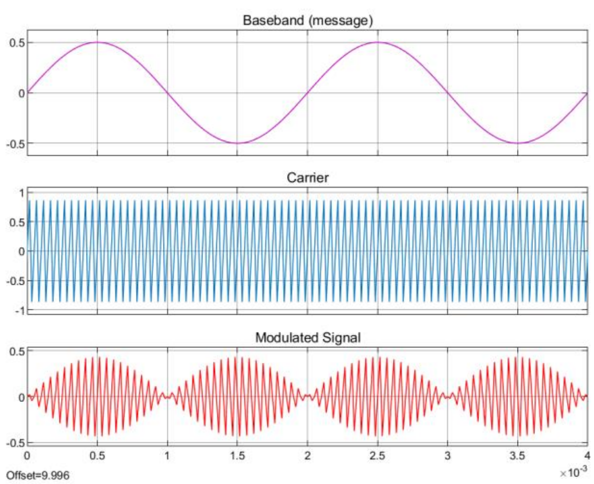

Figure 16: The 0.5V Baseband, 500Hz Plot

The 2 V with 500 Hz:

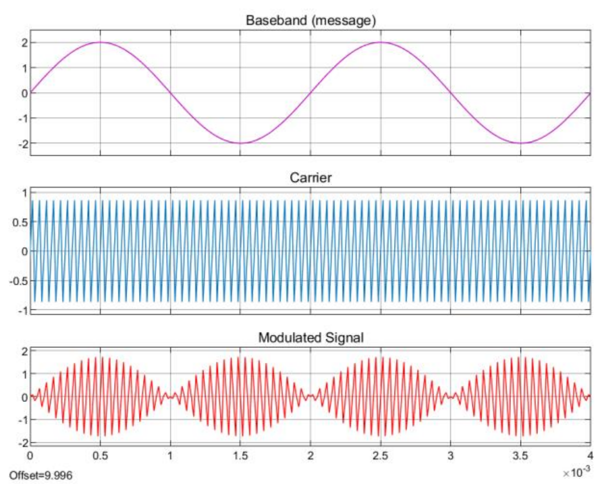

Figure 17: The 2V Baseband, 500Hz Plot

The 0.5 V with 1500 Hz:

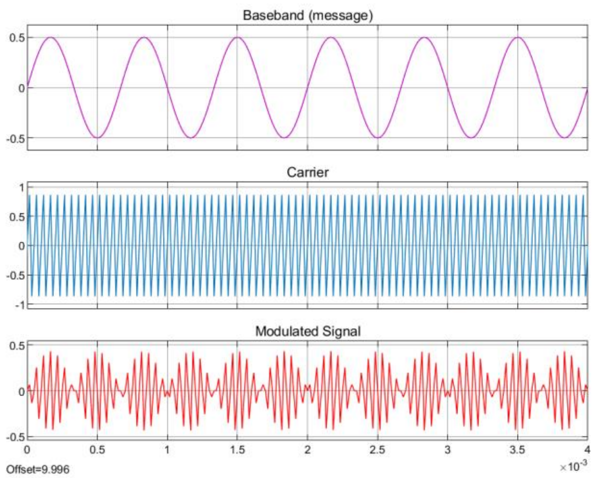

Figure 18: The 0.5V Baseband, 1500Hz Plot

The 2 V with 1500 Hz:

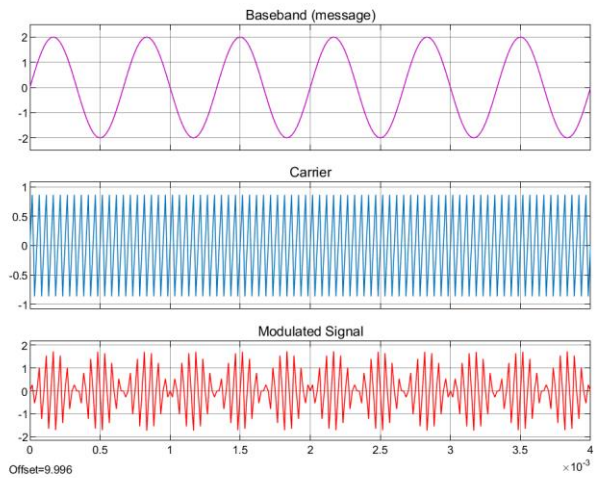

Figure 19: The 2V Baseband, 1500Hz Plot

The 0.5 V with 2000 Hz:

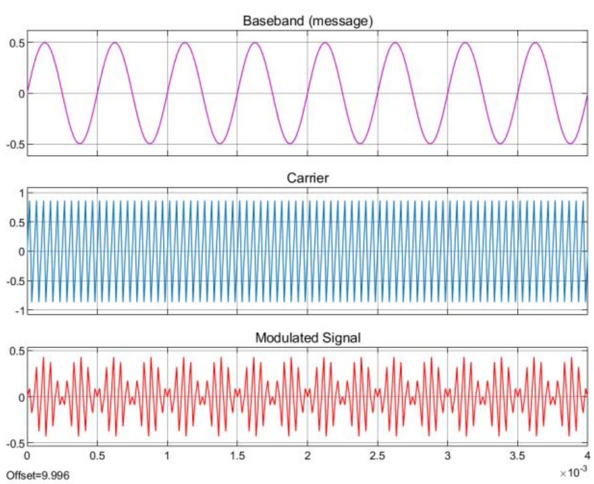

Figure 20: The 0.5V Baseband, 2000Hz Plot

The 2 V with 2000 Hz:

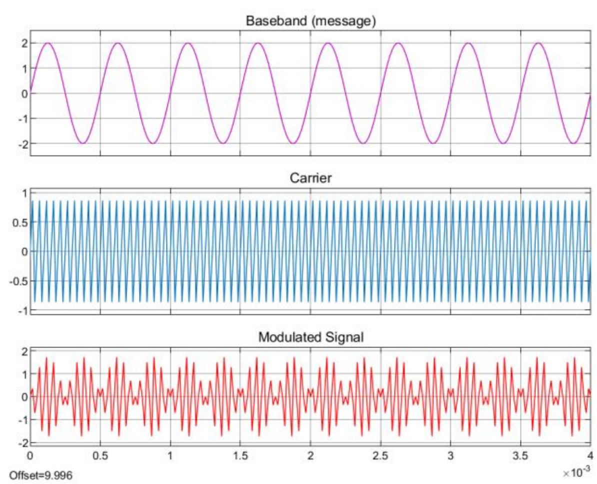

Figure 21: The 2V Baseband, 2000Hz Plot

7. Changing the amplitude of the carrier signal to 0.2 and 2 volts respectively while also changing the frequencies to 2000, 10000, 30000, and 40000 Hz (keeping in mind that I am keeping the baseband values to their default):

The 0.5 V with 2000Hz:

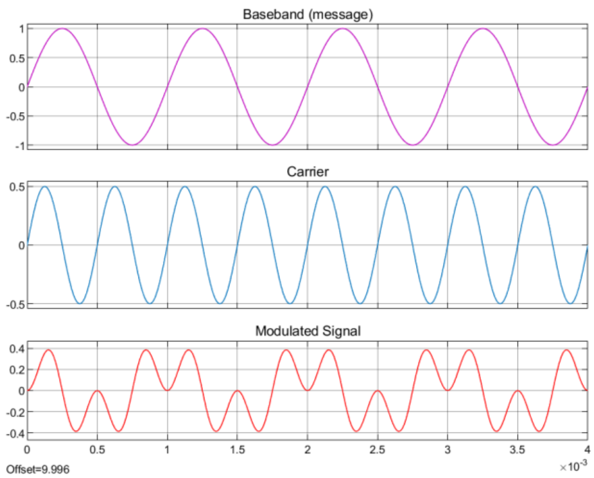

Figure 22: The 0.5V Carrier, 2000Hz Plot

The 2 V with 2000Hz:

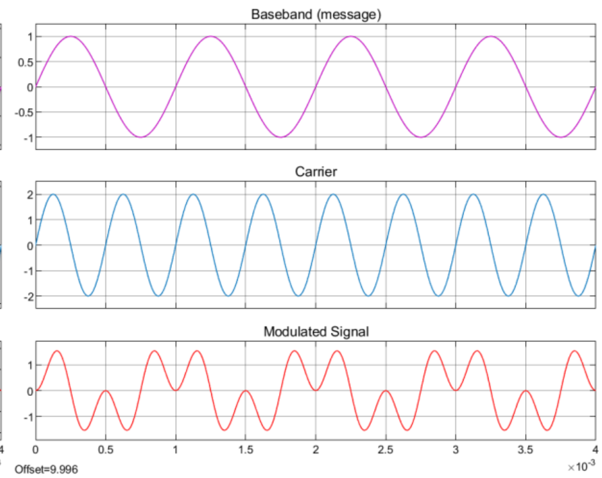

Figure 23: The 2V Carrier, 2000Hz Plot

The 0.5 V with 10000Hz:

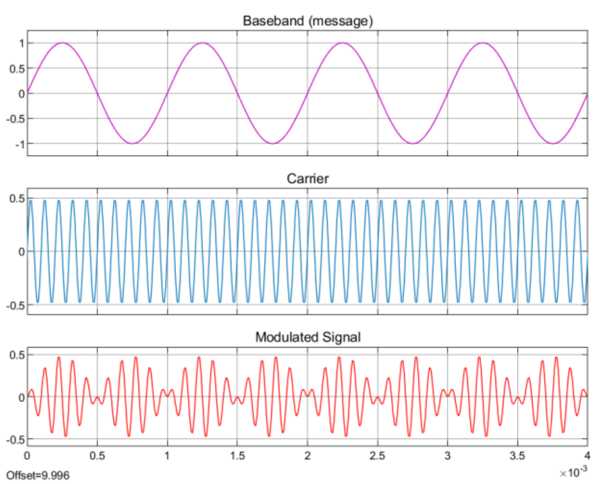

Figure 24: The 0.5V Carrier, 10000Hz Plot

The 2 V with 10000Hz:

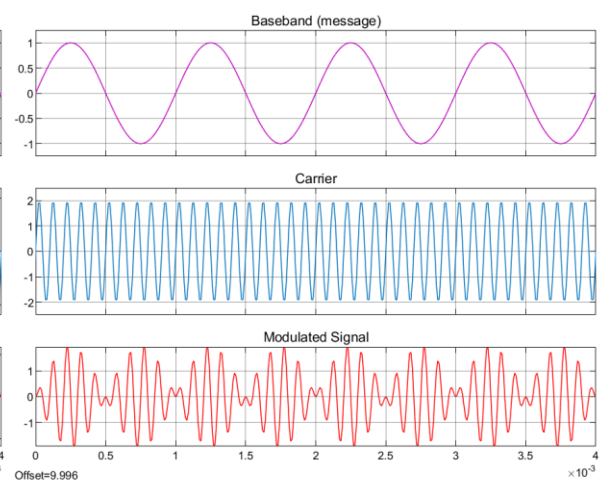

Figure 25: The 2V Carrier, 10000Hz Plot

The 0.5 V with 30000Hz:

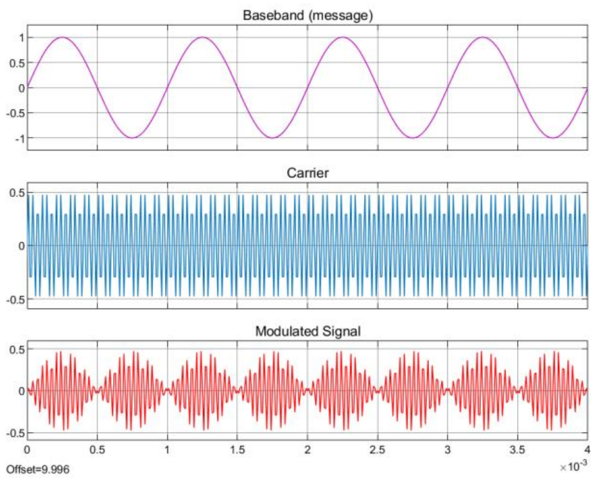

Figure 26: The 0.5V Carrier, 30000Hz Plot

The 2 V with 30000Hz:

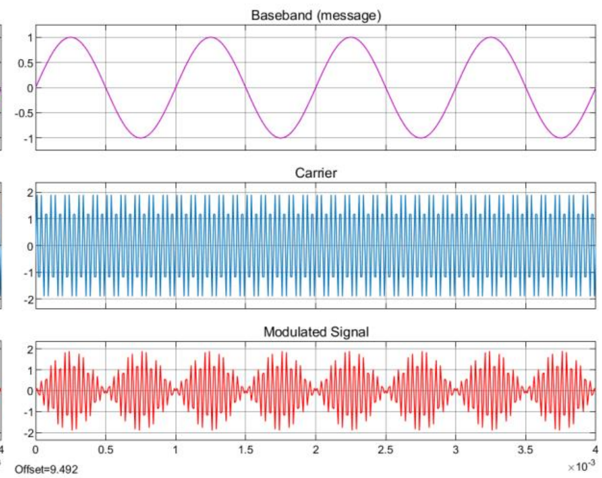

Figure 27: The 2V Carrier, 30000Hz Plot

The 0.5 V with 40000 Hz:

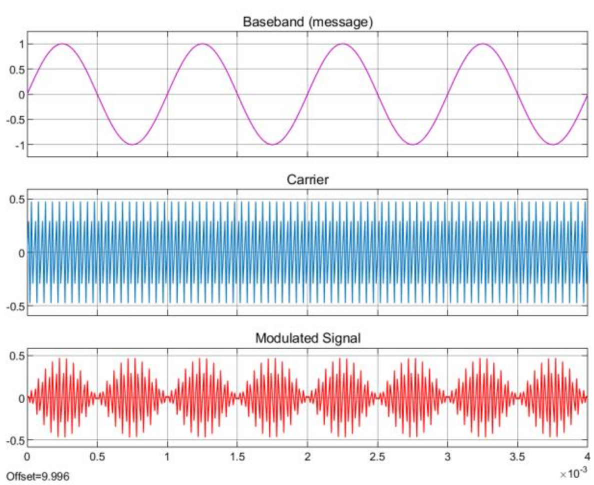

Figure 28: The 0.5V Carrier, 40000Hz Plot

The 2 V with 40000 Hz:

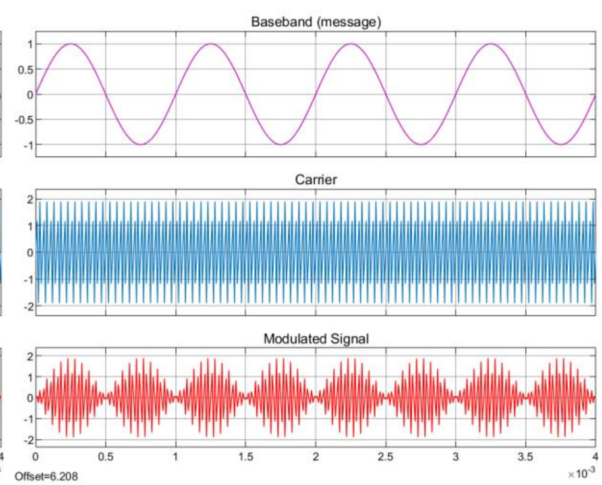

Figure 29: The 2V Carrier, 40000Hz Plot

9. So here are the comments for :
    a. Effect of Changing Frequencies of the Message Signal:

100 Hz: Lowering the frequency of the message signal to 100 Hz results in a slower oscillation pattern, impacting the modulation process. The modulated signal will exhibit a slower rate of variation compared to higher frequencies.

500 Hz: Increasing the frequency to 500 Hz introduces a faster oscillation pattern, affecting the modulation depth and potentially widening the bandwidth occupied by the modulated signal.

1500 Hz: Further increasing the frequency to 1500 Hz enhances the modulation depth and widens the frequency deviation around the carrier signal, resulting in a broader spectral distribution.

