Analog Communication Final Project

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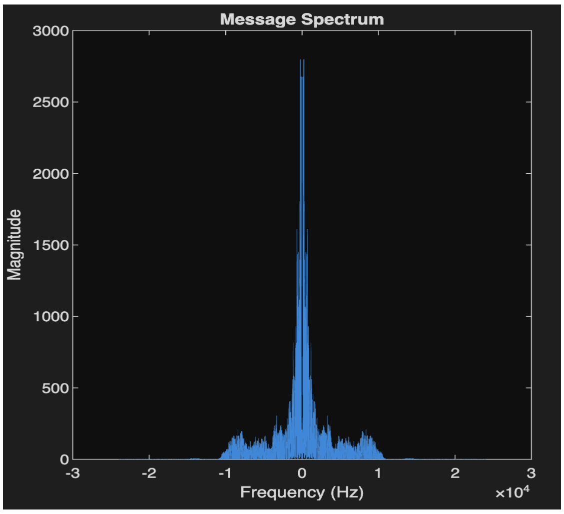
EXPERIMENT ONE

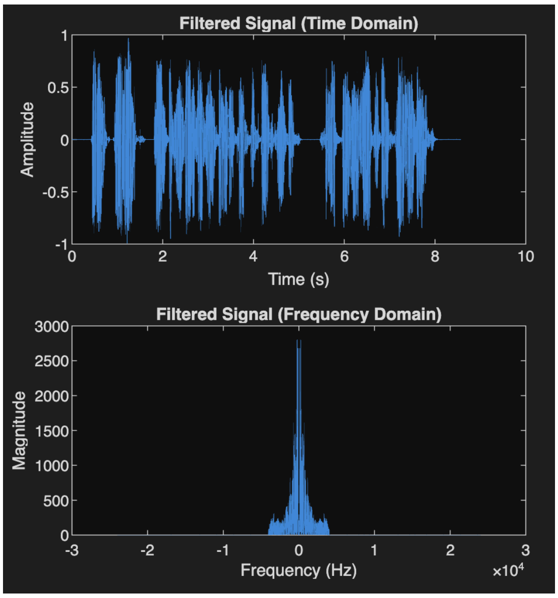
Objective:

Study the performance of Double Sideband Transmitted Carrier (DSB-TC) and Suppressed Carrier (DSB-SC) modulation schemes. DSB-TC is characterized by transmitting the carrier along with the modulated message, allowing for simple reception via an envelope detector. In contrast, DSB-SC is more power-efficient but requires coherent detection.

Pre processing:

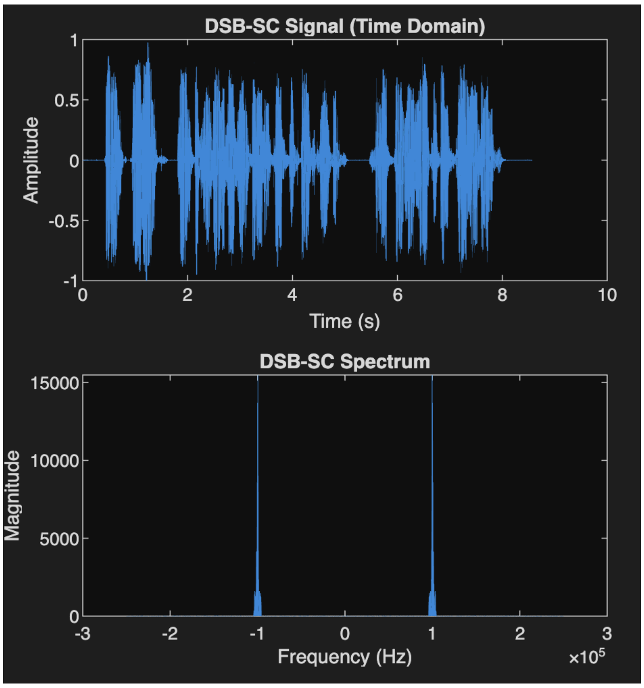
The input audio signal (sampled at 48 kHz) is filtered using an ideal low-pass filter to a bandwidth of **4 kHz**. To satisfy the Nyquist criterion for a 100 kHz carrier, the signal is resampled to Fs=5Fc (500 kHz)

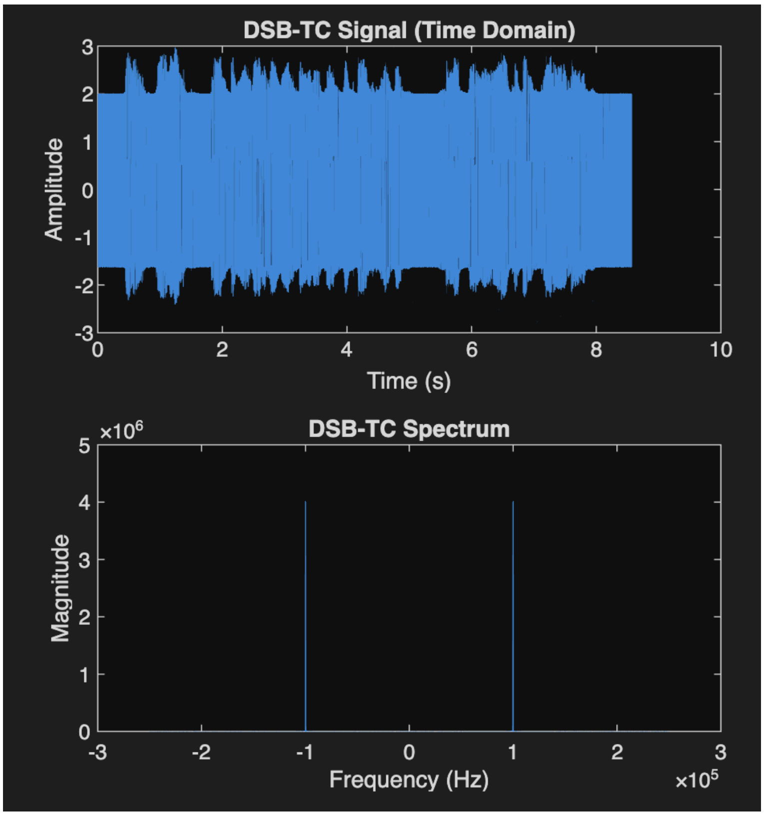




Modulation:

The resampled signal is modulated using a 100 kHz carrier for DSB-SC & DSB-TC. For **DSB-TC**, a DC bias equal to twice the maximum message amplitude is added, resulting in a modulation index u of **0.5**.



