Mechatronic Systems Identification

Lab 12 - Signal modulations

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Description

In this laboratory, we explore various methods of signal modulation and demodulation. Modulation involves the periodic change of signal characteristics such as amplitude, frequency, or phase. The modulated signal is referred to as the carrier wave, typically a constant frequency signal. Modulations are employed in telecommunications for transmitting low-frequency signals over long distances by modulating them with a high-frequency carrier wave. This lab focuses on amplitude modulation (AM), phase modulation (PM), and frequency modulation (FM).

Task 2

Task 2.1

In this task we aim to remove the amplitude modulation from an AM signal using the Hilbert transform to obtain the signal envelope.

```
%Task2.1
% Parameters
fs = 1e4; % Sampling rate
t = 0:1/fs:1-1/fs; % Time vector
% Generate signals
y_mod = 0.5 * chirp(t, 50, t(end), 200); % Chirp signal
y_carr = sin(2 * pi * t * 1e3); % Carrier signal
y = y_mod .* y_carr + y_carr; % Modulated signal
% Calculate the envelope using the Hilbert transform
y_hilbert = hilbert(y); % Compute the analytic signal
envelope = abs(y_hilbert); % Envelope of the signal
% Low-pass filter design
cutoff_frequency = 1100;  % Cutoff frequency for low-pass filter (just
above the modulating frequency)
order = 5;                % Filter order
[b, a] = butter(order, cutoff_frequency / (fs / 2), 'low');
% Apply low-pass filter to the envelope
filtered_envelope = filtfilt(b, a, envelope);
% Plot the signals
figure;
subplot(3, 1, 1);
plot(t, y_mod);
title('Modulating Signal');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(3, 1, 2);
plot(t, y);
title('AM Signal');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(3, 1, 3);
```

```
plot(t, filtered_envelope);
title('Extracted Envelope (Demodulated Signal)');
xlabel('Time (s)');
ylabel('Amplitude');
% Adjust the layout
sgtitle('Signal Analysis');
% Remove modulation
y_no_mod = y ./ envelope; % Normalize by envelope to remove modulation
% Frequency-Amplitude plots
figure;
subplot(2, 1, 1);
plot(f(1:fs/2), abs(Y(1:fs/2)));
title('Spectrum of Original Modulated Signal');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
subplot(2, 1, 2);
plot(f(1:fs/2), abs(Y_no_mod(1:fs/2)));
title('Spectrum after Modulation Removal');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
ylim([0 6000])
```