2000 Hz: At 2000 Hz, the message signal frequency approaches the upper limit of audible frequencies, potentially leading to distortion and signal clipping in the modulation process due to the increased modulation depth.

    b. Effect of Changing Frequencies of the Carrier Signal:

2000 Hz: Employing a carrier signal frequency of 2000 Hz introduces a carrier wave with a moderate frequency, facilitating effective modulation of the message signal within the audible range.

10,000 Hz: Increasing the carrier frequency to 10,000 Hz shifts the carrier signal to higher frequencies, potentially enhancing signal transmission efficiency and reducing interference from lower-frequency noise sources.

30,000 Hz: Further raising the carrier frequency to 30,000 Hz may improve signal fidelity and reduce interference, particularly in environments with high-frequency noise.

40,000 Hz: At 40,000 Hz, the carrier frequency reaches the upper limit of audible frequencies, potentially posing challenges in modulation and demodulation processes due to limitations in human auditory perception.

c. Effect of Changing Amplitude of the Message Signal:

0.5V: Decreasing the amplitude of the message signal to 0.5V reduces the modulation depth, potentially narrowing the frequency deviation around the carrier signal and compressing the spectral distribution of the modulated signal.

2V: Conversely, increasing the amplitude to 2V amplifies the modulation depth, widening the frequency deviation and expanding the spectral distribution of the modulated signal.

d. Effect of Changing Amplitude of the Carrier Signal:

0.5V: Lowering the amplitude of the carrier signal to 0.5V decreases the carrier wave's peak amplitude, potentially reducing the modulation depth and signal-to-noise ratio in the modulated signal.

2V: Increasing the amplitude to 2V enhances the carrier wave's peak amplitude, amplifying the modulation depth and improving signal-to-noise ratio, particularly in environments with low signal strength.

Summary: The changes in message signal frequency, carrier signal frequency, and signal amplitudes in Lab 2 Section One significantly impact the modulation process and the characteristics of the modulated signal. Altering these parameters affects the modulation depth, frequency deviation, spectral distribution, and signal-to-noise ratio, highlighting the importance of parameter optimization in achieving efficient and reliable modulation in communication systems. These observations provide valuable insights into the behavior of amplitude modulation (DSB-SC) and its sensitivity to input signal parameters, facilitating the design and optimization of modulation systems for diverse communication applications.

Section TWO

1. The modulator Connection Diagram:

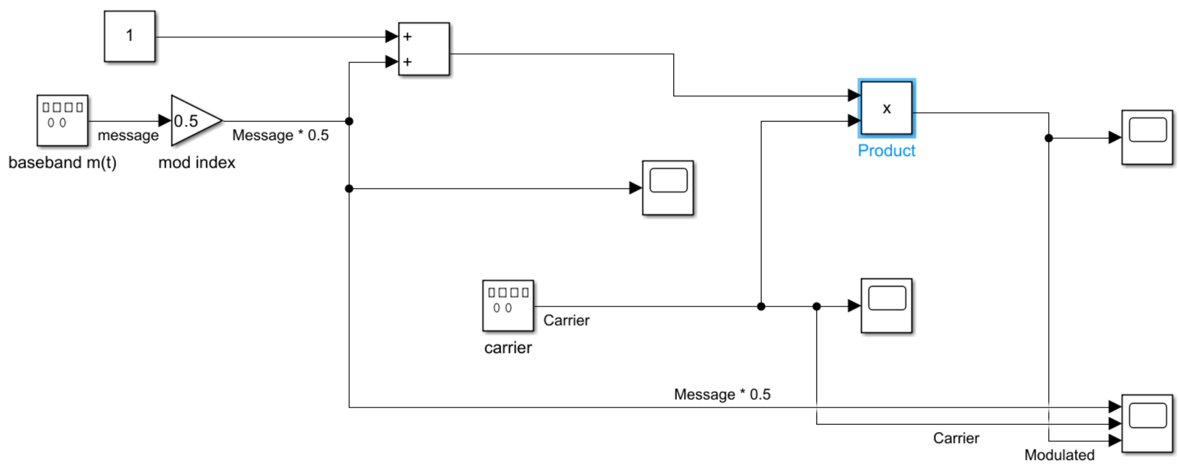

Figure 30: Lab Two Section Two Diagram

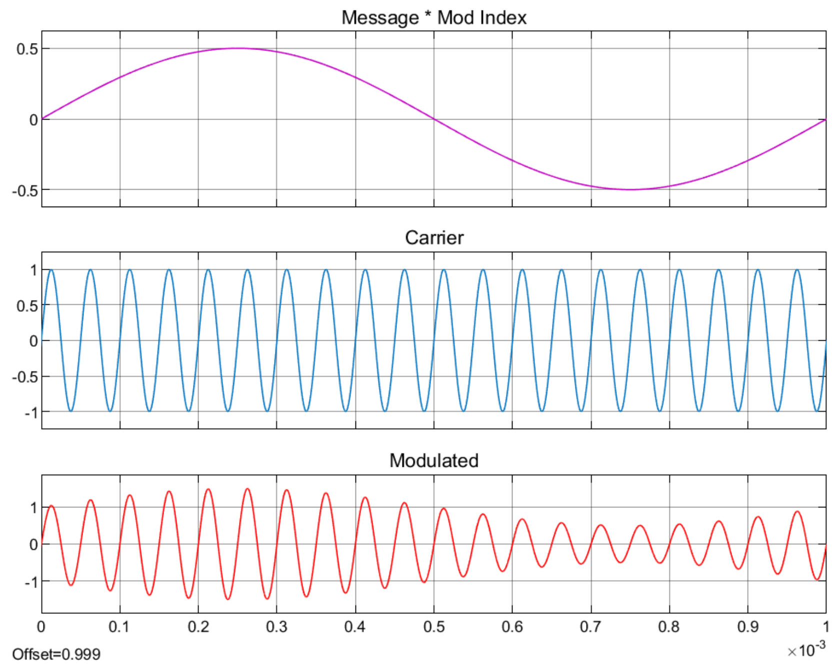

Figure 31: Section Two Plot with parameters of section One

2. Here are the three signals, *(modulation index * m(t), carrier, and modulation signal),* from modulation index of 0.2 to 1 in steps of 0.2 using 100, 500, 1500, and 2000 Hz:

The 0.2 Mod Index with 100 Hz:

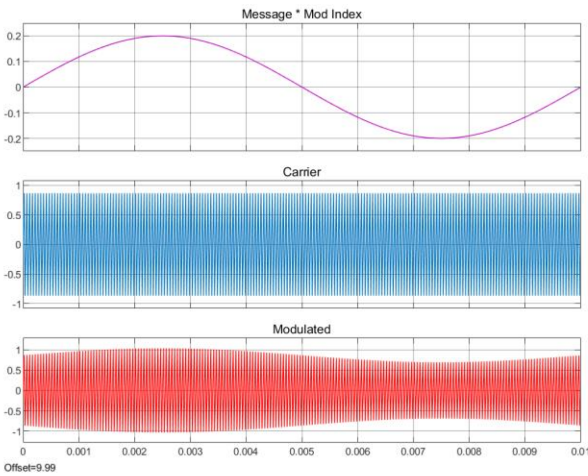

Figure 32: The 0.2 Mod Index 100Hz Plot

The 0.2 Mod Index with 500 Hz:

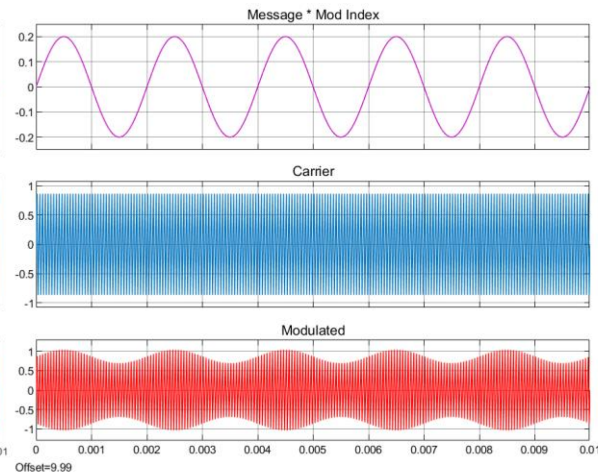

Figure 33: The 0.2 Mod Index 500Hz Plot

The 0.2 Mod Index with 1500 Hz:

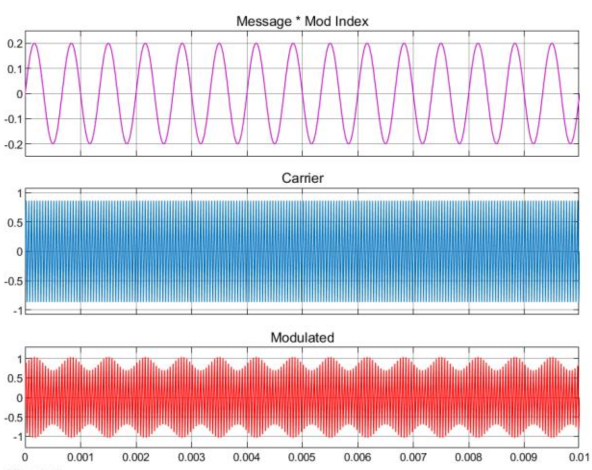

Figure 34: The 0.2 Mod Index 1500Hz Plot

The 0.2 Mod Index with 2000 Hz:

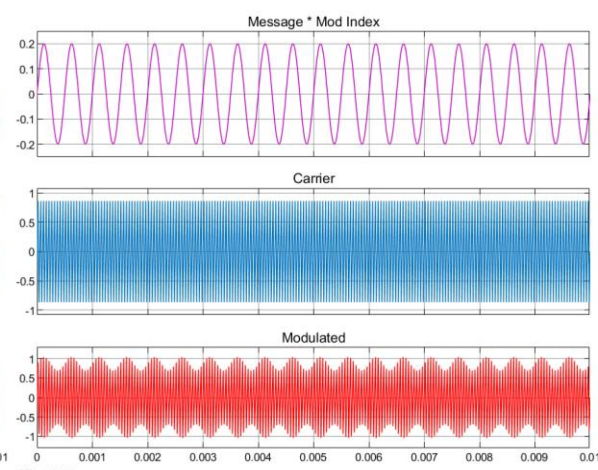

Figure 35: The 0.2 Mod Index 2000Hz Plot

The 0.4 Mod Index with 100 Hz:

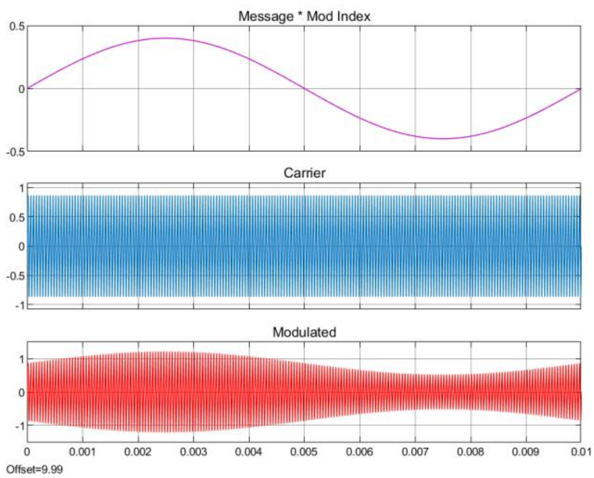

Figure 36: The 0.4 Mod Index 100Hz Plot

The 0.4 Mod Index with 500 Hz:

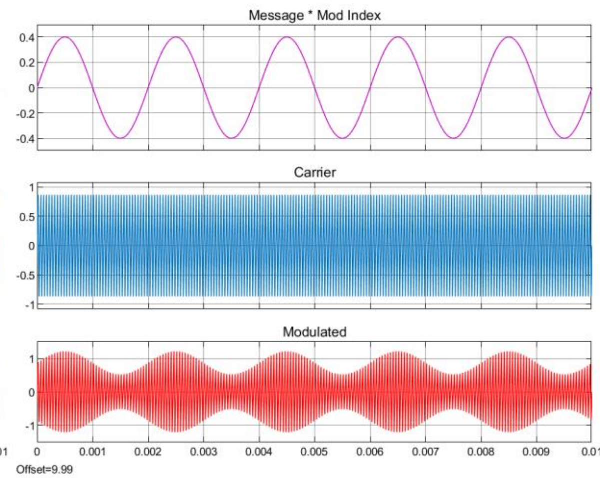

Figure 37: The 0.4 Mod Index 500Hz Plot

The 0.4 Mod Index with 1500 Hz:

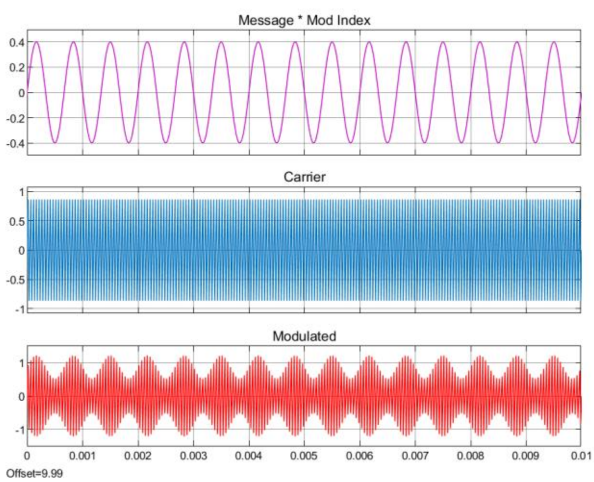

Figure 38: The 0.4 Mod Index 1500Hz Plot

The 0.4 Mod Index with 2000 Hz:

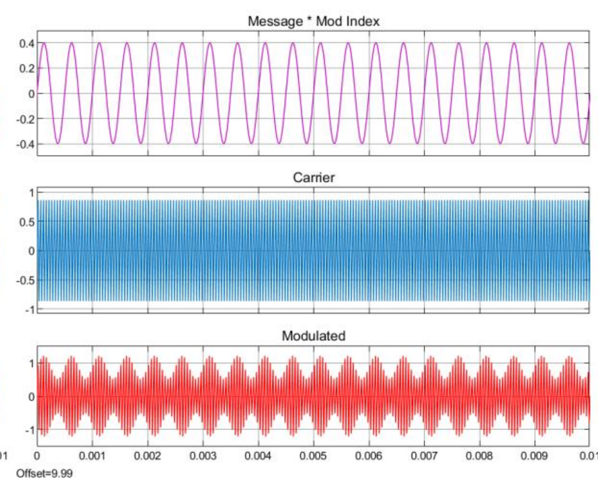

Figure 39: The 0.4 Mod Index 2000Hz Plot

The 0.6 Mod Index with 100 Hz:

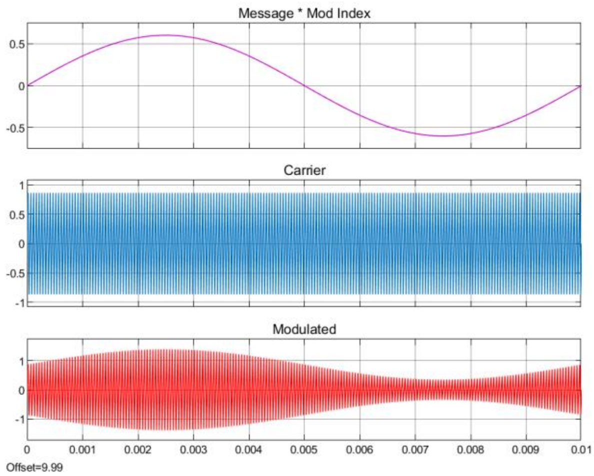

Figure 40: The 0.6 Mod Index 100Hz Plot

The 0.6 Mod Index with 500 Hz:

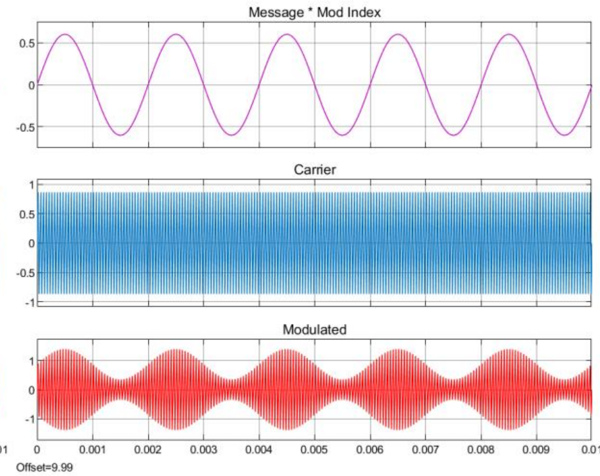

Figure 41: The 0.6 Mod Index 500Hz Plot

The 0.6 Mod Index with 1500 Hz:

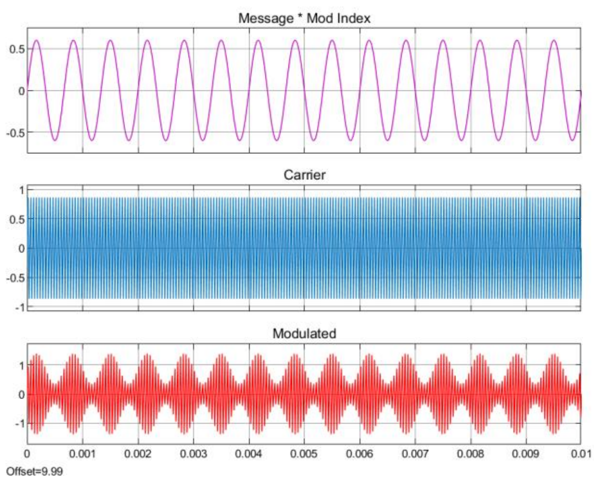

Figure 42: The 0.6 Mod Index 1500Hz Plot

The 0.6 Mod Index with 2000 Hz:

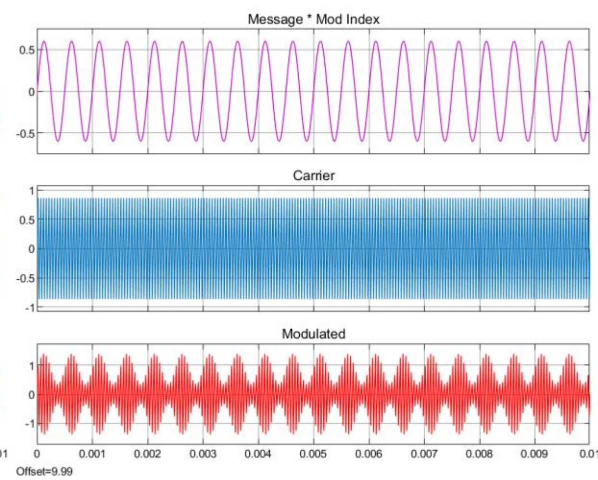

Figure 43: The 0.6 Mod Index 2000Hz Plot

The 0.8 Mod Index with 100 Hz:

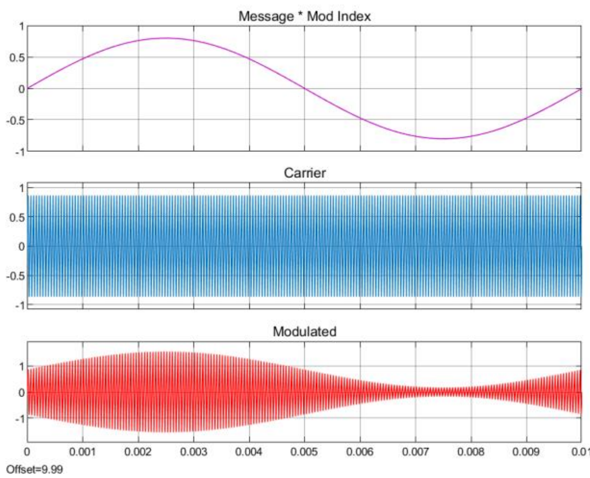

Figure 44: The 0.8 Mod Index 100Hz Plot

The 0.8 Mod Index with 500 Hz:

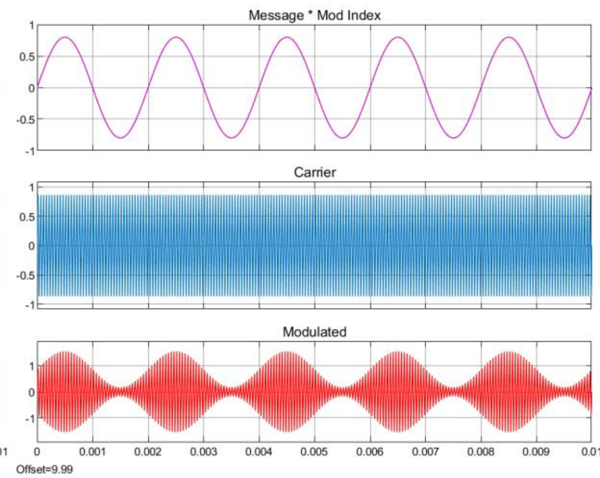

Figure 45: The 0.8 Mod Index 500Hz Plot

The 0.8 Mod Index with 1500 Hz:

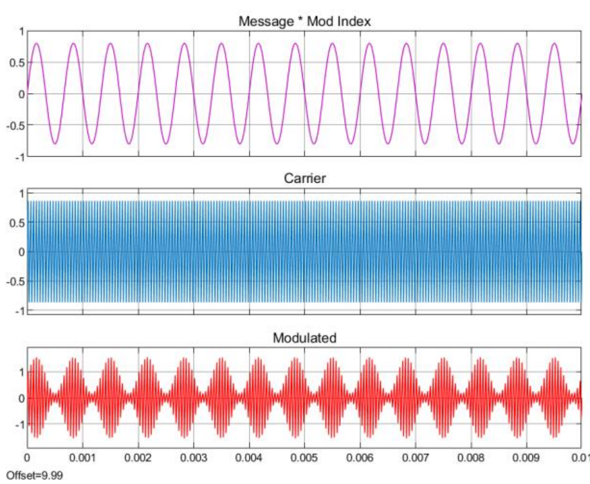

Figure 46: The 0.8 Mod Index 1500Hz Plot

The 0.8 Mod Index with 2000 Hz:

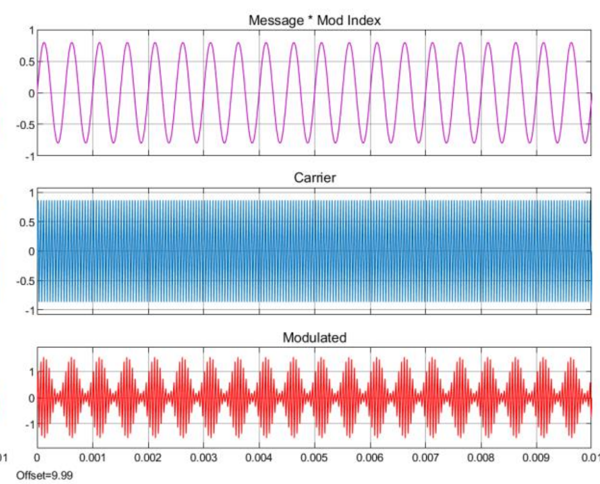

Figure 47: The 0.8 Mod Index 2000Hz Plot

The 1 Mod Index with 100 Hz:

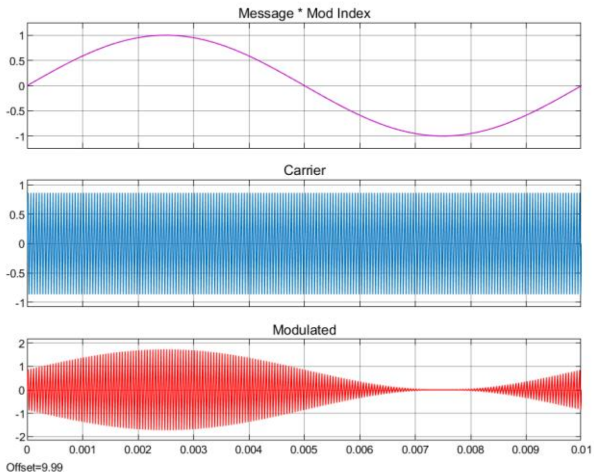

Figure 48: The 1 Mod Index 100Hz Plot

The 1 Mod Index with 500 Hz:

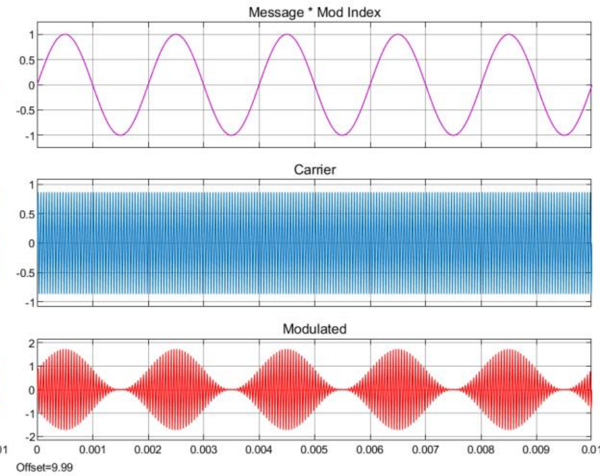

Figure 49: The 1 Mod Index 500Hz Plot

The 1 Mod Index with 1500 Hz:

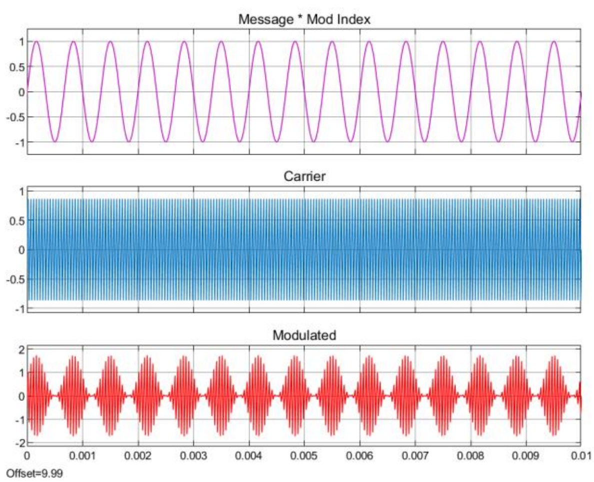

Figure 50: The 1 Mod Index 1500Hz Plot

The 1 Mod Index with 2000 Hz:

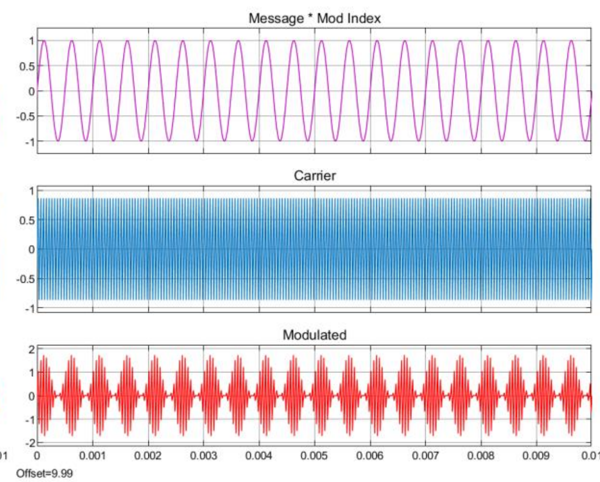

Figure 51: The 1 Mod Index 2000Hz Plot

4. So here is the comparison between sections One and Two:

Modulation Technique:

Lab 2 Section One: Double Sideband Suppressed Carrier (DSB-SC) modulation involves the transmission of sidebands around the carrier frequency without the carrier itself.

Lab 2 Section Two: Double Sideband with Carrier (DSB-WC) modulation includes the carrier component along with the sidebands, resulting in a modulated signal with both sidebands and a carrier.

Spectral Efficiency:

DSB-SC modulation typically offers better spectral efficiency compared to DSB-WC modulation since it eliminates the need to transmit the carrier, thereby conserving bandwidth.

DSB-WC modulation, on the other hand, utilizes more bandwidth due to the inclusion of the carrier component, resulting in a broader spectral distribution.

Demodulation Complexity:

DSB-SC modulation simplifies demodulation since the carrier is absent in the modulated signal, reducing the complexity of the demodulation circuitry.

DSB-WC modulation requires additional circuitry to extract both the carrier and the modulating signal during demodulation, increasing the complexity of the demodulation process.

Power Efficiency:

DSB-WC modulation offers better power efficiency compared to DSB-SC modulation since it allows for the recovery of the original modulating signal at the receiver more efficiently using coherent detection.

DSB-SC modulation may suffer from power loss due to the absence of the carrier, requiring additional power to compensate for the lost carrier energy.

Interference Resilience:

DSB-WC modulation provides better resilience to interference compared to DSB-SC modulation since the presence of the carrier aids in signal recovery and enhances the demodulator's ability to distinguish the desired signal from noise and interference.

DSB-SC modulation may be more susceptible to interference, especially in environments with high levels of noise and distortion, due to the absence of the carrier for reference.

In summary, while DSB-SC modulation offers better spectral efficiency and simpler demodulation, DSB-WC modulation provides improved power efficiency, interference resilience, and coherent detection capabilities. The choice between these modulation techniques depends on the specific requirements of the communication system, balancing factors such as bandwidth efficiency, demodulation complexity, and interference resilience.

Here are the comments on this lab:

a. Effect of Changing Frequencies of the Message Signal:

100 Hz: Lowering the frequency of the message signal to 100 Hz results in a slower oscillation pattern, impacting the modulation process. At this frequency, changes in the modulation index will have discernible effects on the modulation depth and spectral distribution of the modulated signal.

500 Hz: Increasing the frequency to 500 Hz introduces a faster oscillation pattern, affecting the modulation depth and potentially widening the bandwidth occupied by the modulated signal. The impact of changes in the modulation index will be more pronounced at higher frequencies.

1500 Hz: Further increasing the frequency to 1500 Hz enhances the modulation depth and widens the frequency deviation around the carrier signal, resulting in a broader spectral distribution. Changes in the modulation index will exert significant influence on the modulation characteristics and signal fidelity at this frequency.

2000 Hz: At 2000 Hz, the message signal frequency approaches the upper limit of audible frequencies, potentially leading to distortion and signal clipping in the modulation process due to the increased modulation depth. Changes in the modulation index at this frequency will have substantial effects on the modulation depth and spectral occupancy of the modulated signal.

b. Effect of Changing Modulation Index:

Modulation Index 0.2: A modulation index of 0.2 represents a lower level of modulation depth, resulting in narrower frequency deviation and a more compact spectral distribution around the carrier signal. The modulated signal will exhibit relatively low sideband power and may be more susceptible to noise and interference.

Modulation Index 0.4: Increasing the modulation index to 0.4 enhances the modulation depth, widening the frequency deviation and expanding the spectral distribution of the modulated signal. This results in increased sideband power and improved signal-to-noise ratio.

Modulation Index 0.6: Further increasing the modulation index to 0.6 amplifies the modulation depth, leading to a broader spectral distribution and higher sideband power in the modulated signal. Signal fidelity and robustness against noise and interference may improve at this modulation index.

Modulation Index 0.8: At a modulation index of 0.8, the modulation depth reaches higher levels, resulting in significant frequency deviation and a wide spectral distribution around the carrier signal. The modulated signal exhibits increased sideband power and improved signal-to-noise ratio.

Modulation Index 1.0: A modulation index of 1.0 represents full modulation, where the amplitude of the modulating signal equals the amplitude of the carrier signal. At this modulation index, the modulated signal exhibits maximum frequency deviation and the broadest spectral distribution around the carrier signal, resulting in maximum sideband power and optimal signal-to-noise ratio

In Lab 2 Section Two, the interaction between changing frequencies of the message signal and modulation index provides valuable insights into the characteristics of frequency modulation (FM) and its sensitivity to modulation parameters. The frequency deviation, spectral distribution, and signal fidelity of the modulated signal vary significantly with changes in both message signal frequency and modulation index, highlighting the importance of parameter optimization in FM communication systems. These observations contribute to a deeper understanding of FM modulation techniques and facilitate the design and optimization of FM communication systems for diverse applications.