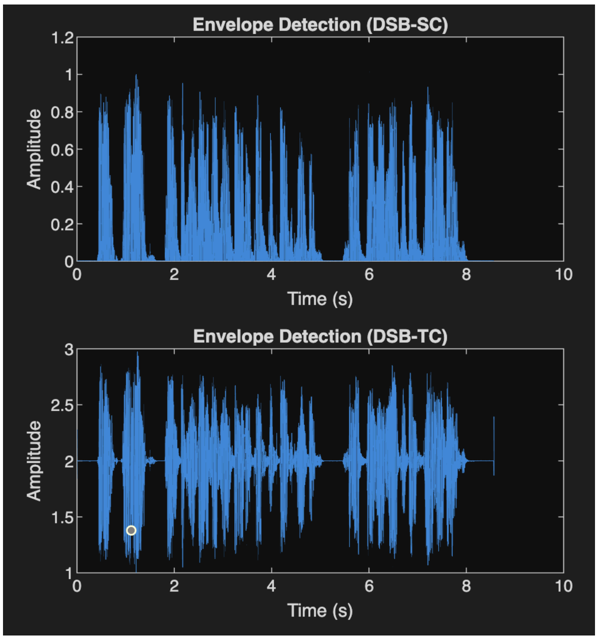


Demodulation:

Envelope Detection:

An envelope detector was used for both signals.

Observation: The envelope detector successfully recovers the message from **DSB-TC** because the envelope always remains positive. However, for **DSB-SC**, the envelope detector produces heavy distortion because the signal crosses zero, causing phase reversals that the detector cannot track.

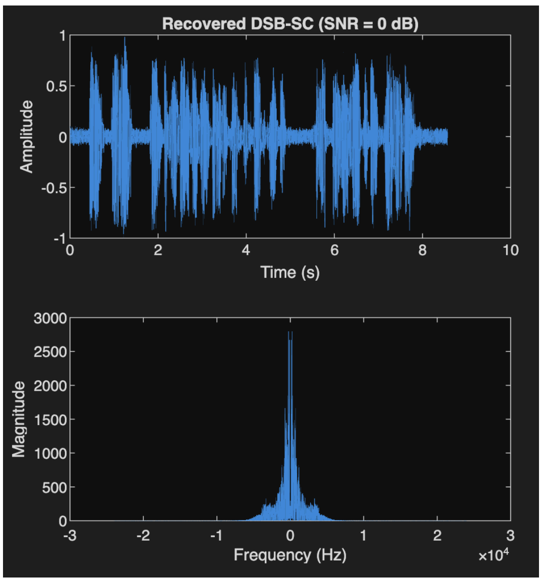


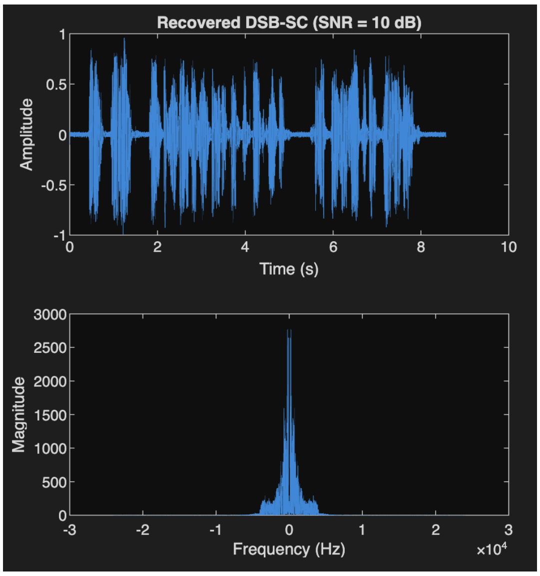
Coherent Detection and Mismatches

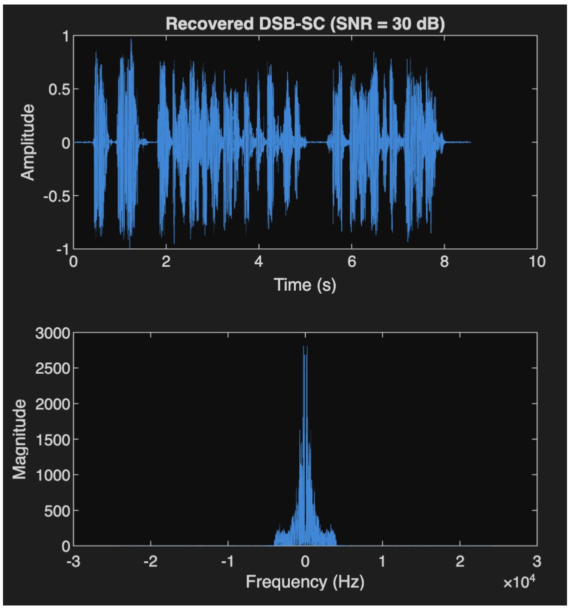
Coherent detection was tested under various Signal-to-Noise Ratios (SNR) and synchronization errors.

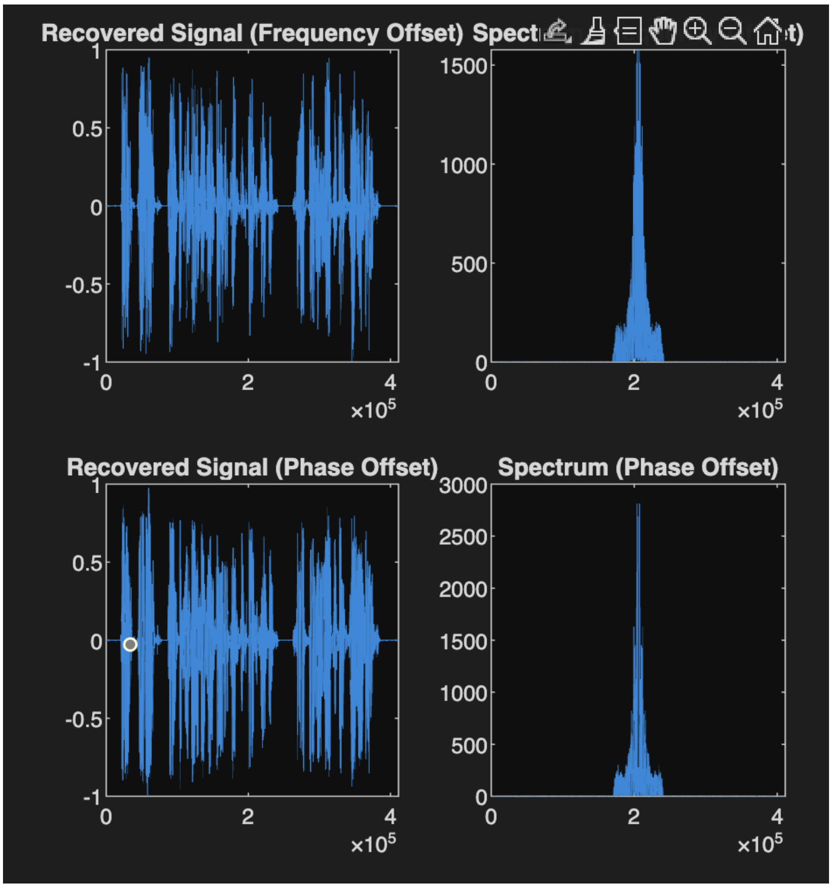
Frequency Mismatch: Using a local oscillator at 100.1 kHz instead of 100 kHz introduces a frequency error, often resulting in "beating" or shifting of the audio pitch.