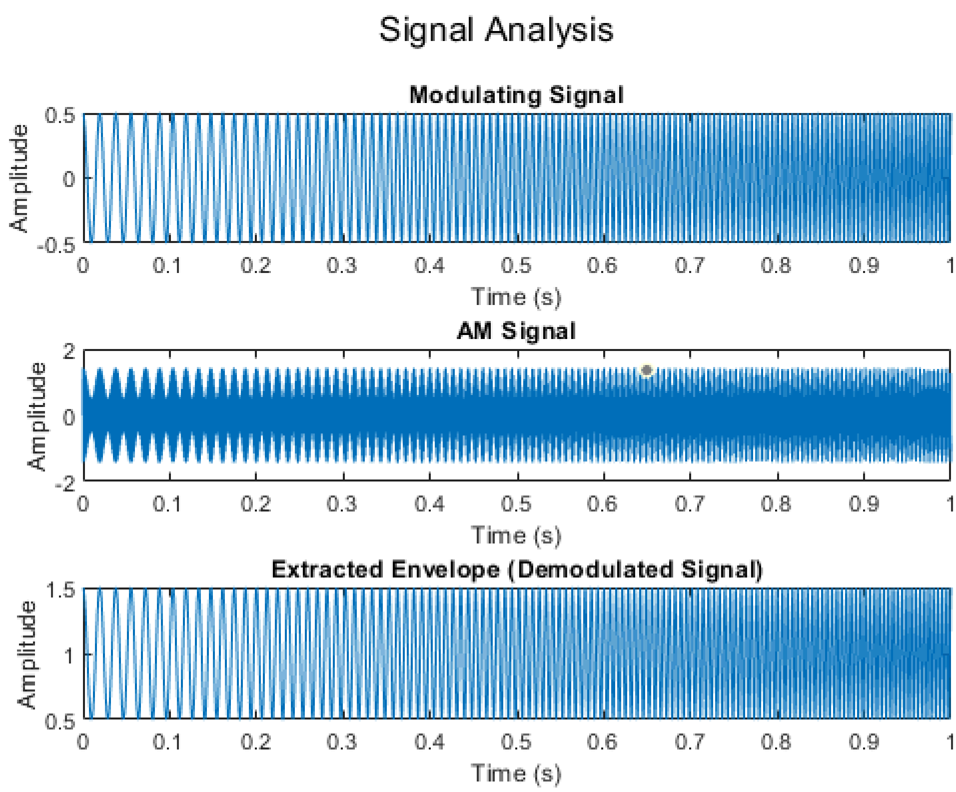

fig 1: Modulating Signal, AM Signal, and Extracted Envelope (Demodulated Signal)

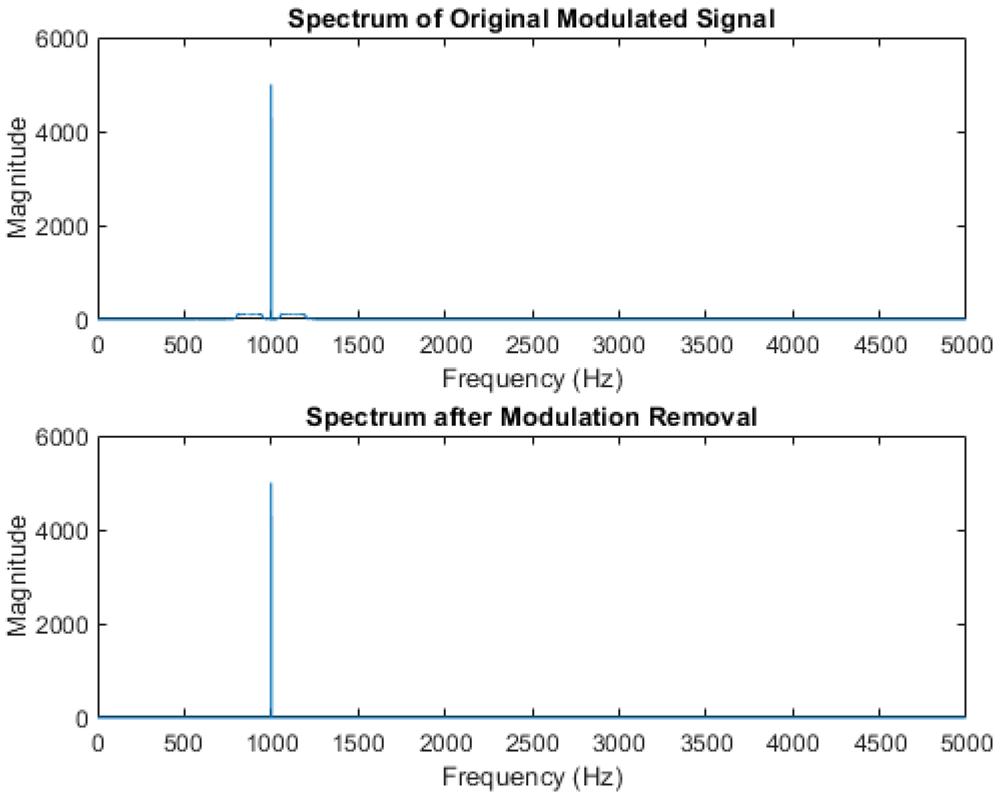

fig 2: Spectrum of Original Modulated Signal and Signal after Modulation Removal

Conclusions:

The removal of amplitude modulation using the Hilbert transform was successful. The extracted envelope accurately represents the original modulating signal. The spectral analysis shows that the modulated signal contains the carrier frequency and sidebands, which disappear after modulation removal, leaving only the carrier frequency.