Task 2:

Changing the Hz values to rad/s, the carrier frequency would be around 20,000*2*pi rad/s and the baseband frequency would be around 1000*2*pi rad/s. 1 Hz = 2*Pi

This change is needed to be able to filter out accurately using the butter low pass filter.

1. Using a pass band edge in the LPF of 7000 rad/s, we can recover the original signal using 2 modulators.

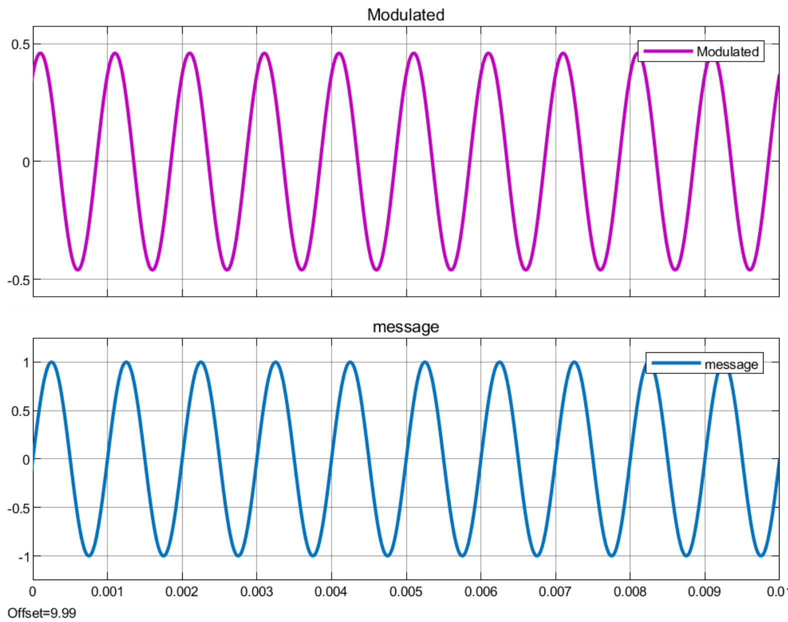

Figure 52: Recovered Signal with LPF

Here is the diagram design in Simulink:

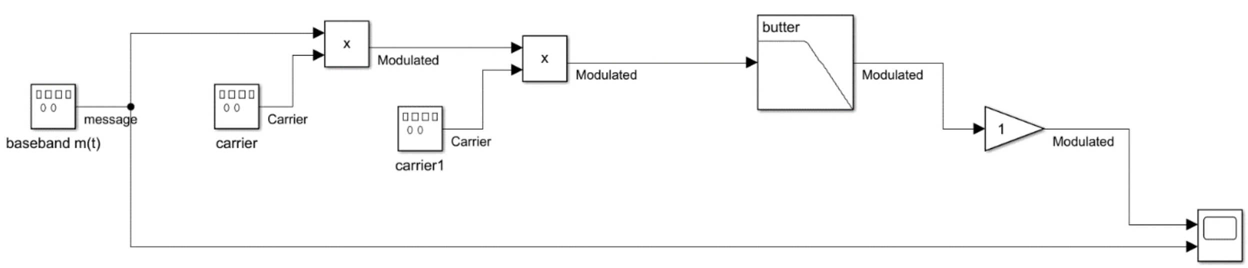

Figure 53: Lab Two Task 2 Diagram

2. We need to change the Passband of the filter to its appropriate Frequency:

A passband of 700 rad/s for 100 Hz:

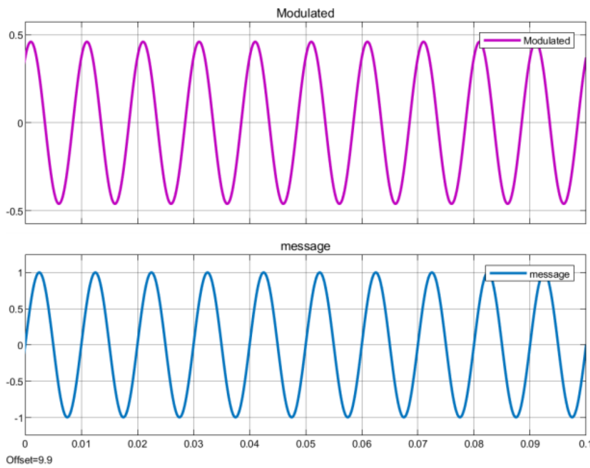

Figure 54: The recovered plot of 100Hz

A passband of 3200 rad/s for 500 Hz:

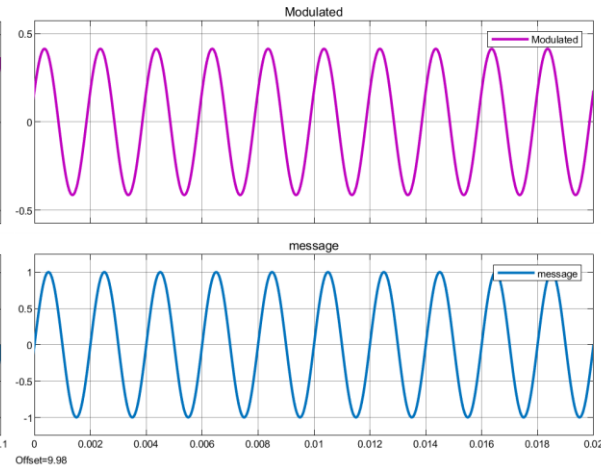

Figure 55: The recovered plot of 500Hz

A passband of 9500 rad/s for 1500 Hz:

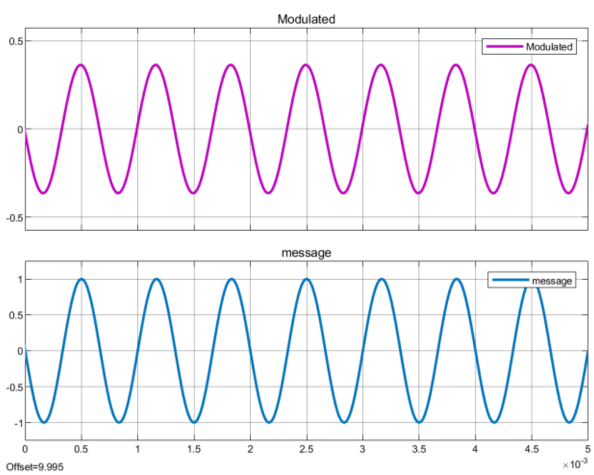

Figure 56: The recovered plot of 1500Hz

A passband of 12600 rad/s for 2000 Hz:

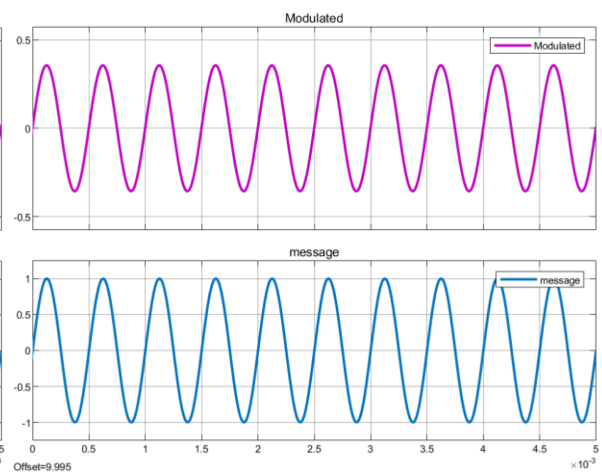

Figure 57: The recovered plot of 2000Hz

3. So here are the comments on DSB-SC Demodulation:

DSB-SC demodulation verifies that demodulation can be achieved by further modulation, emphasizing the principle of coherent detection.

By reversing the modulation process, the original message signal can be recovered from the DSB-SC modulated signal, showcasing the symmetry of modulation and demodulation.

This demodulation technique involves mixing the DSB-SC modulated signal with a local oscillator signal at the carrier frequency, resulting in the extraction of the modulating signal.

The demodulated signal obtained through this process demonstrates the successful retrieval of the original message signal, reaffirming the effectiveness of coherent detection in DSB-SC demodulation.

Verification through Oscilloscope Display:

Displaying the demodulated signal on an oscilloscope provides visual confirmation of the demodulation process, allowing for qualitative assessment of signal fidelity and accuracy.

Observing the demodulated signal on an appropriate scale enables the visualization of signal characteristics such as amplitude, frequency, and phase, facilitating comparison with the original message signal.

The oscilloscope display serves as a valuable tool for verifying the integrity of the demodulated signal and assessing the performance of the demodulation process across different frequency values.

LAB THREE

Task 1:

1. **Using the Signal generator block, we created the sine wave with 100hz and 2V.**

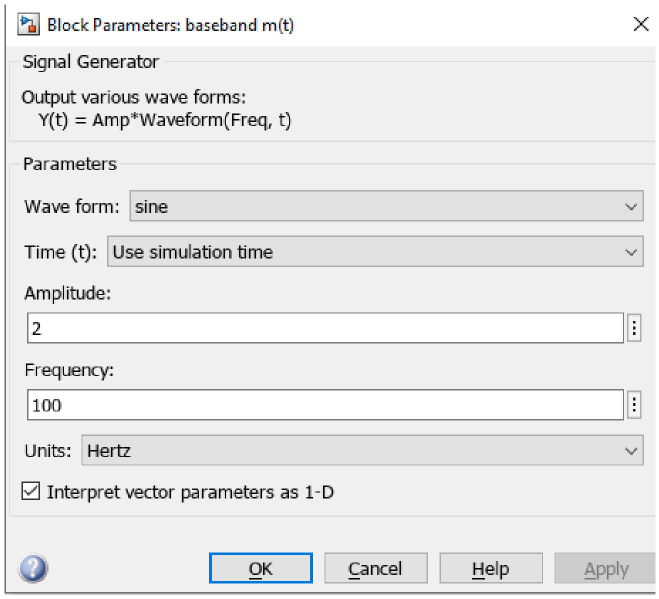

Figure 58: Block Parameters

2. **Here is the Block design of the cascading integrator block:**

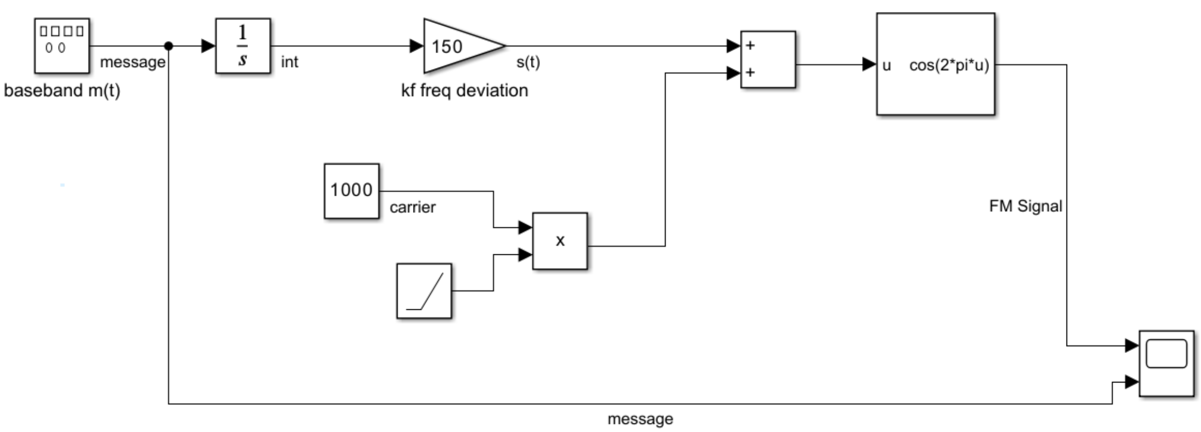

Figure 59: Lab Three Task One Diagram

3. I placed a gain block and named it kf frequency deviation.
4. Placed both the 1000hz constant block as a carrier(fc) and a slope of 1 as the time(t). I also placed the product block, and its inputs are the fc to yield an output of fc*t.
5. Used an add block to combine the Gain block and Product block outputs.
6. Applied the output of the add block to the input of the sine block.
7. After creating the sine block, I made the connection.
8. (and 9) The scope of the input and the output:

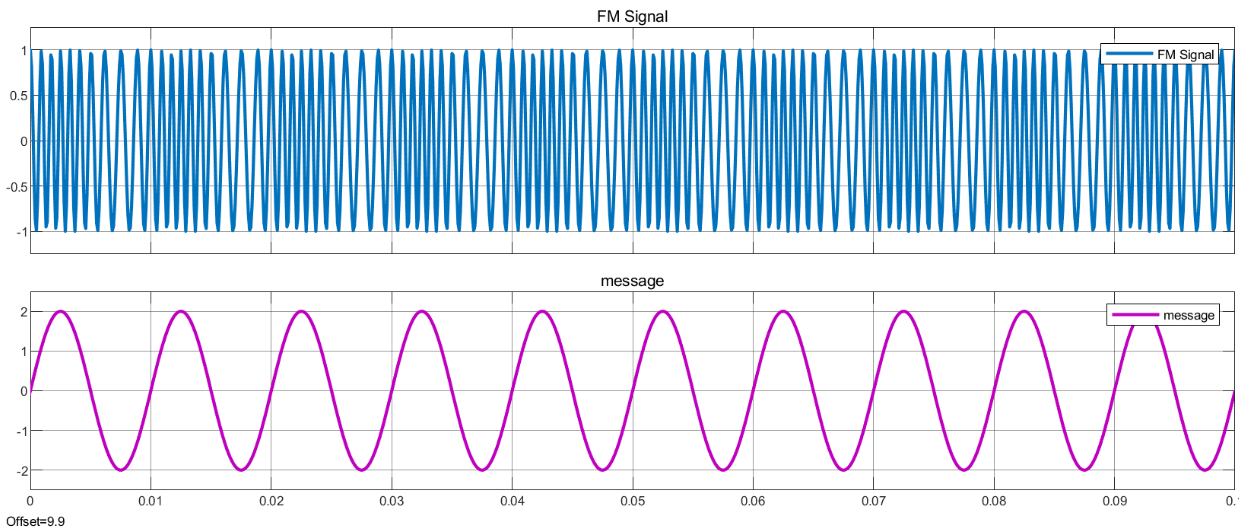

Figure 60: Plot of FM Signal

a. The following are the changes that have been made in the carrier and the baseband signal in the following lab.

