FUNDAMENTALS OF COMMUNICATION

PRACTICAL 1

AMPLITUDE MODULATION USING MATLAB

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Abstract:

Modern communications, such as radio broadcasting, use signal transmission methods such as AM and FM. FM modulation has a sound fidelity advantage over AM. A known causal message signal is FM modulated and demodulated to test the quality of the demodulation. Noise is added to the modulated signal, on which demodulation is attempted again. The bandwidth of the instantaneous frequency in a non-ideal case is not the same as that of the message signal Adding a noise signal of 0.05 variance to the given message signal makes it not possible to easily extract the message signal.

I Introduction

Modern communications are done through these transmission methods. Of the major transmission methods, amplitude and angle modulation, angle modulation has a wide-bandwidth advantage over AM. This makes it a better method of transmission in areas such as the radio broadcasting area. Its high frequency range and bandwidth allow it to have better sound quality compared to AM [1]. This is but one of its advantages over AM modulation.

This document details the steps and procedures taken in the demonstration of an angle modulation scheme, frequency modulation (FM).

A message signal of interest is taken and used to demonstrate how the modulation works. The signal amplitude-time and amplitude-frequency plots are plotted. The signal is then frequency modulated. The time and frequency plots of the modulated signal are obtained. During the inspection of the modulated signal, its instantaneous is obtained. After that, the modulated signal u(t) is demodulated and its time and frequency representations plotted. A noise component is then added to the received signal on the receiver side, and the overall received signal is plotted and compared to the original message.

II The Experimentation

1 Message Signal

The arbitrary message of interest *m(t)* is a causal signal defined by (1).

$$m(t)=\begin{cases} 2\,sinc(100\,t)+10\,t, & 0\le t\le 0.05 \\ 2\,sinc(100\,t)+(1-10\,t), & 0.05\le t\le 0.1 \\ 0, & otherwise \end{cases} \tag{1}$$

Figure 1 shows the time domain representation of the message signal in the domain [0, 0.1], where the signal is non-zero.

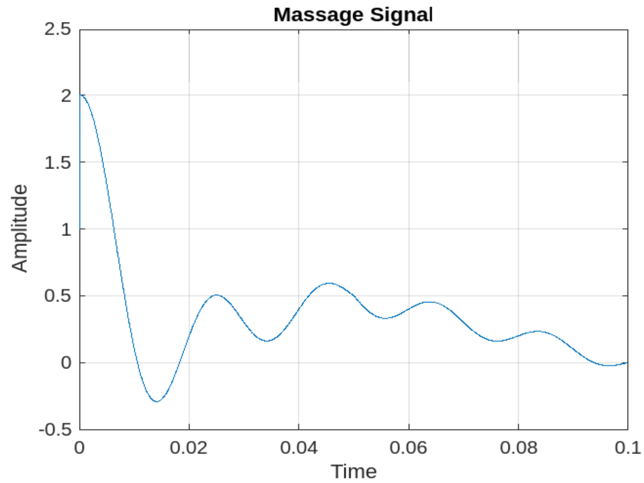

Figure 1: Message Time Domain representation.

The plot has all the expected properties, including the maximum amplitude of 2V. A frequency representation of the message signal was obtained, which also had the expected properties. Those include the high magnitude of zero frequencies, which is due to the Fourier transform of the linear parts of the function being an impulse. These were also expected as the message signal had linear and constant components, having essentially zero frequency. These can be seen in figure 2.