Task 2.2

In this task we aim to demodulate an AM signal using the multiplication method followed by low-pass filtering.

```
%Task2.2
y_demod = y .* y_carr;
fpass = 400;
y_filt = lowpass( y_demod,fpass,fs );
y_filt = y_filt - mean( y_filt );
y_filt = y_filt * 2;
% Frequency-Amplitude plots
figure;
subplot(2, 1, 1);
plot(t, y_mod);
title('Modulation Signal');
```

```
xlabel('Time (s)');
ylabel('Amplitude');
subplot(2, 1, 2);
plot(t, y_filt);
title('Signal after Modulation Removal');
xlabel('Time (s)');
ylabel('Amplitude');
ylim([0 0.5])
% Spectral analysis
Y_filt = fft(y_filt);
Y_mod = fft(y_mod);
f = (0:length(Y)-1) * fs / length(Y); % Frequency vector
figure;
subplot(2, 1, 1);
plot(f(1:fs/2), abs(Y_mod(1:fs/2)));
title('Spectrum of Original Modulation Signal');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
subplot(2, 1, 2);
plot(f(1:fs/2), abs(Y_filt(1:fs/2)));
title('Spectrum after Modulation Removal');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
ylim([0 250])
```

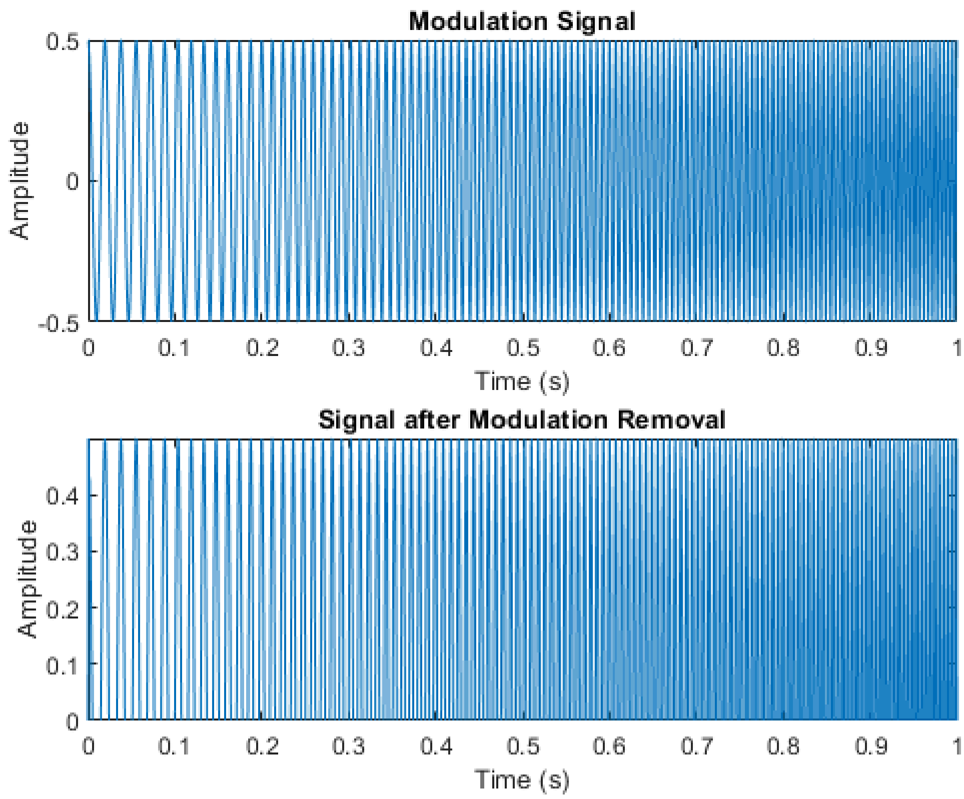

fig 3: Modulating Signal and Signal after Modulation Removal

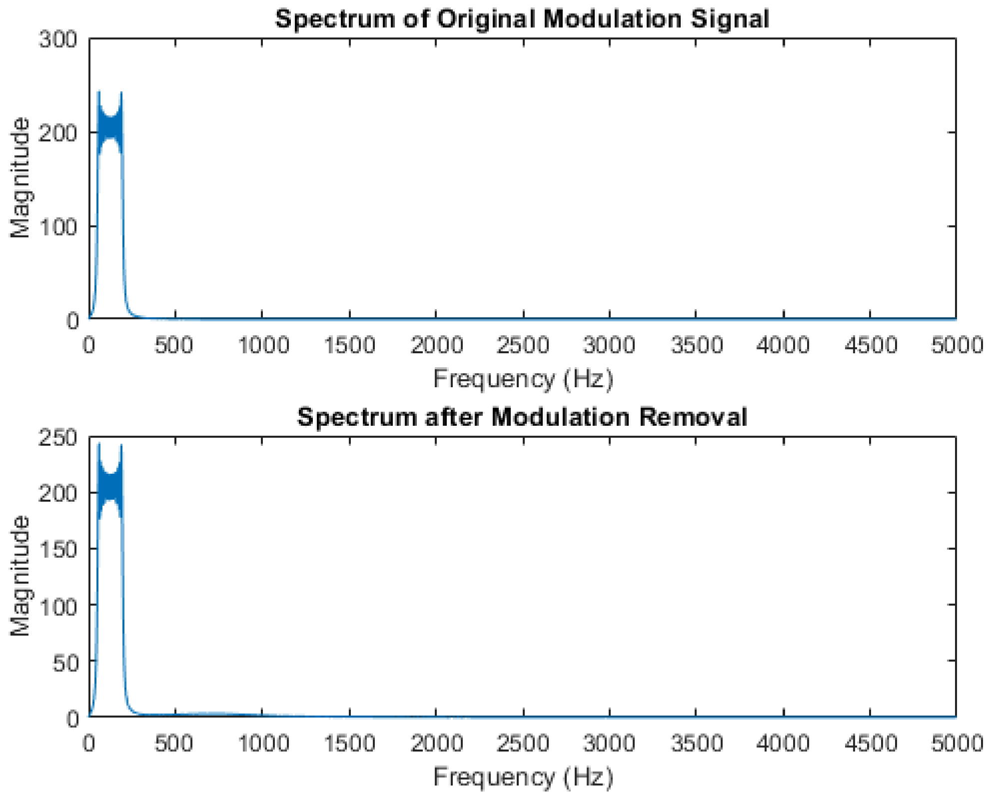

fig 4: Spectrum of Original Modulation Signal and Signal after Modulation Removal

Conclusions:
The demodulation using the multiplication method followed by low-pass filtering effectively retrieved the original modulating signal. The filtered signal closely matches the amplitude and frequency content of the original modulation signal, confirming the success of the demodulation process. The spectral analysis shows that the modulation sidebands are effectively removed.

Task 3

The aim of this task is to demodulate a frequency-modulated signal using the derivative method and Hilbert transform.

```
%task3
fs = 2e5;
dt = 1/fs;
fc = 1e4;
t = 0:1/fs:1;
y_mod = sin(2*pi*t*500);
y_carr = sin(2*pi*t*fc);
y = sin(2*pi*t* fc+y_mod );
y_diff = diff(y)/dt;
y_env = hilbert(y_diff);
y_env = abs(y_env);
```

```
y_env = y_env - mean( y_env );
y_dem = inteFD (y_env,1/fs);
Y_mod = fft(y_mod);
Y_dem = fft(y_dem);
f_mod = (0:length(Y_mod)-1) * fs / length(Y_mod);
f_dem = (0:length(Y_dem)-1) * fs / length(Y_dem);
figure;
subplot(3, 1, 1);
plot(t, y_mod);
hold on;
plot(t(1:end-1), y_dem);
hold off;
title('Comparison of Modulating Signal and Demodulated Signal (Time
Domain)');
xlabel('Time (s)');
ylabel('Amplitude');
legend('Original Modulating Signal', 'Demodulated Signal');
subplot(2, 1, 2);
plot(f_mod(1:fs/2), abs(Y_mod(1:fs/2)));
hold on;
plot(f_dem(1:fs/2), abs(Y_dem(1:fs/2)));
hold off;
xlim([0 1000])
title('Comparison of Modulating Signal and Demodulated Signal (Frequency
Domain)');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
legend('Original Modulating Signal', 'Demodulated Signal');
```