For the baseband m(t) amplitude and frequency changes (keep in mind k = 150):

The 0.5 V of m(t) with 50 Hz:

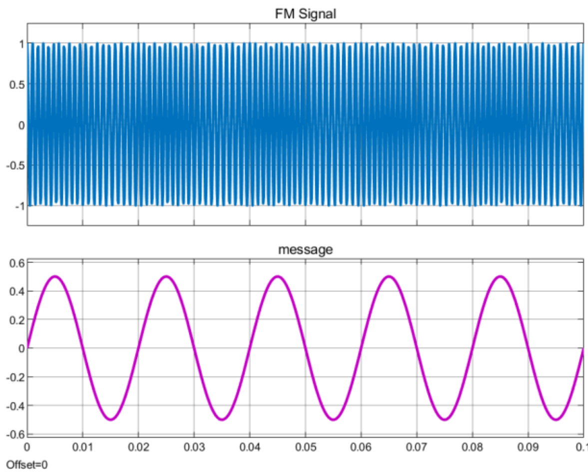

Figure 61: The 0.5V m(t), 50Hz Plot

The 0.5 V of m(t) with 80 Hz:

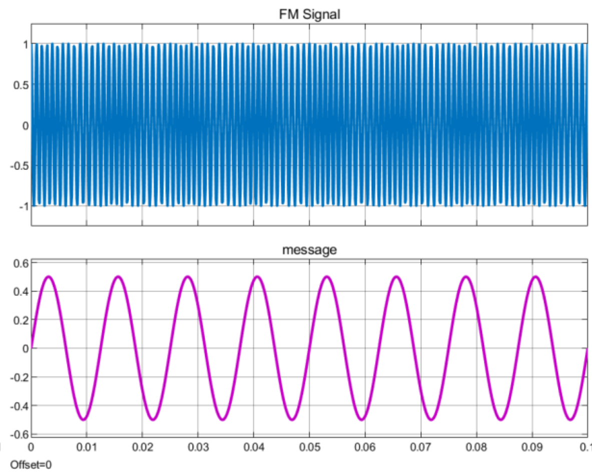

Figure 62: The 0.5V m(t), 80Hz Plot

The 0.5 V of m(t) with 120 Hz:

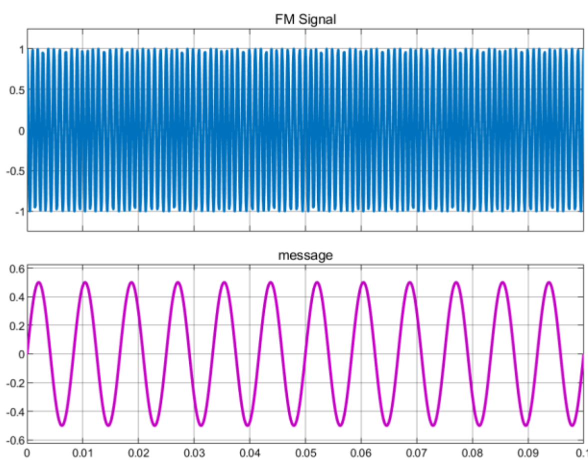

Figure 63: The 0.5V m(t), 120Hz Plot

The 0.5 V of m(t) with 150 Hz:

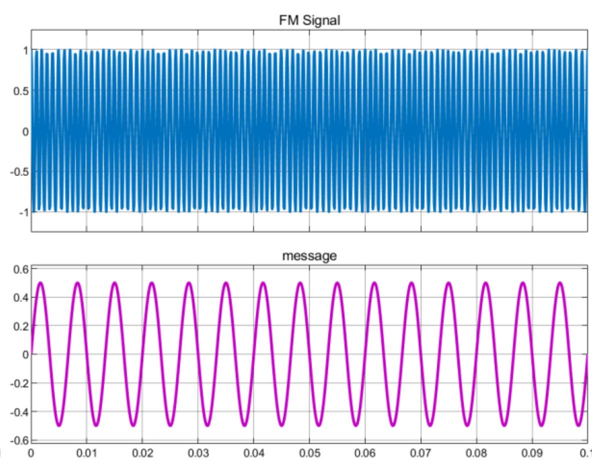

Figure 64: The 0.5V m(t), 150Hz Plot

The 5 V of m(t) with 50 Hz:

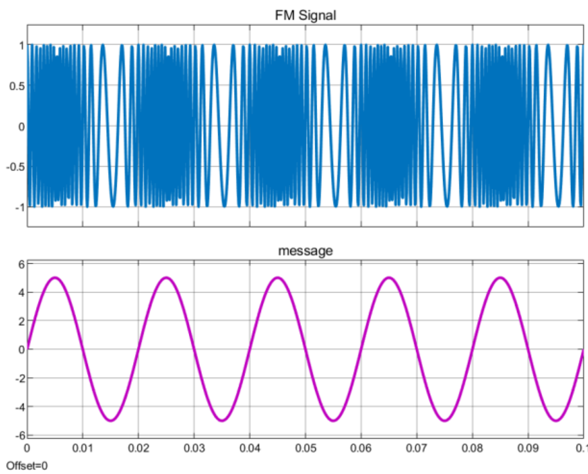

Figure 65: The 5V m(t), 50Hz Plot

The 5 V of m(t) with 80 Hz:

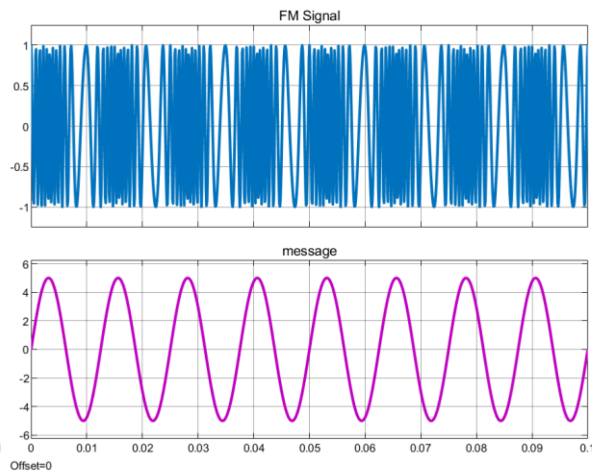

Figure 66: The 5V m(t), 80Hz Plot

The 5 V of m(t) with 120 Hz:

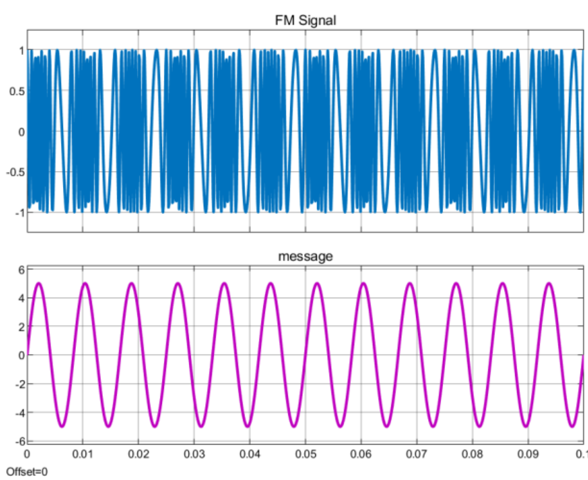

Figure 67: The 5V m(t), 120Hz Plot

The 5 V of m(t) with 150 Hz:

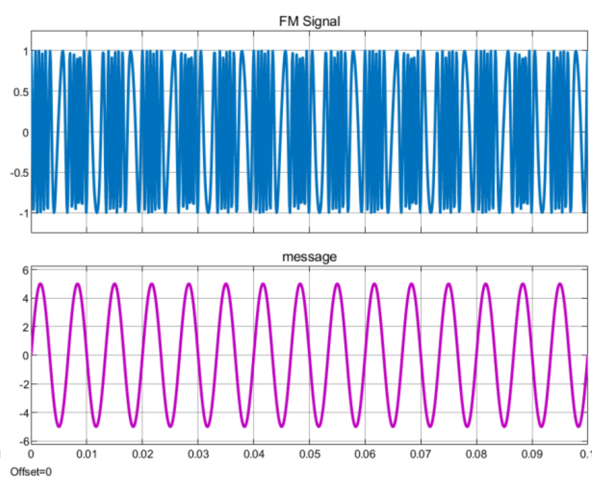

Figure 68: The 5V m(t), 150Hz Plot

For the Carrier amplitude and frequency changes:

The 0.5 V Carrier with 500 Hz:

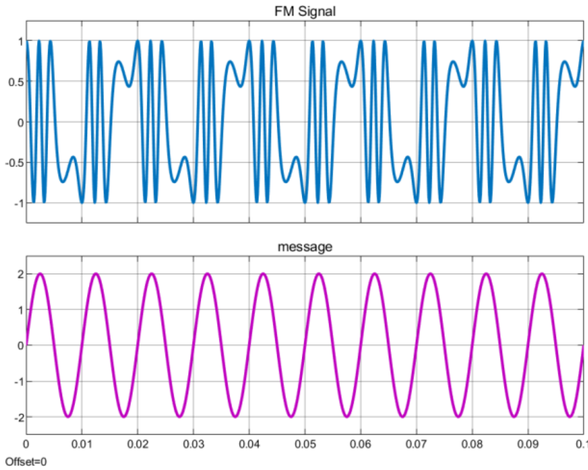

Figure 69: The 0.5V Carrier, 500Hz Plot

The 0.5 V Carrier with 800 Hz:

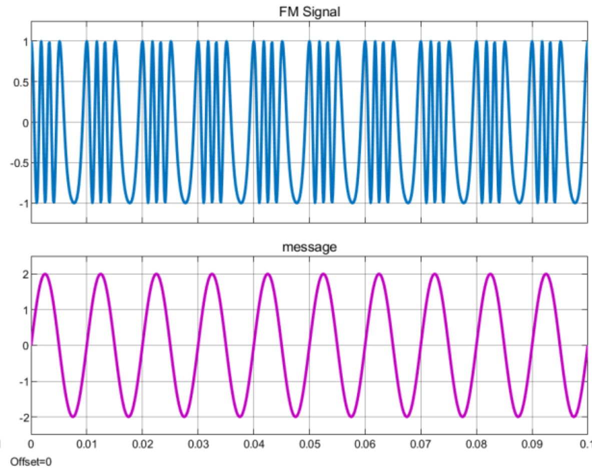

Figure 70: The 0.5V Carrier, 800Hz Plot

The 0.5 V Carrier with 1200 Hz:

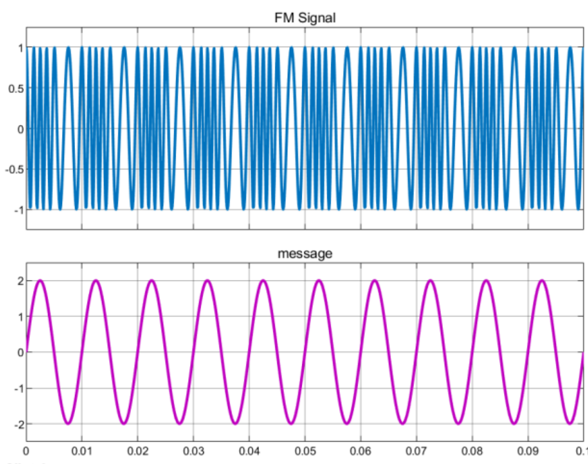

Figure 71: The 0.5V Carrier, 1200Hz Plot

The 0.5 V Carrier with 1500 Hz:

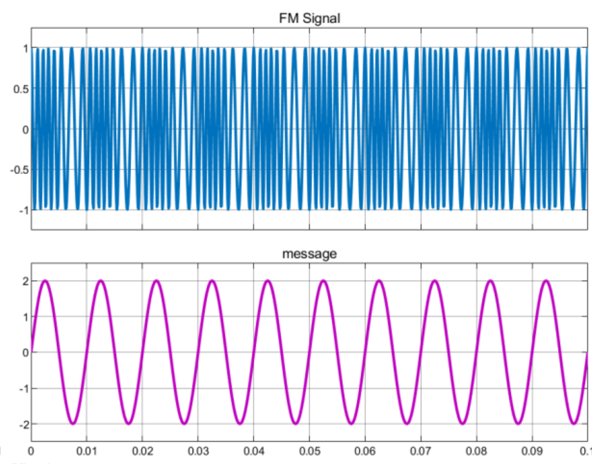

Figure 72: The 0.5V Carrier, 1500Hz Plot

The 2 V Carrier with 500 Hz:

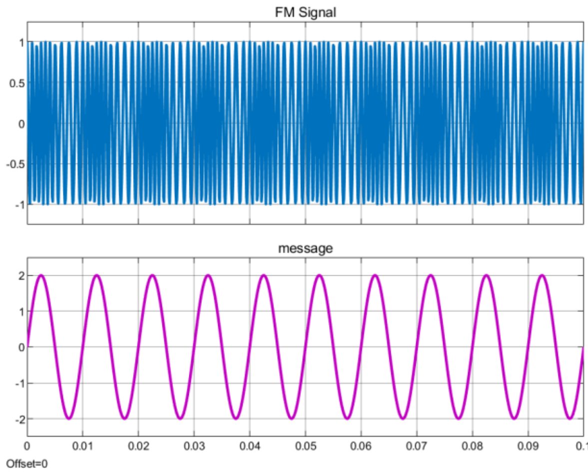

Figure 73: The 2V Carrier, 500Hz Plot

The 2 V Carrier with 800 Hz:

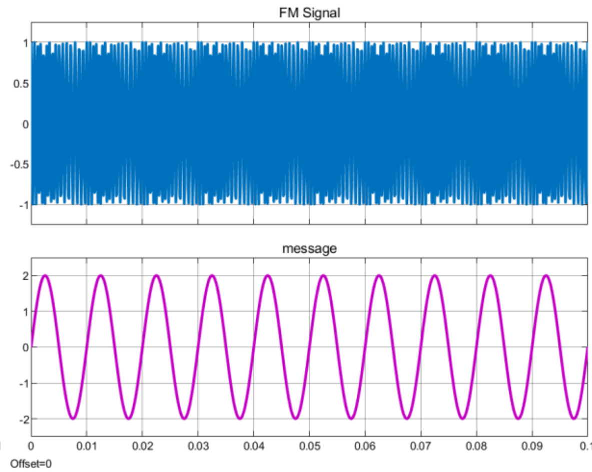

Figure 74: The 2V Carrier, 800Hz Plot

The 2 V Carrier with 1200 Hz:

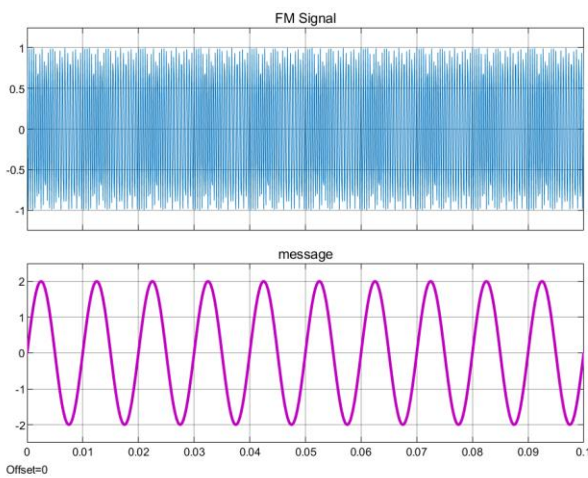

Figure 75: The 2V Carrier, 1200Hz Plot

The 2 V Carrier with 1500 Hz:

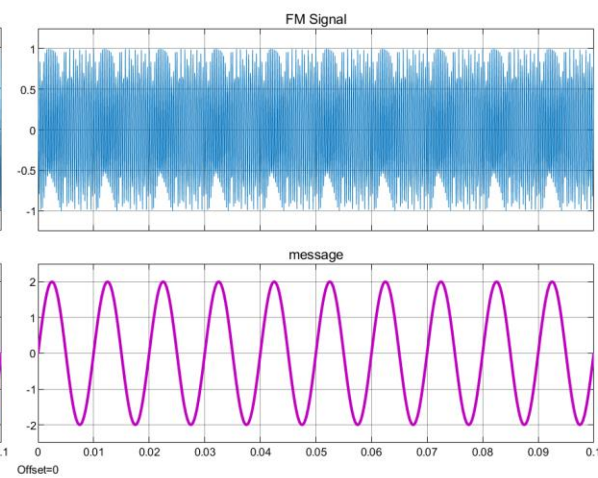

Figure 76: The 2V Carrier, 1500Hz Plot

b. The following are changes in the 3 Changes in Frequency Deviation Constant (k):

When K = 50:

The 0.5 V of m(t) with 50 Hz:

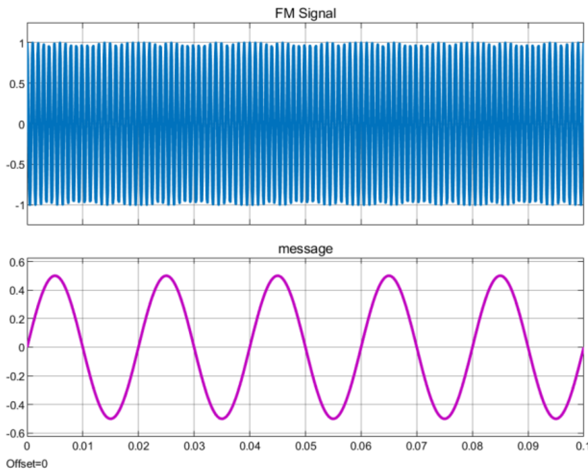

Figure 77: The 0.5V m(t), 50Hz Plot K=50

The 0.5 V of m(t) with 80 Hz:

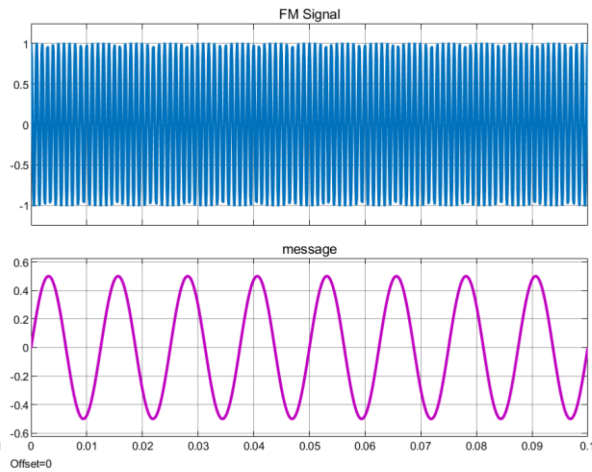

Figure 78: The 0.5V m(t), 80Hz Plot K=50

The 0.5 V of m(t) with 120 Hz:

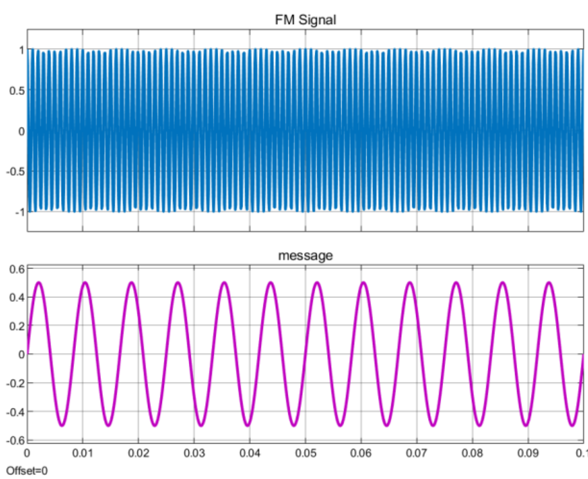

Figure 79: The 0.5V m(t), 120Hz Plot K=50

The 0.5 V of m(t) with 150 Hz:

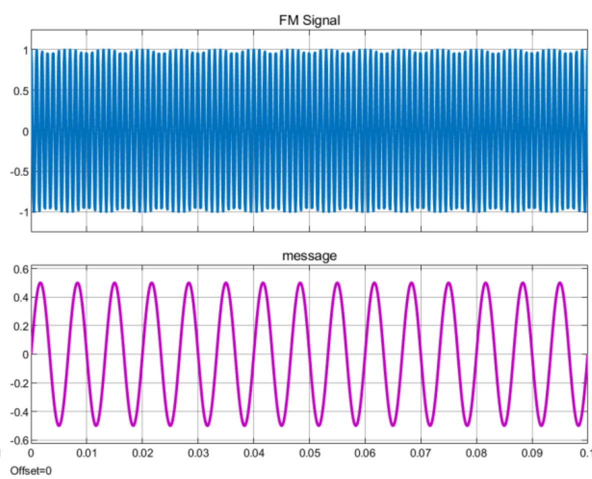

Figure 80: The 0.5V m(t), 150Hz Plot K=50

The 5 V of m(t) with 50 Hz:

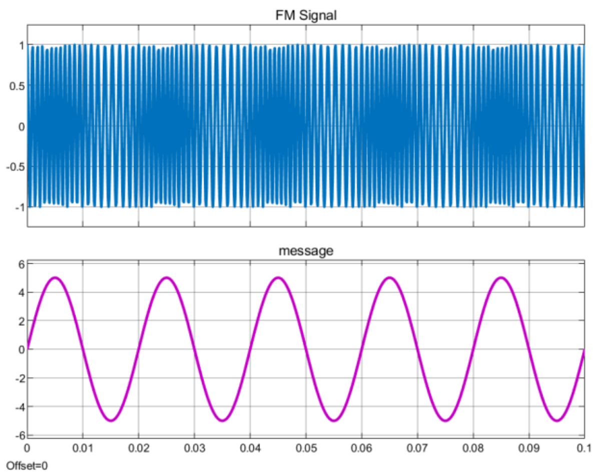

Figure 81: The 5V m(t), 50Hz Plot K=50

The 5 V of m(t) with 80 Hz:

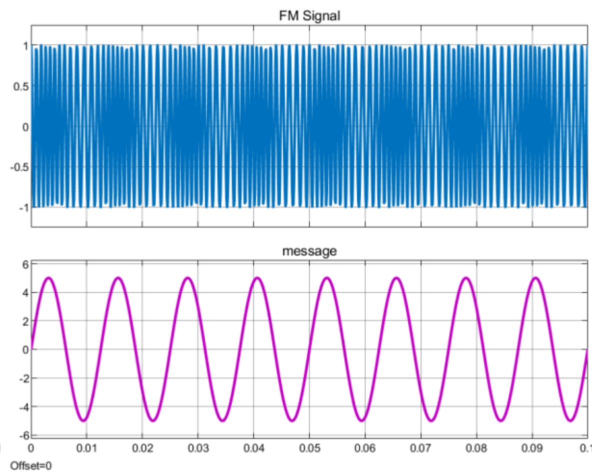

Figure 82: The 5V m(t), 80Hz Plot K=50

The 5 V of m(t) with 120 Hz:

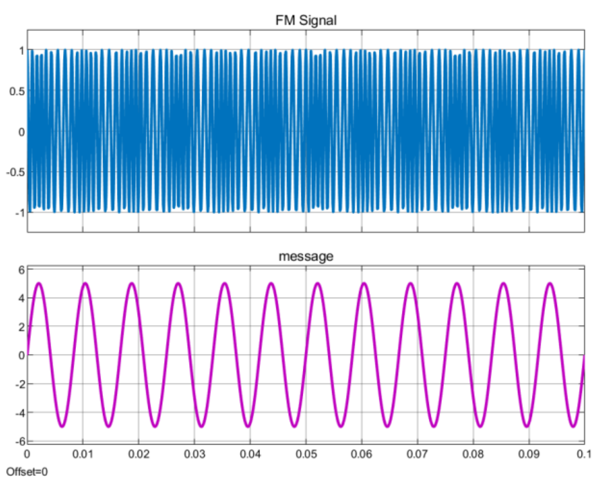

Figure 83: The 5V m(t), 120Hz Plot K=50

The 5 V of m(t) with 150 Hz:

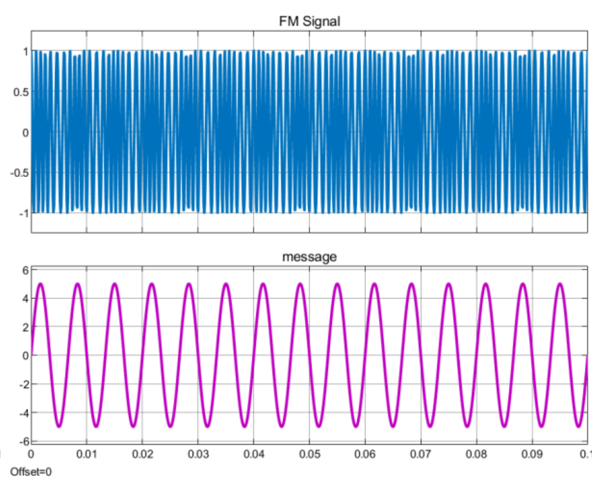

Figure 84: The 5V m(t), 150Hz Plot K=50

When K = 100:

The 0.5 V of m(t) with 50 Hz:

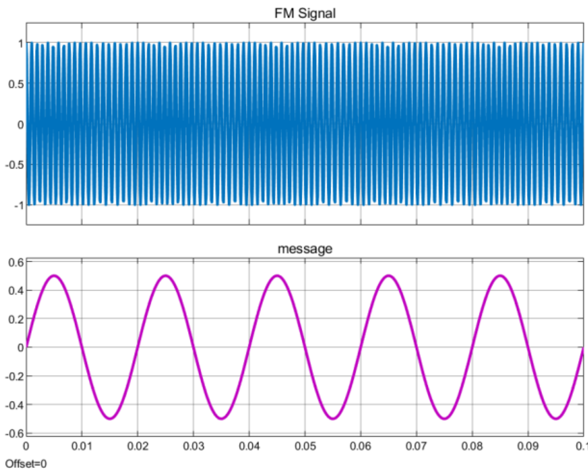

Figure 85: The 0.5V m(t), 50Hz Plot K=50

The 0.5 V of m(t) with 80 Hz:

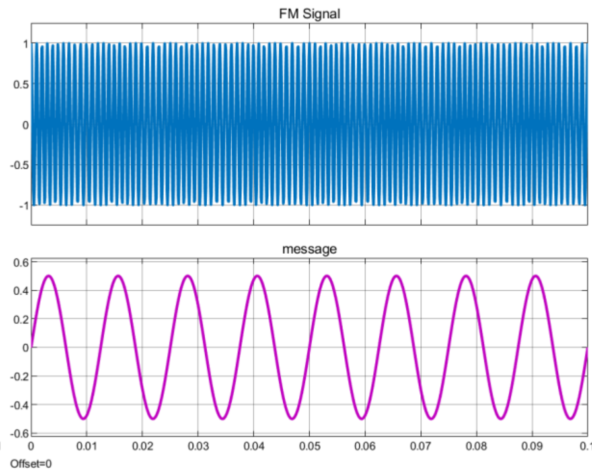

Figure 86: The 0.5V m(t), 80Hz Plot K=50

The 0.5 V of m(t) with 120 Hz:

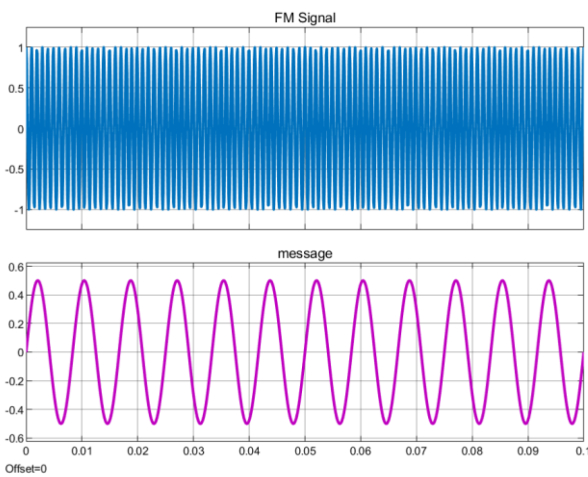

Figure 87: The 0.5V m(t), 120Hz Plot K=50

The 0.5 V of m(t) with 150 Hz:

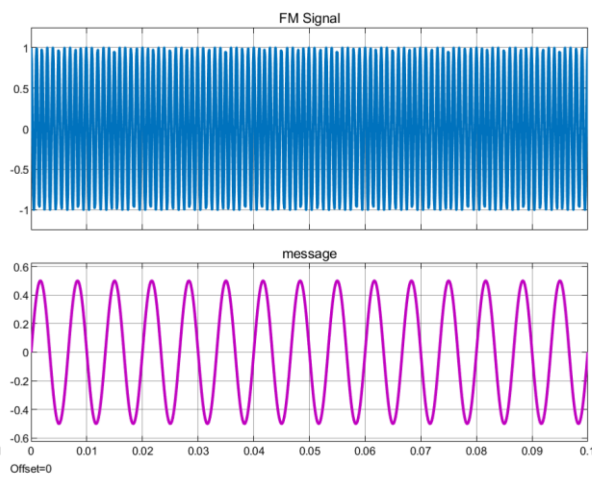

Figure 88: The 0.5V m(t), 150Hz Plot K=50

The 5 V of m(t) with 50 Hz:

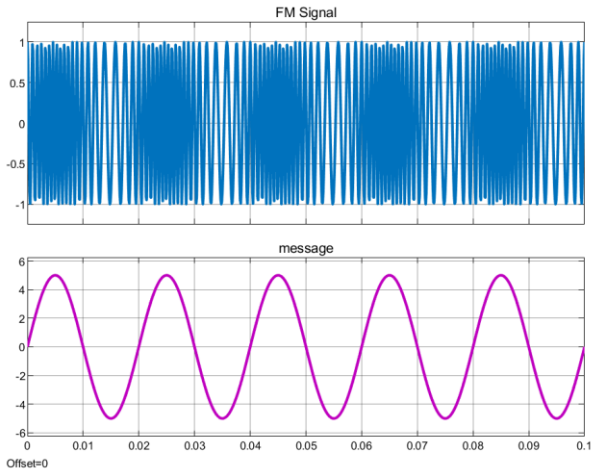

Figure 89: The 5V m(t), 50Hz Plot K=50

The 5 V of m(t) with 80 Hz:

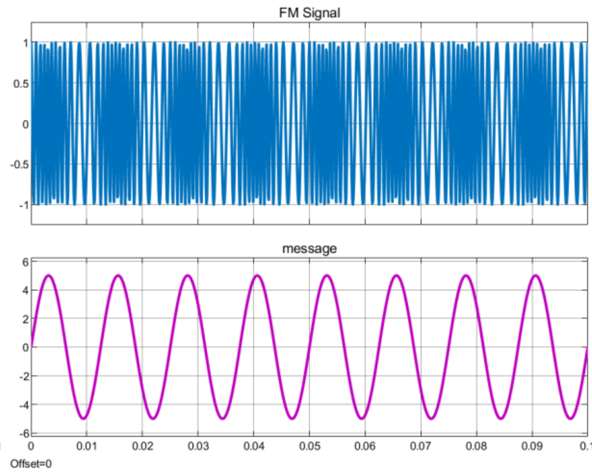

Figure 90: The 5V m(t), 80Hz Plot K=50

The 5 V of m(t) with 120 Hz:

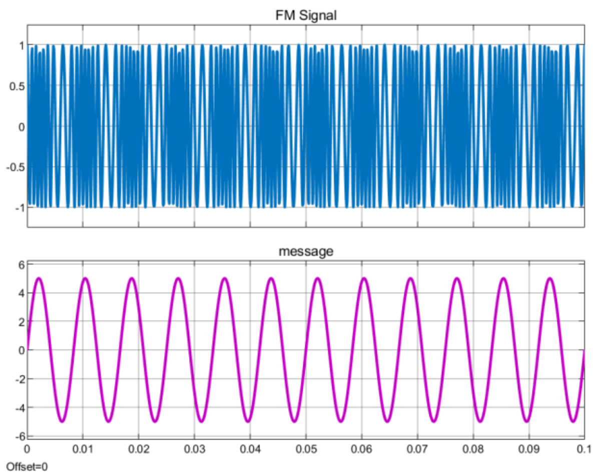

Figure 91: The 5V m(t), 120Hz Plot K=50

The 5 V of m(t) with 150 Hz:

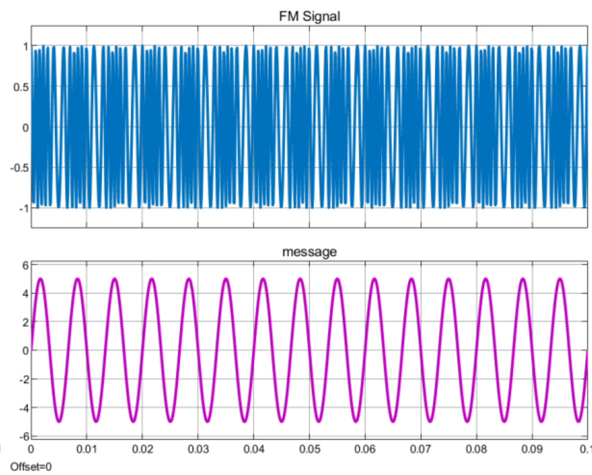

Figure 92: The 5V m(t), 150Hz Plot K=50

When K = 250:

The 0.5 V of m(t) with 50 Hz:

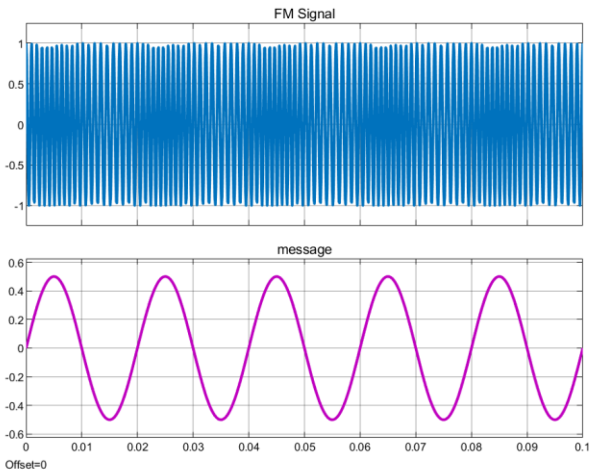

Figure 93: The 0.5V m(t), 50Hz Plot K=50

The 0.5 V of m(t) with 80 Hz:

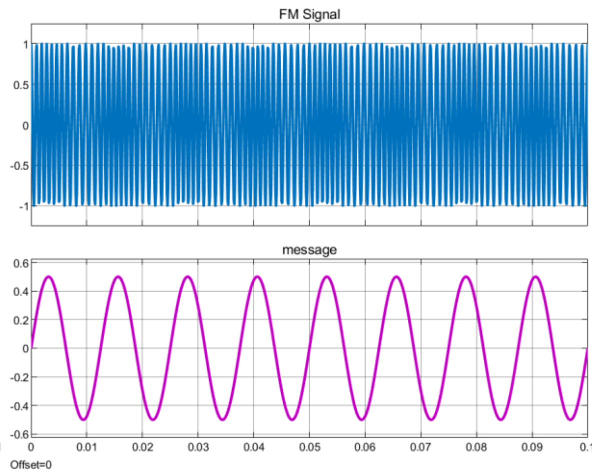

Figure 94: The 0.5V m(t), 80Hz Plot K=50

The 0.5 V of m(t) with 120 Hz:

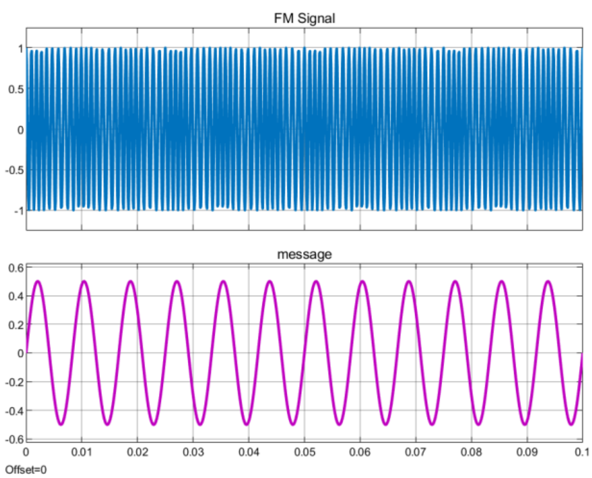

Figure 95: The 0.5V m(t), 120Hz Plot K=50

The 0.5 V of m(t) with 150 Hz:

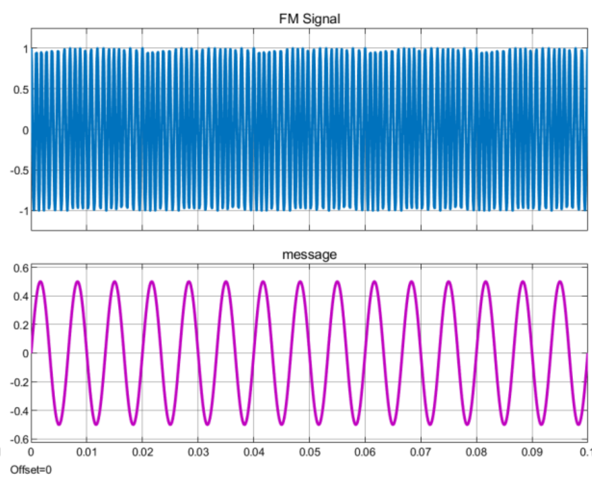

Figure 96: The 0.5V m(t), 150Hz Plot K=50

The 5 V of m(t) with 50 Hz:

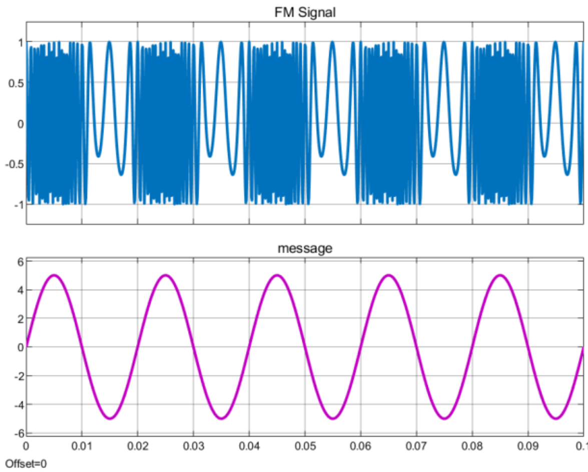

Figure 97: The 5V m(t), 50Hz Plot K=50

The 5 V of m(t) with 80 Hz:

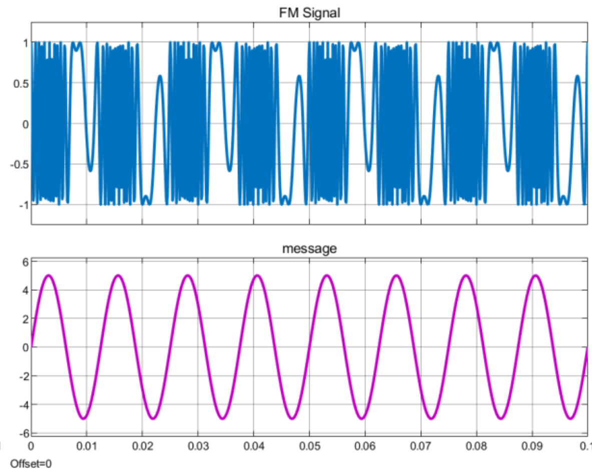

Figure 98: The 5V m(t), 80Hz Plot K=50

The 5 V of m(t) with 120 Hz:

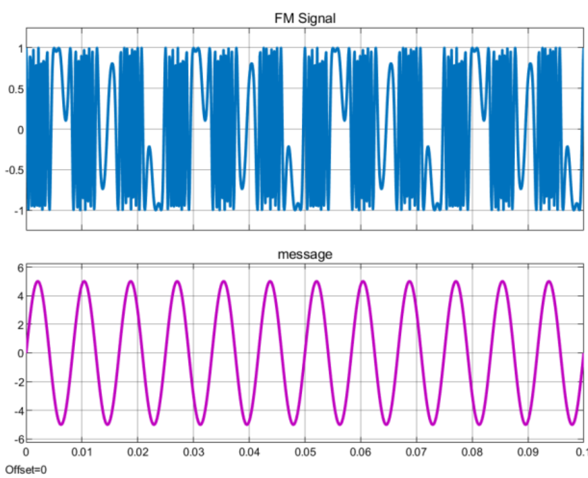

Figure 99: The 5V m(t), 120Hz Plot K=50

The 5 V of m(t) with 150 Hz:

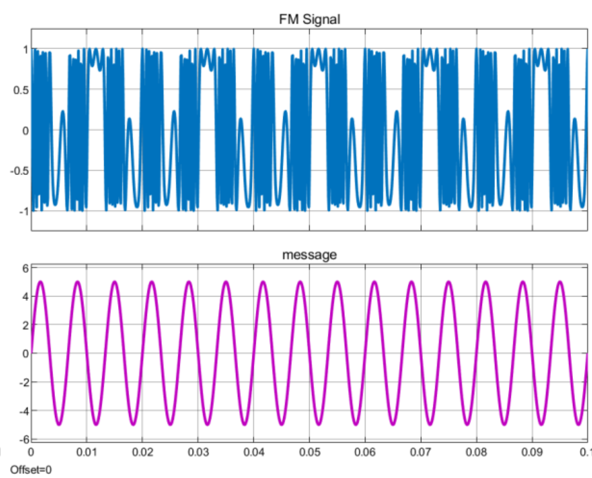

Figure 100: The 5V m(t), 150Hz Plot K=50

c. Here are the comments:

Signal Amplitude Effect:

- Increasing the signal amplitude amplifies the modulation depth, leading to a more pronounced frequency deviation from the carrier frequency.
- This wider frequency swing results in a broader spectral distribution around the carrier, increasing the bandwidth occupied by the FM signal.
- However, excessively high signal amplitudes can cause overmodulation, leading to distortion and potential loss of signal fidelity.
- Conversely, reducing the signal amplitude decreases the modulation depth, resulting in a narrower frequency deviation and a compressed frequency spectrum closer to the carrier frequency.
- Lower signal amplitudes can enhance spectral efficiency by reducing bandwidth usage, but they may also decrease the signal-to-noise ratio and increase vulnerability to noise and interference.

Frequency Deviation Index Effect:

- Increasing the frequency deviation index widens the frequency modulation range around the carrier frequency.
- This broader frequency deviation increases the signal's bandwidth and can improve signal detectability, especially in environments with high noise levels.
- However, excessively high-frequency deviation indices can lead to spectral splatter, where spectral components spread out beyond the desired bandwidth, causing interference with adjacent channels.
- Conversely, decreasing the frequency deviation index narrows the frequency modulation range, reducing the signal's bandwidth.
- Narrower frequency deviation indices can conserve bandwidth and improve spectral efficiency but may also reduce the signal's immunity to noise and distortion, particularly in environments with high-frequency noise.

Effect of Changing Frequencies of the Message Signal:

50 Hz: Lowering the frequency of the message signal to 50 Hz results in a slower oscillation pattern, impacting the frequency modulation process. At this frequency, changes in the frequency deviation parameter will have discernible effects on the modulation depth and spectral distribution of the FM signal.

80 Hz: Increasing the frequency to 80 Hz introduces a faster oscillation pattern, affecting the modulation depth and potentially widening the bandwidth occupied by the FM signal. The impact of changes in the frequency deviation parameter will be more pronounced at higher frequencies.

120 Hz: Further increasing the frequency to 120 Hz enhances the modulation depth and widens the frequency deviation range around the carrier frequency, resulting in a broader spectral distribution. Changes in the frequency deviation parameter will exert a significant influence on the modulation characteristics and signal fidelity at this frequency.

150 Hz: At 150 Hz, the message signal frequency approaches the upper limit of the low-frequency range, potentially leading to distortion and signal clipping in the FM modulation process due to the increased modulation depth. Changes in the frequency deviation parameter at this frequency will have substantial effects on the modulation depth and spectral occupancy of the FM signal.

Effect of Changing Frequency Deviation (k):

k = 50: A lower frequency deviation value of k = 50 represents a narrower frequency modulation range around the carrier frequency. This results in a more compact spectral distribution and reduced bandwidth occupied by the FM signal.

k = 100: Increasing the frequency deviation to k = 100 widens the frequency modulation range, leading to expanded spectral distribution and increased bandwidth occupancy. The FM signal will exhibit higher sideband power and improved signal detectability.

k = 250: Further increasing the frequency deviation to k = 250 amplifies the modulation depth significantly, resulting in a broader spectral distribution and wider frequency modulation range. However, excessively high-frequency deviation values may lead to spectral splatter and interference with adjacent channels.

In Lab 3 Section One, the interaction between changing frequencies of the message signal and frequency deviation parameter (k) provides valuable insights into the characteristics of frequency modulation (FM) and its sensitivity to modulation parameters. Adjusting the message signal frequency impacts the modulation depth and spectral distribution of the FM signal, while changes in the frequency deviation parameter influence the bandwidth occupancy and spectral characteristics. Finding an optimal balance between these parameters is crucial for achieving efficient and reliable FM signal transmission in practical communication systems.

Task 2:

1. Implementing the FM Demodulator:

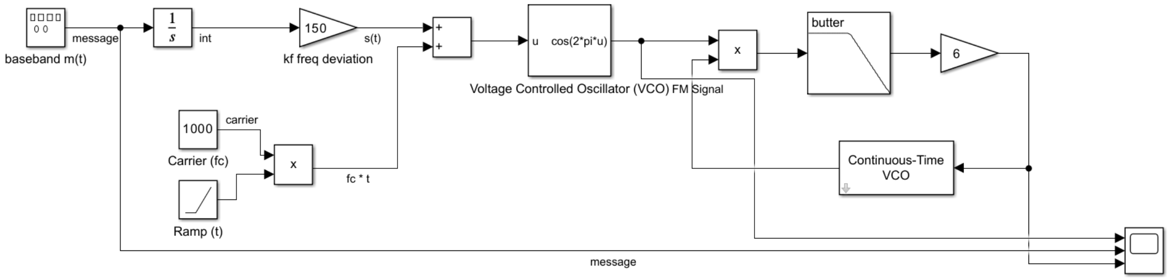

Figure 101: Lab Three Task Two Diagram

2. Modified the required values in the Continuous-time VCO and the Low pass filter:

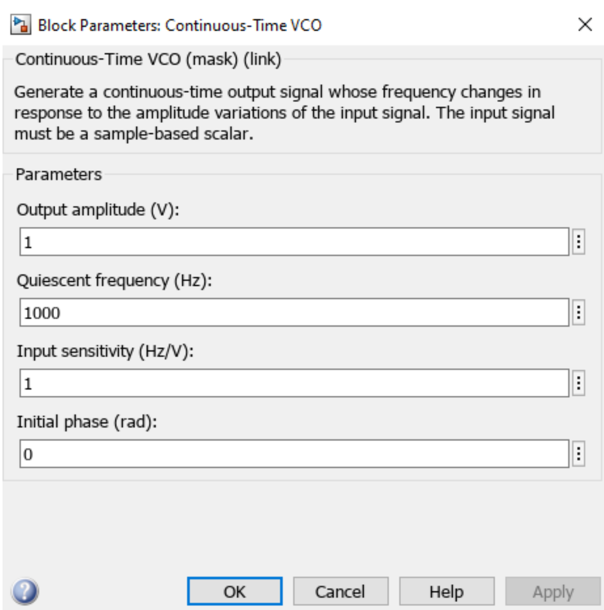

Figure 102: CT-VCO Parameters

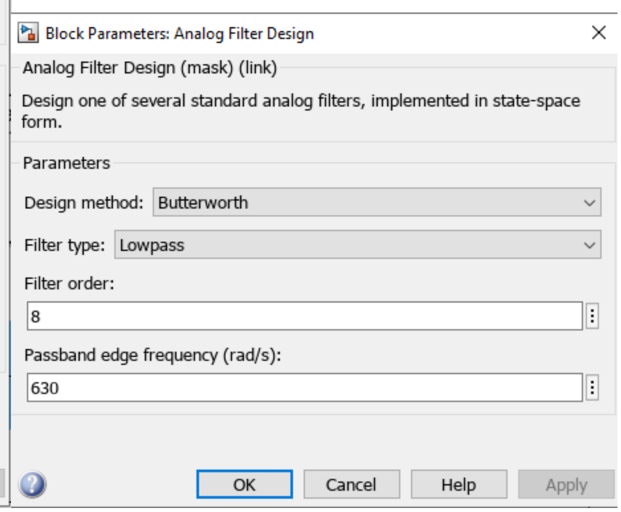

Figure 103: Low pass filter Parameters

3. Fixing the parameters of the LPF and changing the amplitude and the frequency of the message signal m(t):

The 0.5 V with 50 Hz:

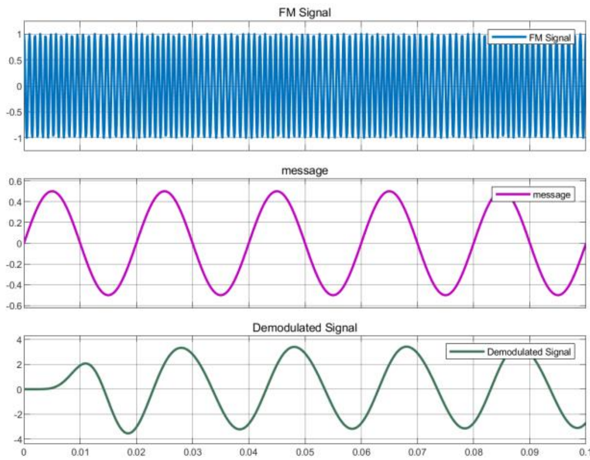

Figure 104: The 0.5V Baseband, 50Hz Plot

The 5 V with 50 Hz:

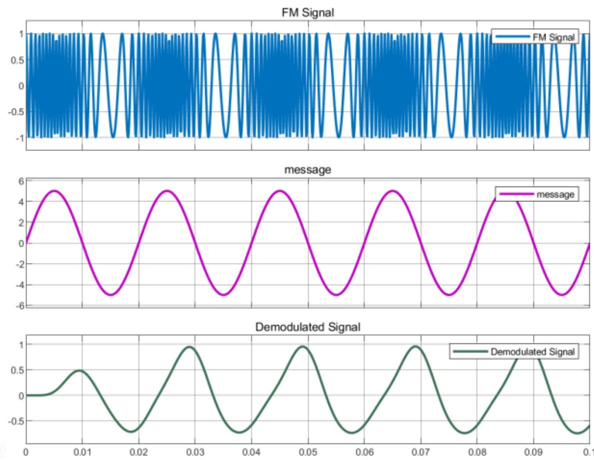

Figure 105: The 5V Baseband, 50Hz Plot

The 0.5 V with 80 Hz:

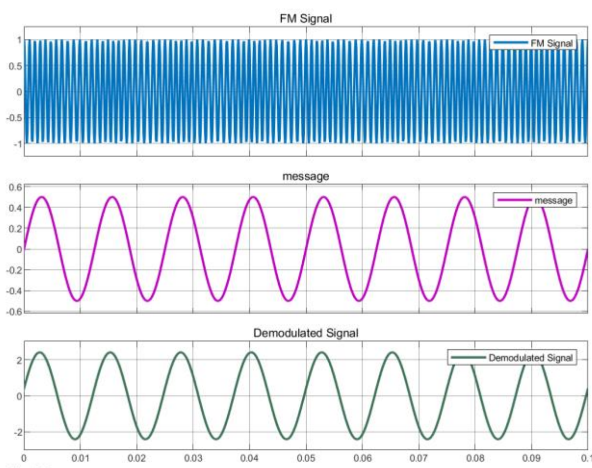

Figure 106: The 0.5V Baseband, 80Hz Plot

The 5 V with 80 Hz:

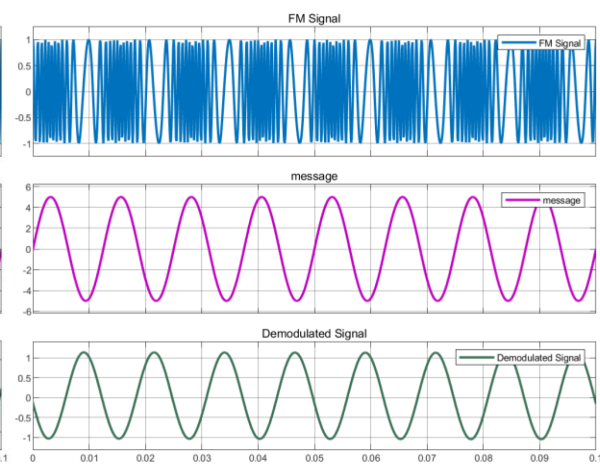

Figure 107: The 5V Baseband, 80Hz Plot

The 0.5 V with 120 Hz:

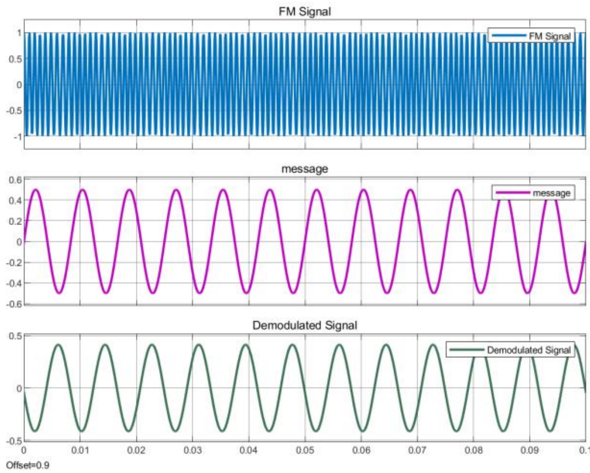

Figure 108: The 0.5V Baseband, 120Hz Plot

The 5 V with 120 Hz:

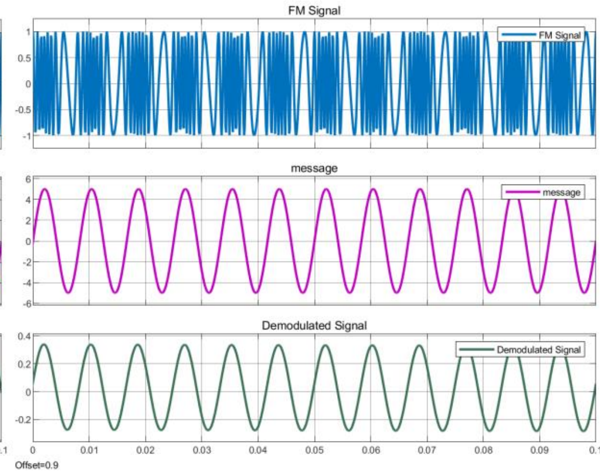

Figure 109: The 5V Baseband, 120Hz Plot

The 0.5 V with 150 Hz:

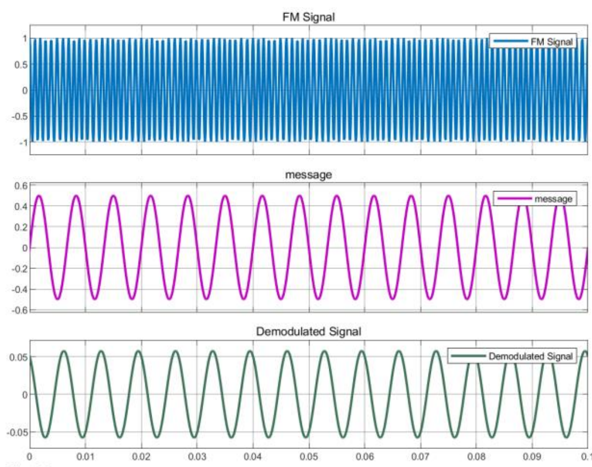

Figure 110: The 0.5V Baseband, 150Hz Plot

The 5 V with 150 Hz:

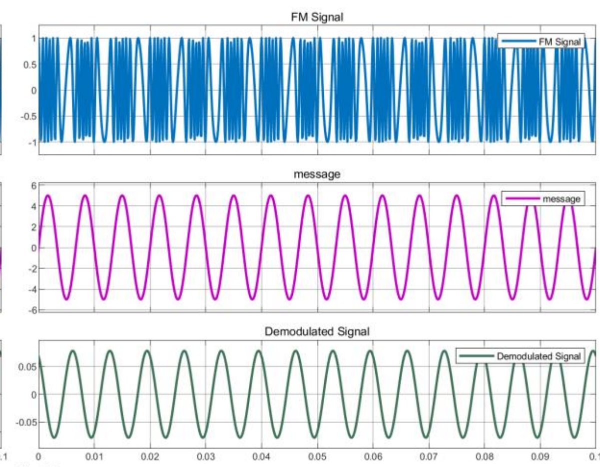

Figure 111: The 5V Baseband, 150Hz Plot

The original message signal of 100 Hz and 2V:

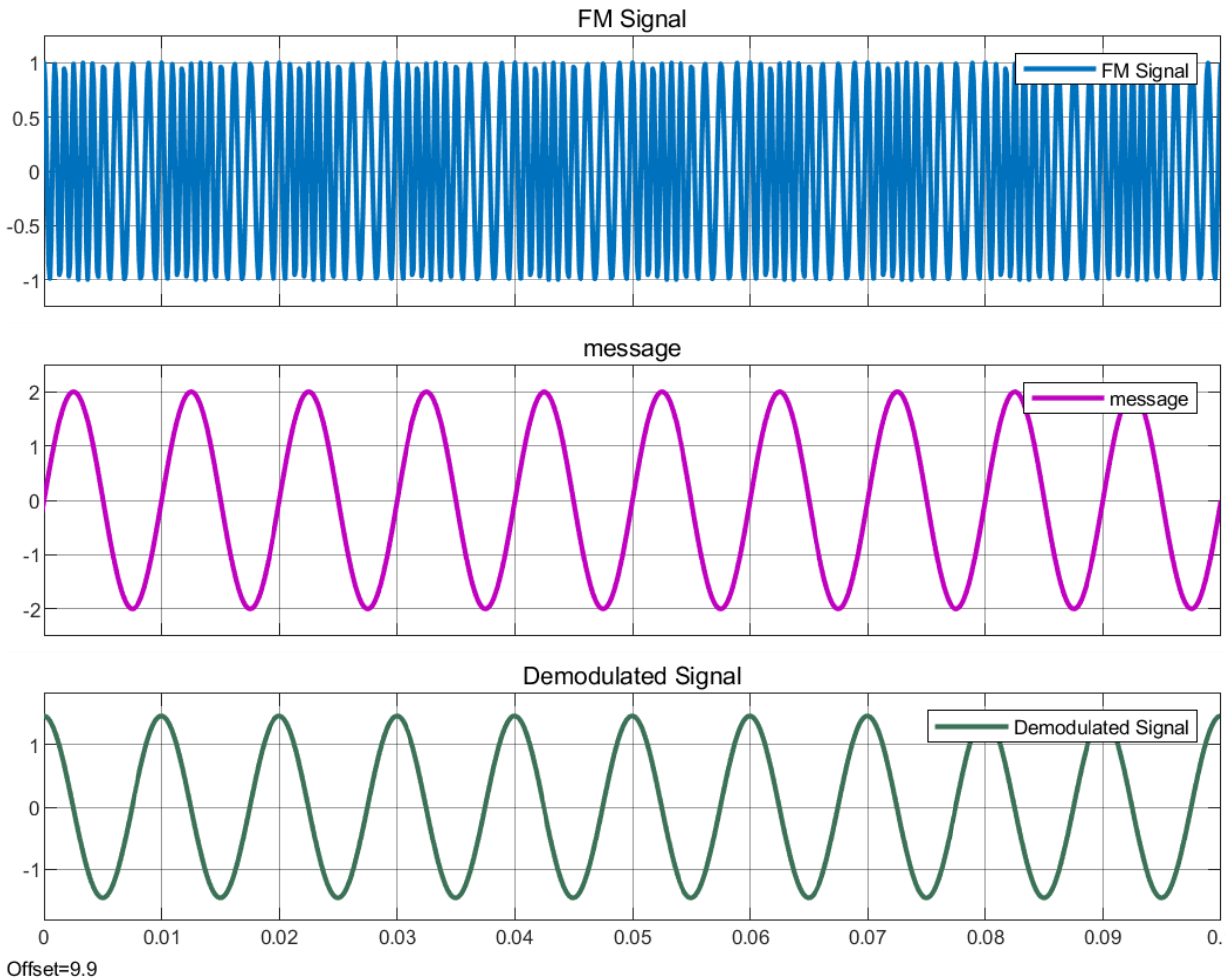

Figure 112: Lab 3 Task 2 graph

So here are the comments FM Demodulation:

Diagram Configuration:

Lab 3 Section Two utilizes the same diagram as Lab 3 Section One, with the addition of a low-pass filter and a continuous-time Voltage Controlled Oscillator (VCO) looping back.

The low-pass filter with a gain of 6 serves to filter out high-frequency noise and unwanted signal components, ensuring the demodulated signal contains primarily the original message signal.

The continuous-time VCO looping back is integrated into the demodulation process to generate an output that is proportional to the frequency deviation of the input FM signal. This feedback loop helps in recovering the modulating signal from the FM signal.

Low-Pass Filter:

The low-pass filter with a gain of 6 is essential for isolating the modulating signal from the FM signal. It attenuates high-frequency components while preserving the lower-frequency components corresponding to the modulating signal.

By applying a gain of 6, the filter amplifies the modulating signal, enhancing its detectability and improving the signal-to-noise ratio.

Continuous-Time VCO:

The continuous-time VCO looping back mechanism plays a crucial role in demodulating the FM signal. It generates an output voltage proportional to the frequency deviation of the input FM signal.

By incorporating feedback from the output of the VCO, the demodulator adjusts its frequency based on the instantaneous frequency deviation of the input FM signal, facilitating the recovery of the modulating signal.

Demodulation Process:

The FM demodulating technique in Lab 3 Section Two operates by extracting the modulating signal from the input FM signal using the low-pass filter and continuous-time VCO looping back mechanism.

The low-pass filter attenuates high-frequency components, leaving behind the modulating signal. The continuous-time VCO looping back generates an output proportional to the frequency deviation, effectively demodulating the FM signal and recovering the original modulating signal.

Signal Recovery and Analysis:

After demodulation, the recovered modulating signal can be analyzed and compared with the original message signal for fidelity and accuracy.

The effectiveness of the demodulating technique can be evaluated based on the fidelity of the recovered signal and its similarity to the original message signal.

In summary, Lab 3 Section Two employs a demodulating technique combining a low-pass filter with a gain of 6 and a continuous-time VCO looping back mechanism to extract the modulating signal from the input FM signal. This technique enables the recovery of the original message signal from the FM signal, facilitating signal analysis and evaluation.

Discussion and Conclusion

In conclusion, the series of experiments conducted in Labs 1, 2 (Task One Sections One, Two, and Task Two), and 3 (Sections One and Two) have provided valuable insights into various aspects of analog and digital communications. Through these experiments, we explored fundamental concepts, modulation techniques, demodulation processes, and the behavior of communication systems under different parameters.

Lab 1 introduced us to the design and analysis of digital filters, focusing on low-pass filter design to meet specific passband and stopband specifications. By varying the frequency of the message signal and analyzing the filter's response, we gained a deeper understanding of its frequency-selective characteristics and performance metrics such as gain.

In Lab 2, we delved into amplitude modulation (AM) and frequency modulation (FM) techniques through Task One Sections One and Two and Task Two. Section One demonstrated the effect of changing message signal frequencies and carrier signal frequencies on the modulation process, highlighting the importance of parameter optimization for efficient modulation. Section Two extended our exploration to FM modulation, emphasizing the impact of modulation index changes on signal characteristics such as modulation depth and spectral distribution. Task Two further reinforced our understanding by verifying demodulation techniques, showcasing the coherence between modulation and demodulation processes.

Lab 3 continued our exploration of FM modulation in Section One, focusing on the effects of changing signal amplitude and frequency deviation index on the resulting modulated signal. Through comprehensive analysis, we observed how these parameters influence signal bandwidth, spectral efficiency, and susceptibility to noise and interference. In Section Two, we further deepened our understanding by implementing FM demodulation techniques, employing low-pass filters and continuous-time VCO looping back mechanisms to recover the modulating signal from the FM signal.

Overall, these experiments have equipped us with essential knowledge and practical skills in analog and digital communication systems. We have learned to design, analyze, and optimize modulation and demodulation processes, laying the foundation for tackling more complex challenges in communication engineering. As we continue our journey in this field, the lessons learned from these labs will undoubtedly guide us in solving real-world problems and advancing the forefront of communication technology.

Thank you,
Omar Elmahy