Phase Mismatch: A 20 degree phase error reduces the amplitude of the recovered signal




Recovered DSB-SC (SNR = 10 dB)
Amplitude
Time (s)
Magnitude
Frequency (Hz)
×10^4


Recovered DSB-SC (SNR = 30 dB)
Amplitude
Time (s)
Magnitude
Frequency (Hz)
×10^4



Conclusion:

DSB-TC simplifies receiver design through envelope detection but is less power-efficient. Coherent detection is necessary for DSB-SC but is highly sensitive to frequency and phase synchronization between the transmitter and receiver

EXPERIMENT TWO

SINGLE SIDEBAND MODULATION

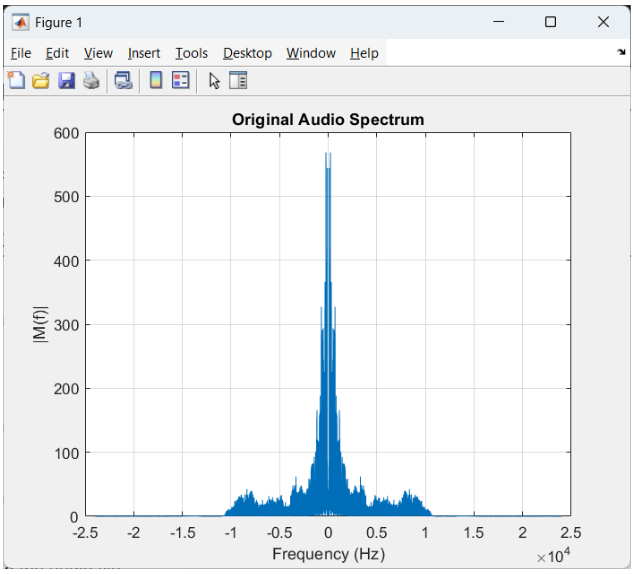
OBJECTIVE

The objective of this experiment is to study **Single Sideband (SSB) modulation**. The experiment demonstrates the generation of DSB-SC and SSB signals using MATLAB, investigates SSB demodulation using coherent and envelope detectors, and highlights the advantages and disadvantages of SSB in terms of bandwidth efficiency, noise performance, and receiver complexity.

PROCEDURE

Step 1: Read and Process Audio Signal

The frequency spectrum of the signal is obtained using the FFT to observe its bandwidth and frequency content.

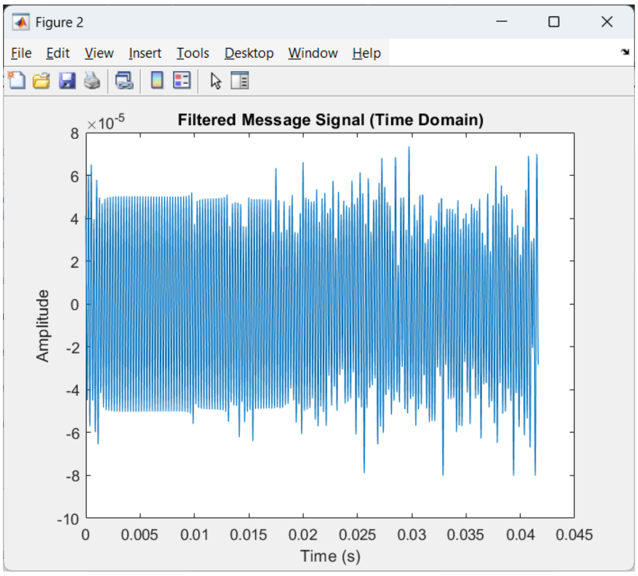


Step 2: Band-limit the Signal to 4 kHz

An ideal low-pass filter is applied in the frequency domain to remove all frequency components above 4 kHz.

Step 3: Convert Back to Time Domain

The filtered signal is converted back to the time domain using the inverse FFT. The filtered audio is played to confirm that only minimal distortion was introduced.



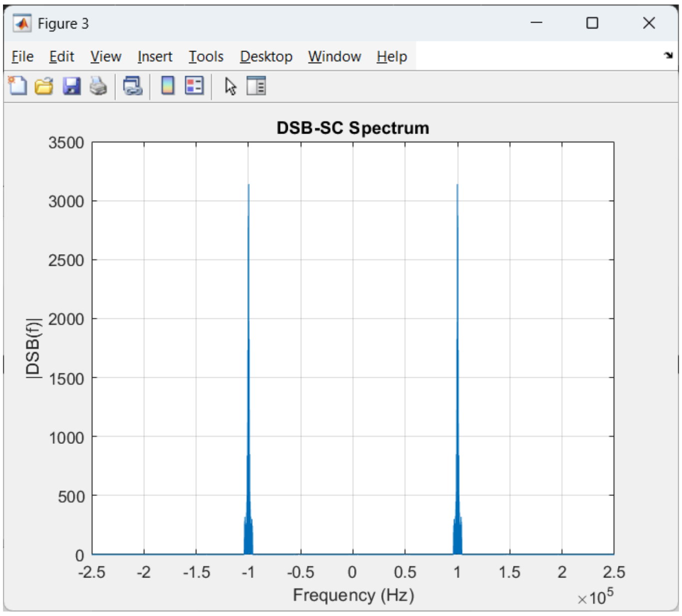
Step 4: Generate DSB-SC Signal

The band-limited message signal is modulated using DSB-SC modulation with:

- Carrier frequency: Fc = 100 kHz
- Sampling frequency: Fs = 5Fc = 500 kHz

The spectrum of the DSB-SC signal is plotted.

It shows two symmetric sidebands (upper and lower) around the carrier frequency, confirming the bandwidth inefficiency of DSB transmission.