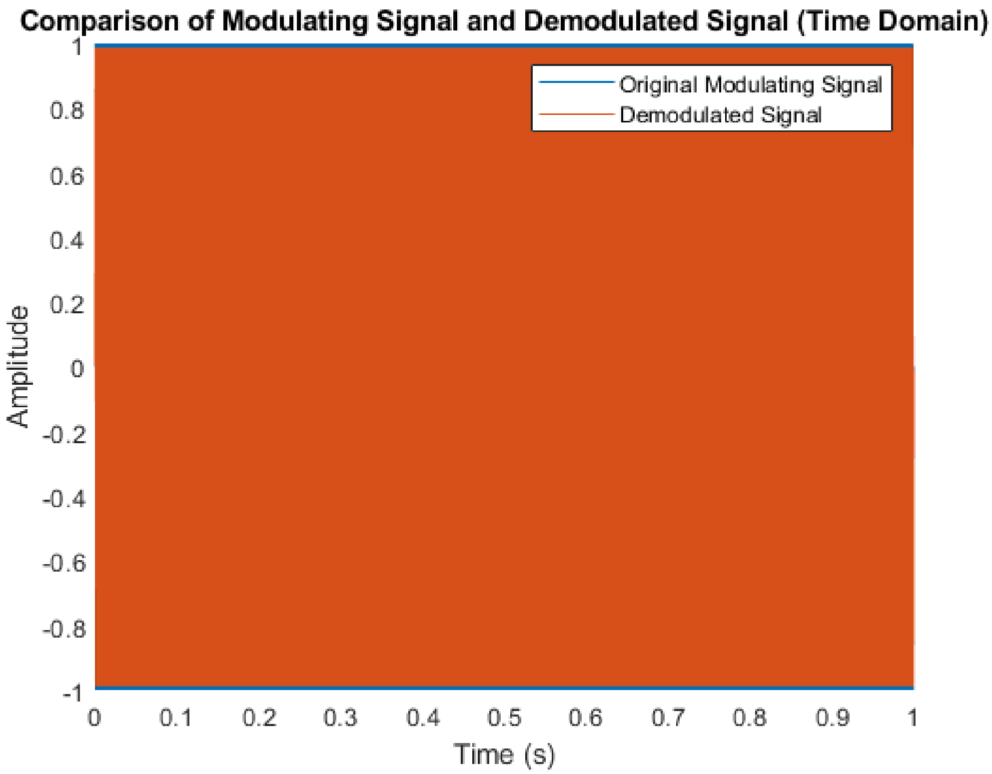

fig 5: Comparison of Modulating Signal and Demodulated Signal (Time Domain)