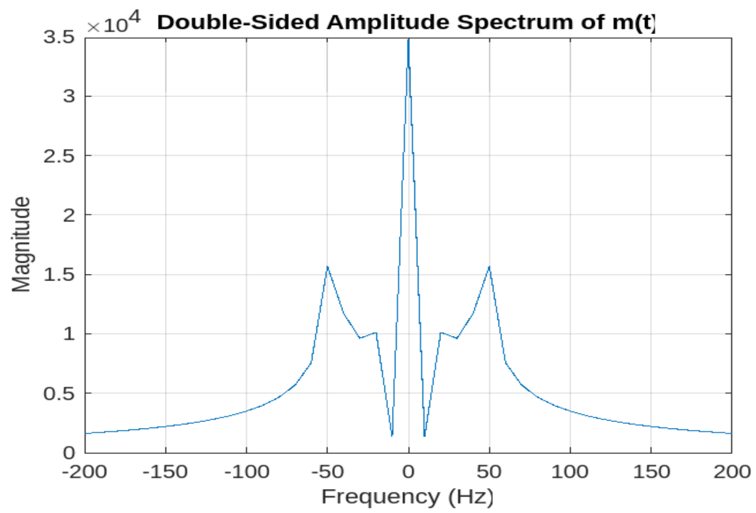

Figure 2: Message signal Frequency representation.

With the time variable of the sinc function having a coefficient of 100, it was also expected for there to be significant 50Hz frequencies since the Fourier transform of the sinc function is rectangle function between -0.5 and 0.5. Which when solved result in the frequency domain leads to the bandwidth of the signal being 0.5*100Hz = 50Hz.

Other and higher frequencies are also present, as can be expected in sinc function, but their magnitude approaches zero as the frequency goes high. The Matlab code associated with the above figures can be found in the appendix.

2 Modulated Signal

The FM modulated signal is given by (2). However, since the message signal is known to be a causal signal, the message integration part of (2) was evaluated from 0 instead of -∞ to time t.

$$u(t)=A_c\cos\left(2\pi f_c t+2\pi k_f\int_{-\infty}^{t} m(\tau)\,d\tau\right) \quad (2)$$

Figure 3 shows the obtained visual representation of the modulated signal u(t). All variables in (2) known except k_f which can be be written as (3).

$$k_f=\frac{\beta_f W}{max(|m_t|)}m(t) \qquad (3)$$

Making a plot of (2) using the ideal message bandwidth $\beta_f=50$ yields a modulated signal whose frequency modulation properties are hard to visually see. This is due to the fact that practically occupied frequency range is larger than the ideal one where the amplitude make sharp drops to 0 after W.

To compute a visual plot for the modulated signal, an estimate of the occupied bandwidth was directly extracted on Matlab for the message signal. This was then used as the actual bandwidth of the message. This was estimated to be 1.4104kHz.

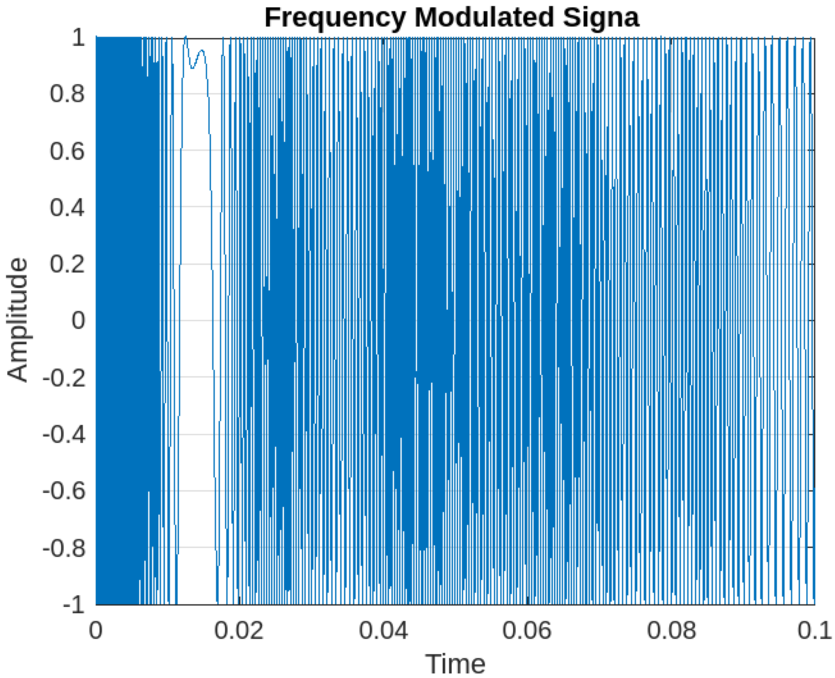

Figure 3: Modulated Signal Time-Domain plot.