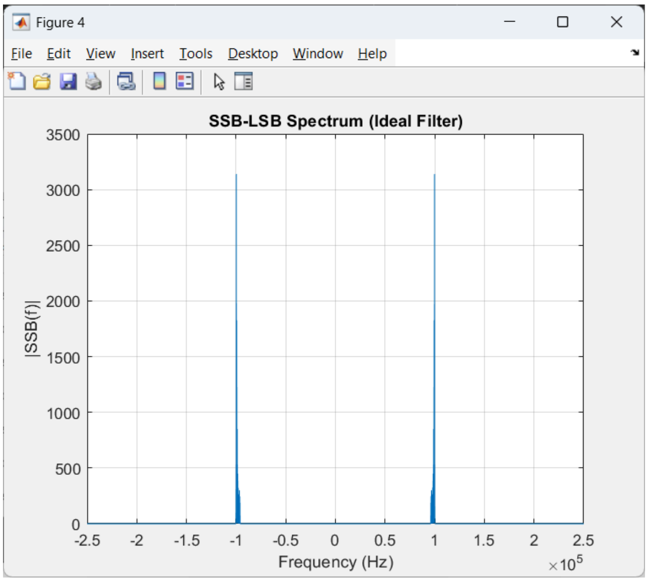


Step 5: Generate SSB Signal Using Ideal Filter

The Lower Sideband (LSB) is extracted from the DSB-SC signal by removing the Upper Sideband (USB) using an ideal band-pass filter in the frequency domain.

The resulting SSB spectrum shows:

- Only one sideband (LSB) present
- Bandwidth equal to the baseband bandwidth (≈ 4 kHz)
- Bandwidth reduced by 50% compared to DSB-SC



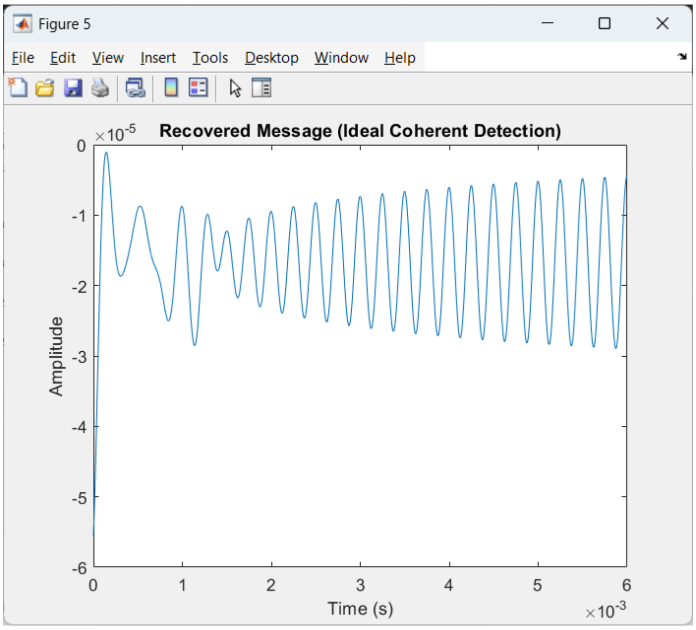
Step 6: Coherent Detection of SSB (Ideal Filter, No Noise)

The SSB-SC signal is demodulated using coherent detection by multiplying with a locally generated carrier synchronized in frequency and phase.

The recovered signal is:

- Filtered using an ideal low-pass filter
- Plotted in time and frequency domains
- Played back to verify correct demodulation

The original message is successfully recovered with minimal distortion.



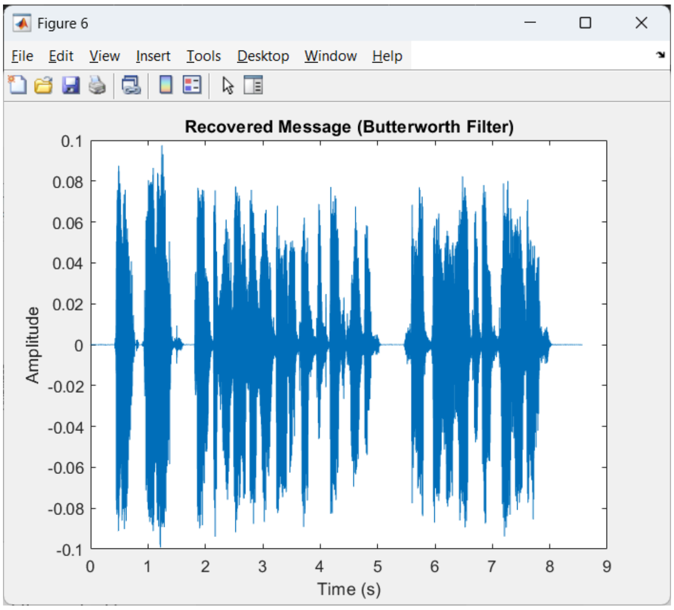
Step 7: Practical Filter Case (Butterworth Filter)

Steps 5 and 6 are repeated using a 4th-order Butterworth filter instead of an ideal filter.

Observations:

- Slight amplitude distortion appears in the recovered signal
- Some attenuation near band edges due to non-ideal filter response
- Audio quality is slightly degraded compared to the ideal case

This demonstrates the practical limitation of SSB systems due to filter imperfections.



Step 8: Effect of Noise on SSB (Ideal Filter Case)

Additive white Gaussian noise (AWGN) is added to the SSB-SC signal with:

- SNR = 0 dB
- SNR = 10 dB
- SNR = 30 dB

For each case:

- The demodulated waveform and spectrum are plotted
- The recovered audio is played

Observations:

- At 0 dB, noise significantly distorts the signal
- At 10 dB, speech is intelligible but noisy
- At 30 dB, the recovered signal closely resembles the original

SSB is sensitive to noise, especially at low SNRs, due to the absence of carrier.