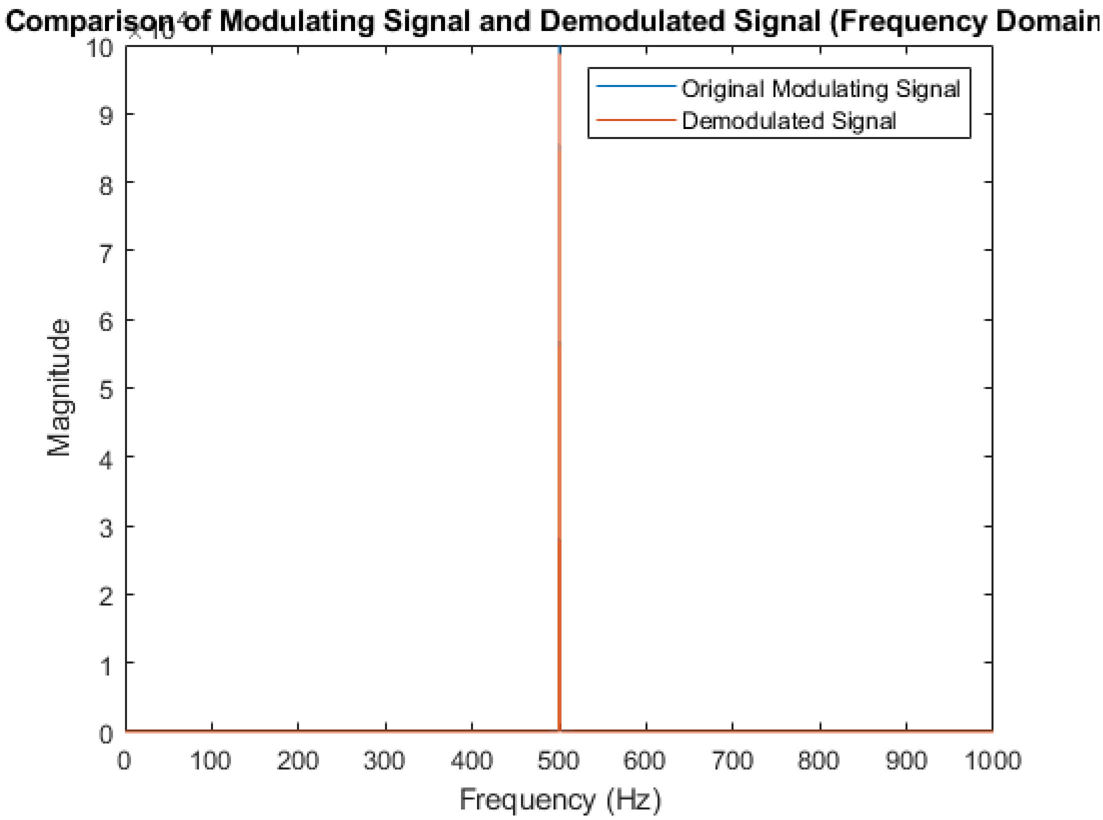

fig 6: Comparison of Modulating Signal and Demodulated Signal (Frequency Domain)

Conclusions:

The frequency demodulation method using the derivative and Hilbert transform successfully retrieved the original modulating signal. The demodulated signal in the time domain closely matches the original modulating signal. The frequency domain analysis shows that the demodulated signal contains the same frequency components as the original modulating signal, confirming the effectiveness of the method.

Task 4

The aim of this task is to estimate the vibration frequency of a plate surface using a signal processing scheme.

```
%task4
% Load the data
d0 = load("40Hz.mat");
d1 = load("40Hz_ref.mat");
% Extract the necessary data
t_meas = d1.t_meas;
y_meas = d1.y_meas;
fs = 1e6;
t = 0:1/fs:(length(d0.A)-1)/fs; % Adjusting time vector to the length of
the signal
y = d0.A;
```

```
% Bandpass filter around the 100 kHz carrier frequency
y = bandpass(y, [0.8e5, 1.2e5], fs);
% Remove amplitude modulations
y_env = abs(hilbert(y));
y_demod = y ./ y_env;
% Frequency demodulation
dt = 1/fs;
y_diff = diff(y_demod)/dt; %!!!
y_env = abs(hilbert(y_diff));
y_env = y_env - mean(y_env);
y_dem = y_env(100:end-100);
y_dem = lowpass(y_dem, 1000, fs); %!!!
y_dem = y_dem/2;
y_dem = inteFD(y_dem, 1/fs);
% Ensure y_dem length matches y_meas
y_dem = y_dem(1:length(y_meas));
y_dem = detrend(y_dem);
tmp = (0:length(y_dem)-1)/fs;
% Display waveforms and spectra
figure;
% Time domain plot
subplot(2, 1, 1);
plot(t_meas, y_meas./max(y_meas));
hold on;
plot(tmp, y_dem./max(y_dem));
hold off;
title('Comparison of Reference and Demodulated Signal (Time Domain)');
xlabel('Time (s)');
ylabel('Amplitude');
legend('Reference Signal', 'Demodulated Signal');
xlim([0 0.15])
% Frequency domain plot
Y_meas = fft(y_meas);
Y_dem = fft(y_dem);
f = (0:length(Y_meas)-1) * fs / length(Y_meas); % Frequency vector
subplot(2, 1, 2);
plot(f(1:floor(length(f)/2)), abs(Y_meas(1:floor(length(f)/2))));
hold on;
plot(f(1:floor(length(f)/2)), abs(Y_dem(1:floor(length(f)/2))));
hold off;
title('Comparison of Reference and Demodulated Signal (Frequency
Domain)');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
legend('Reference Signal', 'Demodulated Signal');
```