Since it is known that the message signal has its peaks at time 0s, and at about 0.025s, 0.045s and 0.065s, it is visually evident that those properties are present in the modulated FM signal. It is clear that the frequencies at those times are higher, as expected, and lower at time segments where the message amplitude was low.

Looking at fig. 3, it is evident that the message signal was properly modulated.

The frequency spectrum of the modulated signal u(t) is shown in fig. 4. The plot in the figure only shows a segment of the spectrum. It is clear that the modulated signal has got a bandwidth of roughly 8kHz, which agrees with the results from Carson's rule (4) for the effective bandwidth of an angle modulated signal, which estimates it to be roughly 8.46kHz. A Matlab estimate was also observed, and was found to be roughly 8kHz, which agrees with Carson's rule estimate.

$$B_c = 2(B_f + 1) f_m \qquad (4)$$

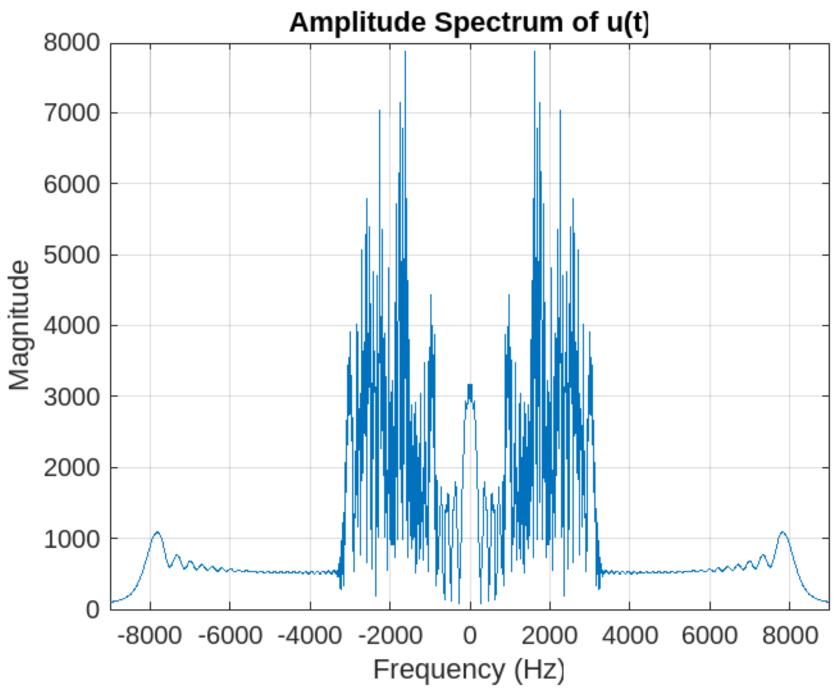

Figure 4: Modulated signal frequency representation.

The Matlab code associated with the above figures can be found in the appendix.

3 Instantaneous frequency

A frequency modulated signal has an instantaneous frequency defined by (5). Considering the known properties of the message and modulation, (5) can be rearranged into (6).

$$f_i = f_c + k_f m(t) \qquad (5)$$

$$f_i = f_c + \frac{\beta_f W}{max(|m|)} m(t) \qquad (6)$$

Figure 5 shows a visual representation of (6). It is clear that the instantaneous frequency is the message signal shifted up by f_c and its amplitude multiplied. This makes the range [-30, 8050], which is similar to what Matlab estimate, which is [-31.3, 8052].