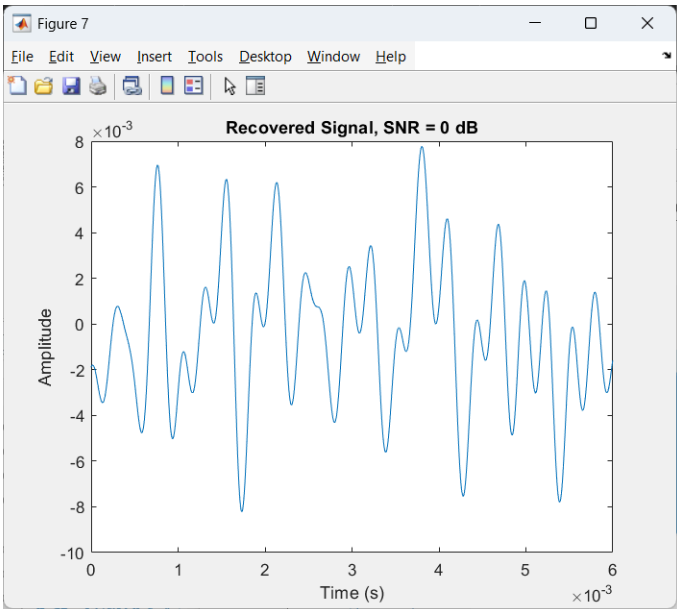


Figure 7
File Edit View Insert Tools Desktop Window Help
Recovered Signal, SNR = 0 dB
×10^-3
Amplitude
Time (s)
×10^-3

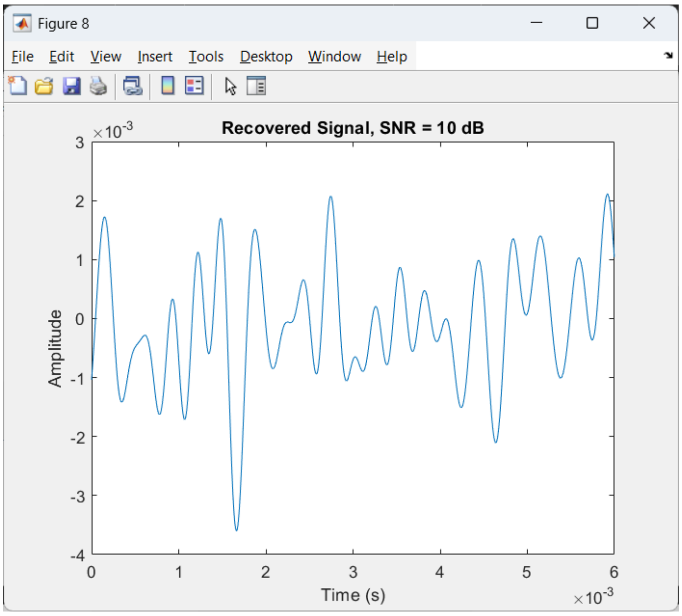


Figure 8
File Edit View Insert Tools Desktop Window Help
Recovered Signal, SNR = 10 dB
×10^-3
Amplitude
Time (s)
×10^-3

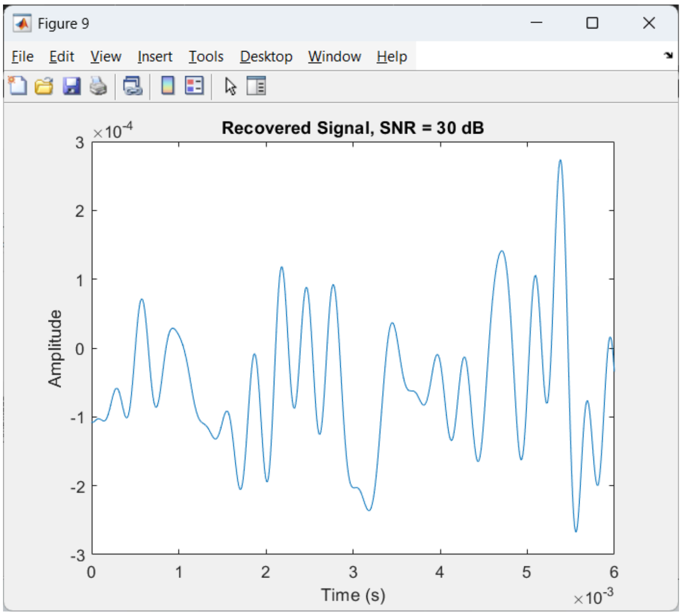


Figure 9
File Edit View Insert Tools Desktop Window Help
Recovered Signal, SNR = 30 dB
×10^-4
Amplitude
Time (s)
×10^-3

Step 9: SSB-PC and Envelope Detection

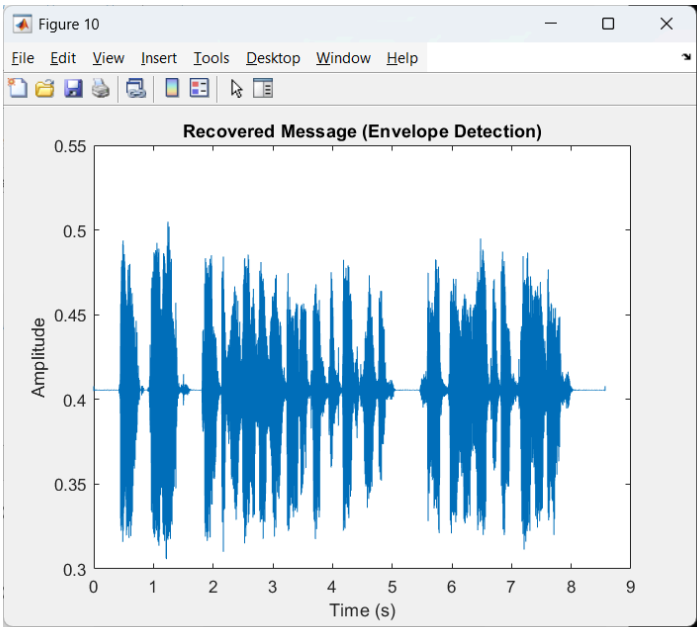
A Single Sideband with Transmitted Carrier (SSB-PC) signal is generated by adding a DC bias equal to twice the maximum message amplitude, ensuring a non-zero envelope.

The signal is demodulated using an envelope detector (without noise).

Results:

- The message is successfully recovered
- Audio playback confirms intelligibility
- Envelope detection works only when a sufficient carrier is transmitted

This highlights the trade-off between receiver simplicity and power efficiency.



CONCLUSION

Single Sideband modulation was successfully generated and demodulated using MATLAB. The experiment demonstrated the bandwidth advantage of SSB, the importance of coherent detection, and the impact of practical filtering and noise. While SSB offers superior spectral efficiency, it comes at the cost of increased receiver complexity and sensitivity to noise.