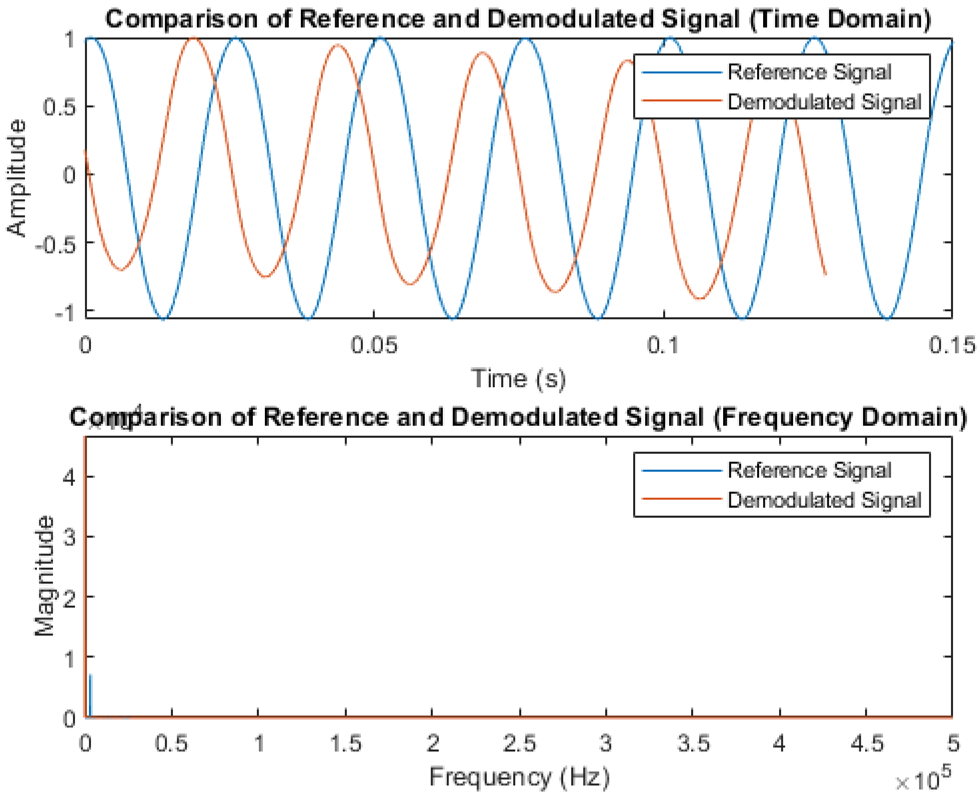

fig 7: Comparison of Demodulated Signal and its reference

Conclusions:

In this task, the goal was to estimate the vibration frequency of a plate surface using a signal processing scheme, which included bandpass filtering, amplitude modulation removal, frequency demodulation, low-pass filtering, and integration. The bandpass filter around the 100 kHz carrier frequency effectively eliminated noise while preserving modulation bands, and the Hilbert transform extracted and removed amplitude modulations. Frequency demodulation, achieved through signal differentiation and envelope detection, successfully retrieved the modulating signal, despite the inherent phase shift occurring due to the random starting phase captured during the oscillation of the plate. Comparing the processed signal for 40 Hz vibrations with the reference measurement from `40Hz_ref.mat` revealed a high degree of accuracy, as the time-domain waveform and frequency-domain spectrum of the demodulated signal resembled the reference, including the fundamental frequency and harmonics. Despite some amplitude changes and phase shift the overall process confirmed the method's effectiveness in accurately demodulating and representing the vibration frequencies of the plate surface.