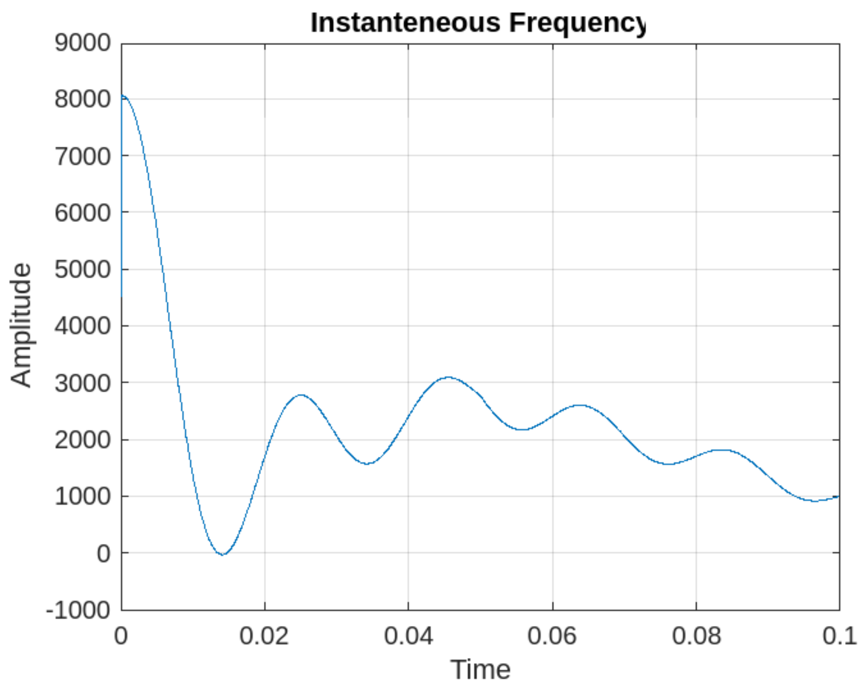

Figure 5: Modulated signal Instantaneous frequency

Ideally, the bandwidth of instantaneous frequency is the same as that of the message signal. That is because the instantaneous frequency is equivalent to the message signal shifted by a constant and also multiplied by a constant. The shift and multiplication do not affect the frequency of the message signal, which leads to it staying the same even for the instantaneous frequency.

Hence, ideally it would be 50Hz. In this semi-practical situation, however, it is roughly half of that of the semi-practical estimate of the message signal, 717Hz. This is because there were fewer components or lower amplitudes than those of the message signal, which in-turn means the Matlab estimator will discard more frequencies for the same area considered.

The Matlab code associated with the above figures can be found in the appendix.

4 FM Demodulation

The FM demodulation was carried out as shown in the flowchart in fig 6. The modulated signal received modulated signal was used to extract the theta component of the it. This was done by using (7).

$$\theta = \cos^{-1}(u(t)) - 2\pi f_c t \quad (7).$$

After finding theta, it is differentiated. This result in a signal that is both frequency and amplitude modulated. The amplitude modulated property of it is demodulated like in an amplitude modulated signal by finding its envelope.

Figure 6: The FM Demodulation flowchart.

Figure 7 shows the results of the AM and FM modulated signal, along with the overall found envelope of the signal. That is the assumed to have the amplitude properties of the original message.