EXPERIMENT THREE

FREQUENCY MODULATION

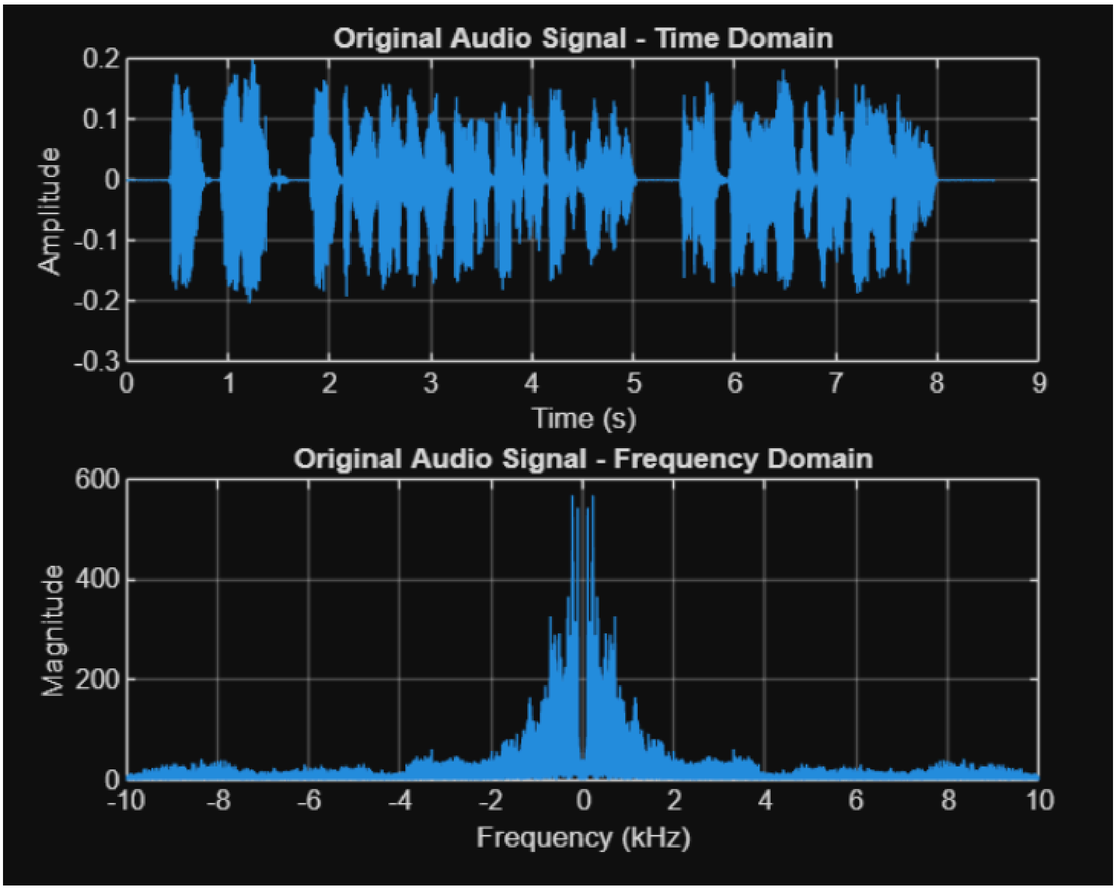
OBJECTIVE

The objective of this experiment is to study Narrowband Frequency Modulation (NBFM). The experiment demonstrates the generation and demodulation of an NBFM signal using MATLAB, and highlights the condition required for narrowband operation as well as the spectral characteristics of NBFM.

PROCEDURE

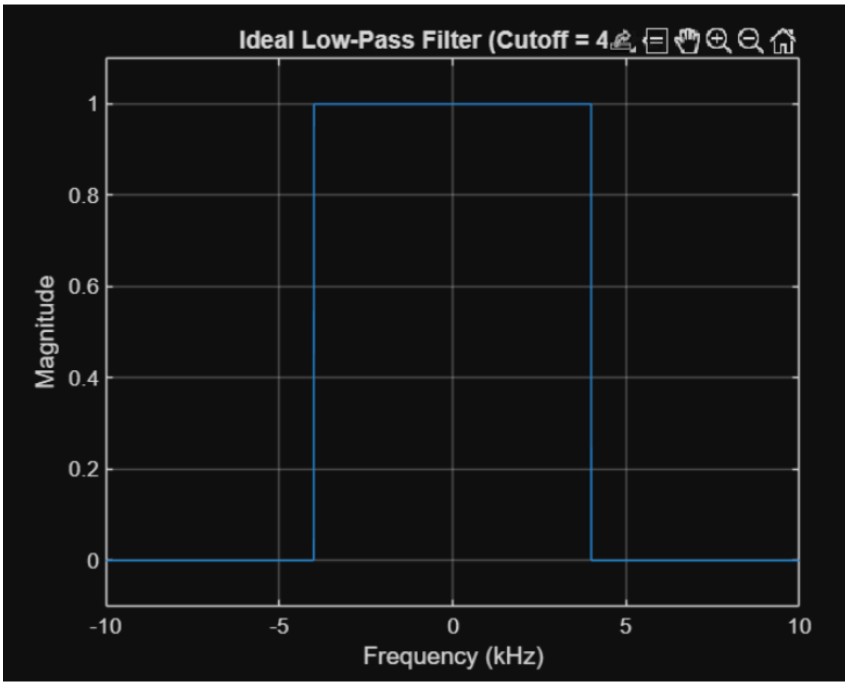
Step 1: Read and Process Audio Signal

Read the audio file

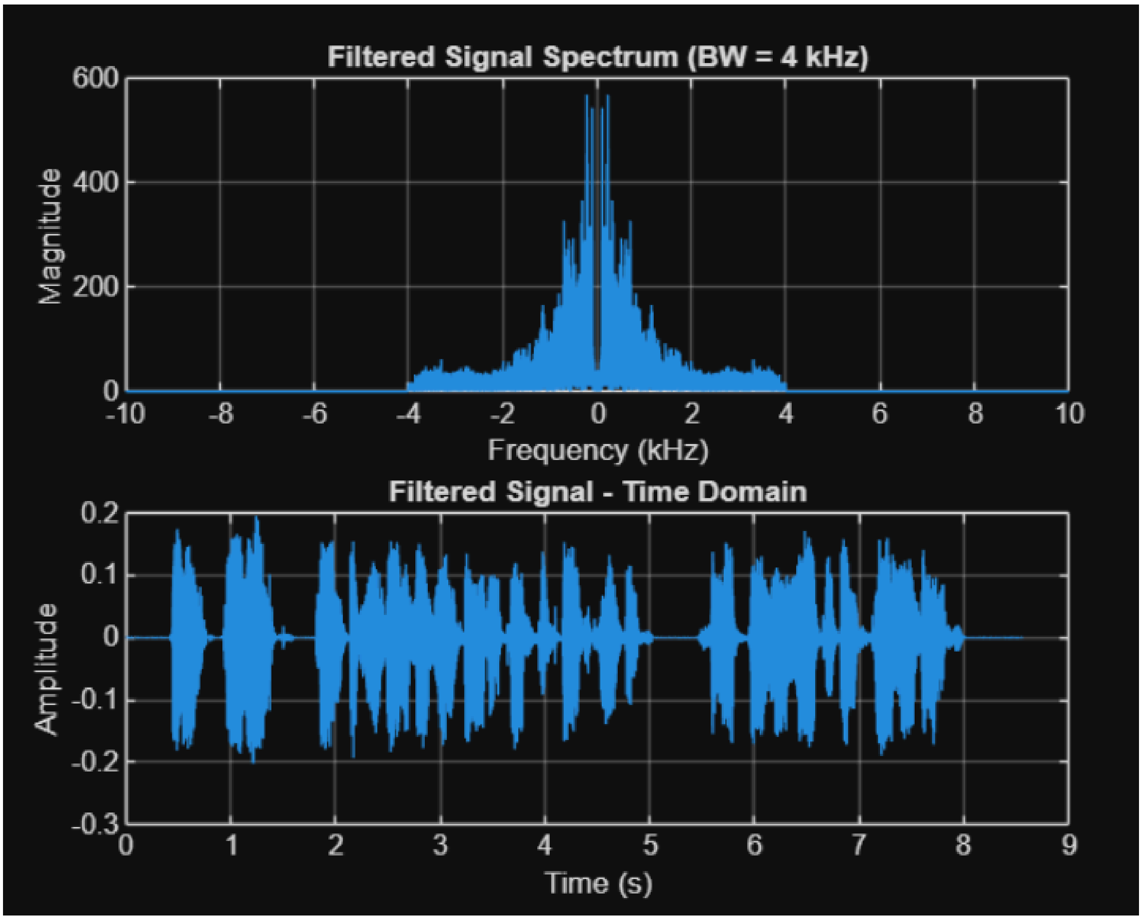


Step 2: Band-limit the signal to 4 kHz using ideal filter

Create ideal low-pass filter (frequency domain)



Step 3: Convert back to time domain



Step 4: Play the filtered audio

Playing filtered audio...

Step 5: Resample for modulation

Set carrier frequency and new sampling frequency

- Original Fs: 48000 Hz
- New Fs: 500000 Hz
- Carrier Fc: 100000 Hz

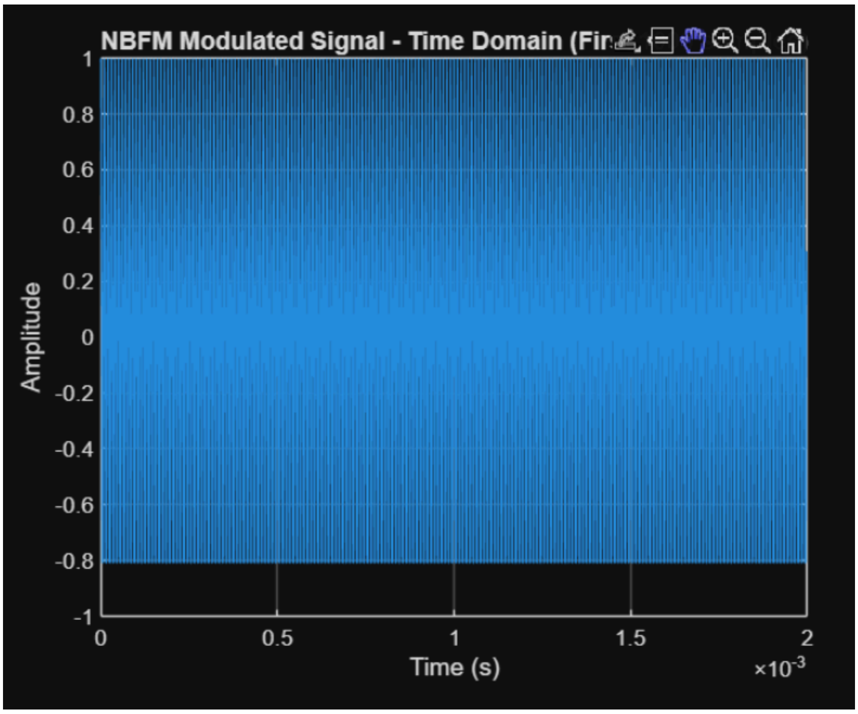
Step 6: Generate NBFM Signal

NBFM Theory: For NBFM, the modulation index β must be << 1 (typically β < 0.3)

<u>General fm signal:</u> s_FM(t) = Ac*cos(2πfc*t + 2π*kf*∫m(τ)dτ)

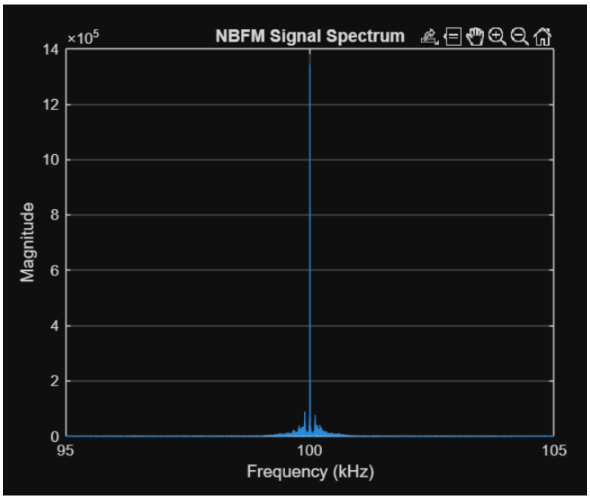
<u>For NBFM (β << 1):</u> s_NBFM(t) ≈ Ac*cos(2πfc*t) - Ac*β*m(t)*sin(2πfc*t)

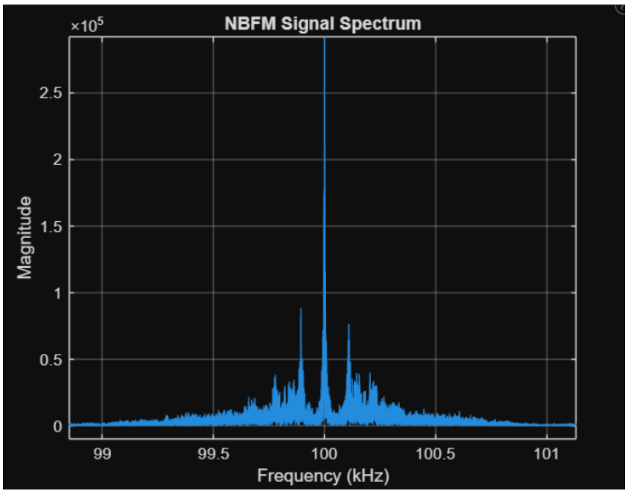
- Modulation Index β = 0.1875
- For NBFM, β should be < 0.3. Current β = 0.1875 (Satisfies condition)