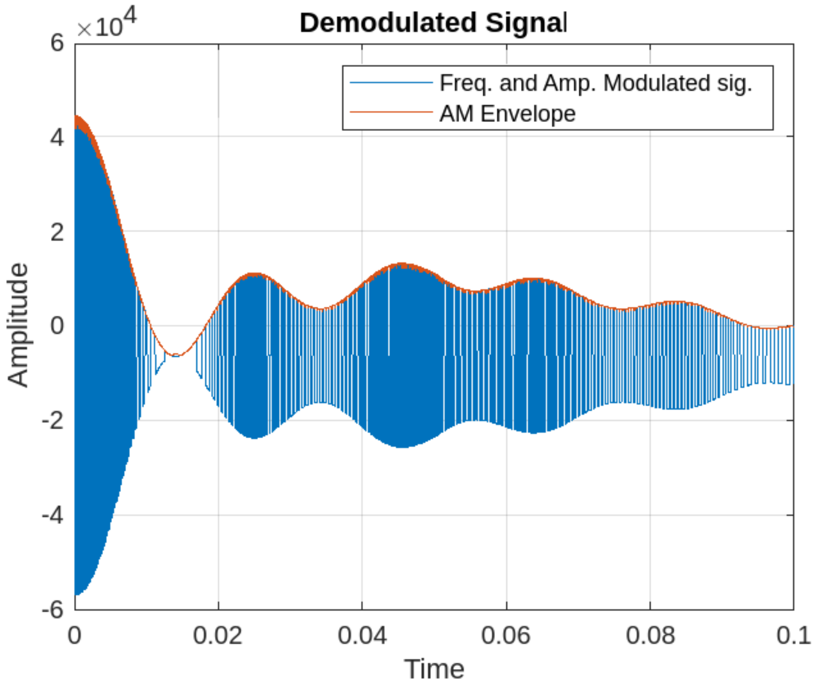

Figure 7: The AM and FM modulated signal with the Envelope.

The demodulated signal, the envelope, matches the original sent message almost perfectly in shape. Considering that fact, it can be said that the demodulation went well. It however was noted that the amplitude of the demodulated signal was on higher orders compared to the original. This is because the factors such as the amplifications to the message signal, the coefficient of the integral part of (2), were not taken into consideration when attempting to extract the original message. That resulted in a signal with the same shape, but amplified amplitudes.

Given how similar the shape of the demodulated signal is to that of the original signal, it apparent that the two have approximate base-bands, with the demodulated signal having a little larger baseband due to the oscillations on from the envelope detector.

The Matlab code associated with the above figures can be found in the appendix.

5 Noisy Modulated Signal

Adding noise of 0.05 variance to the modulated signal u(t), a visual representation of the total received signal y(t) was plotted. Figure 8 shows the plot.

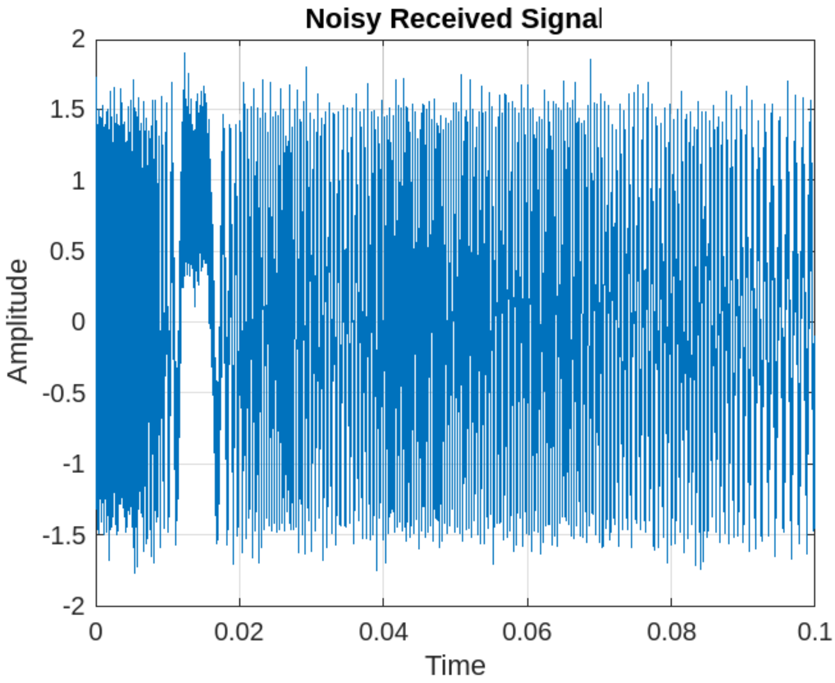

Figure 8: The total, noisy, received signal.

While it is clearly noisy compared to the u(t) plot in fig. 3, it is still apparent that the signal was frequency modulated.

Following the same modulation as was done with the clean signal, figure 9 was obtained.