Step 7: Plot NBFM Spectrum

Both are same spectrum but right spectrum is more zoomed in to show sidebands





□ Observation of NBFM Spectrum □

The NBFM spectrum shows:

1. A dominant carrier component at fc = 100 kHz
2. Sidebands around the carrier (similar to DSB-SC pattern)
3. Multiple frequency components due to FM modulation
4. For NBFM with small β, spectrum resembles AM/DSB
5. Approximate bandwidth ≈ 2*(Δf + fm) = 2*(0.8 + 4) = 9.5 kHz (Carson's Rule)
6. The "hill" shape shows the distribution of energy across frequencies

Step 8: Answer to Question 3 - Condition for NBFM

<u>The condition needed to achieve NBFM is:</u>

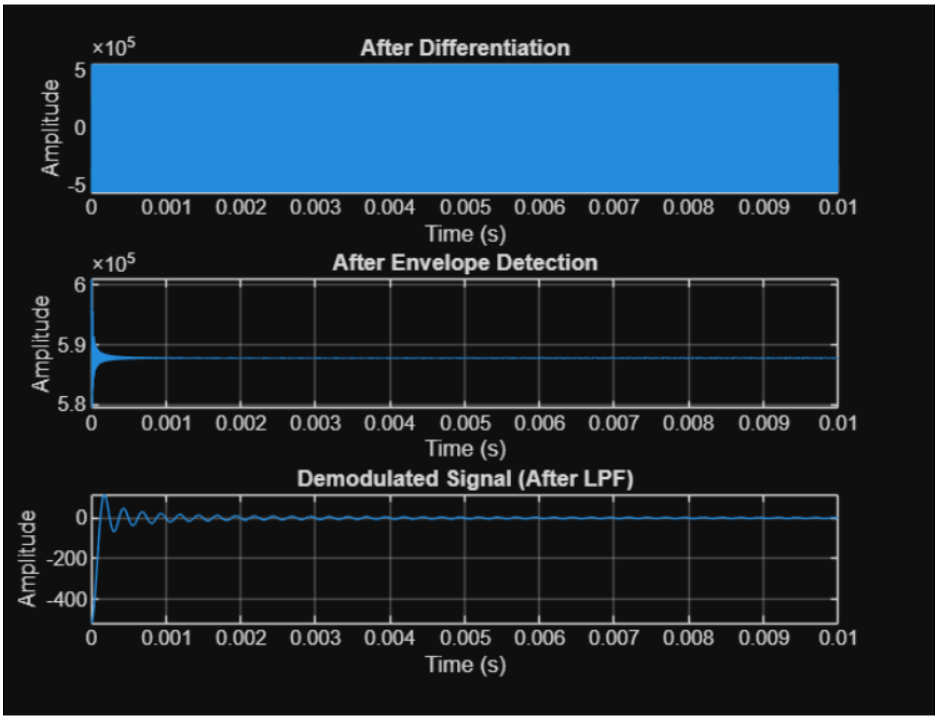
β = Δf/fm << 1 (typically β < 0.3)

Where:

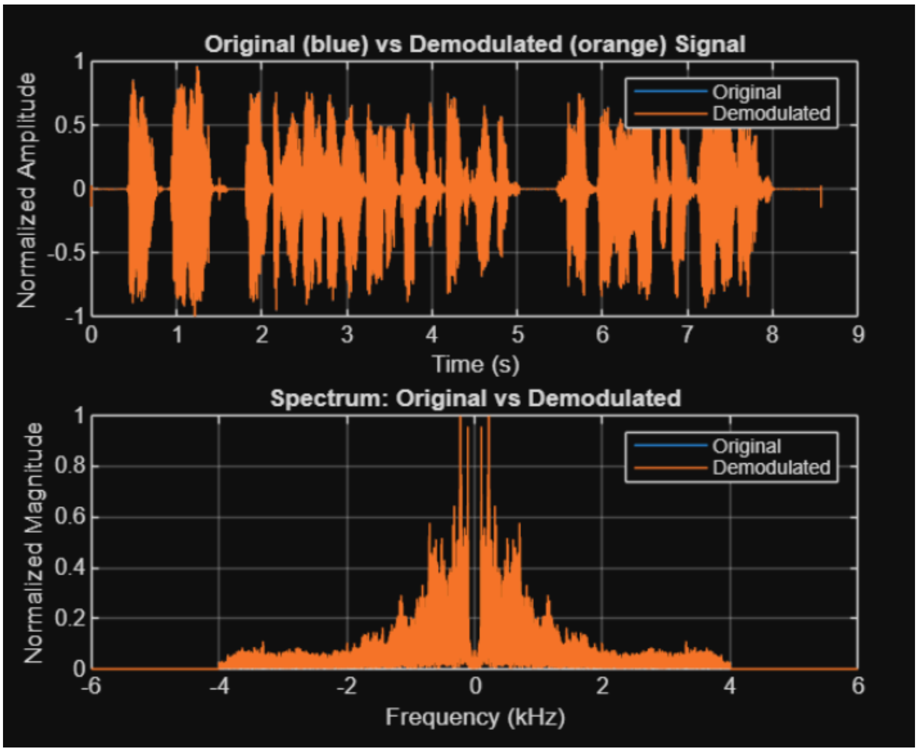
- Δf = frequency deviation = kf*max(|m(t)|)/(2π)
- fm = maximum message frequency

Current β = 0.1875 ✓ (NBFM satisfied)

Step 9: Demodulate NBFM using Differentiator + Envelope Detector



Step 10: Compare original and demodulated signals



Step 11: Play demodulated audio

Playing demodulated audio...

Summary and Conclusions of experiment 3:

1. NBFM modulation requires $\beta << 1$ ($\beta = 0.1875$)
2. NBFM spectrum resembles DSB-SC when β is small
3. Demodulation: Differentiator + Envelope Detector
4. NBFM provides better noise immunity than AM

Bandwidth efficiency: NBFM BW ≈ $2\Delta f$, similar to DSB

ANSWERS TO QUESTIONS

Question 2:
The NBFM spectrum shows a dominant carrier component at 100 kHz with sidebands around it. Due to the small modulation index, the spectrum resembles that of AM or DSB modulation.

Question 3:
The condition for achieving NBFM is that the modulation index β must be much less than 1 (typically $\beta < 0.3$). In this experiment, the chosen parameters satisfy this condition.

CONCLUSION

NBFM modulation and demodulation were successfully implemented. The obtained results confirm that when the modulation index is small, the FM spectrum remains narrow and similar to AM, while providing better noise immunity. The differentiator and envelope detector combination effectively recovered the original message.