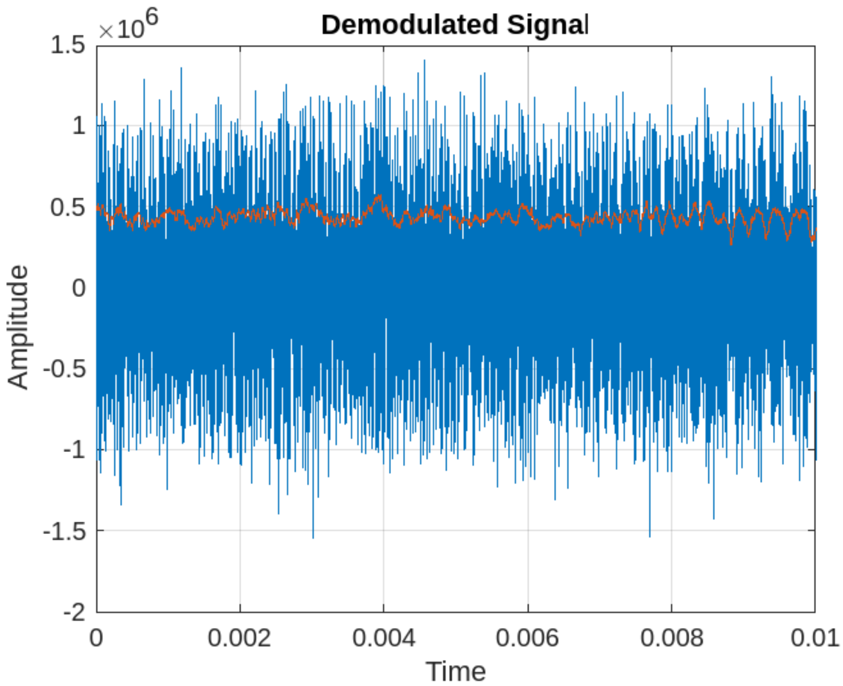

Figure 9: Noisy AM and FM modulated signal with the Envelope.

The demodulation in this case did not go as well as it did with the non-noisy signal. It is visually evident that the obtained message signal is not quite similar to the sent signal, and so clearly the neither is the base-band.

After attempting to perform the demodulation using the Matlab in-build ‘fmdemod’ function which yielded similar results, its was concluded that the noisy signal cannot be easily demodulated. That was after using the same function to demodulate the clean signal, which yielded a signal with the same shape as the original message, as well as the amplitude.

The Matlab code associated with the above figures can be found in the appendix.

III Conclusion

Frequency modulation sounds have an advantage over amplitude modulation in areas such as radio broadcasting. The ideal message signal bandwidth, 50Hz, is not the same as the practical or semi-practical message signal bandwidth. This is because the magnitude of the frequencies in the non-ideal case does not drop to 0 immediately after the expected W=50Hz. It gradually approaches 0, which leads to the overall signal bandwidth being greater than the ideal bandwidth.

The instantaneous frequency ideally has the same bandwidth as the message signal. However, in non-ideal cases, its bandwidth is lower than that of the message signal due to its frequencies' amplitudes having lower amplitudes.

When the noise variance in the received signal is greater or equal to 0.05, the original message signal cannot be easily recovered.

REFERENCES

[1] Faruque, S., 2017. Radio Frequency Modulation Made Easy. 1st ed. Denmark: Springer Cham, pp.33–44.

Appendix

% sub.Q1 -- Message Signal

```
clear; close all;
fs = 1*10^6;
T = 1/fs;
L = 100000;
t = (0:L)*T;
fc = 1000;
Ac = 1;
Bf = 5;

m_t1 = 2*sinc(100*t) + 10.*t;
m_t2 = 2*sinc(100*t) + (1 - 10.*t);

m_t = m_t1.*(heaviside(t)-heaviside(t-0.05)) + ...
    m_t2.*(heaviside(t-0.05)-heaviside(t-0.1));

plot(t, m_t);
title('Massage Signal');
xlabel('Time');
ylabel('Amplitude');
xlim([0 0.1]);

M_f = fft(m_t);
fshift = (-L/2: L/2 )*(fs/L);
ushift = fftshift(M_f);
plot(fshift,abs(ushift));
title('Double-Sided Amplitude Spectrum of m(t)');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
xlim([-200 200]);
```

% Sub.Q2 -- Modulated Signal.

```
W = obw(m_t,fs);
m_max = max(m_t);
kf = Bf*W/m_max;
intg_m = cumtrapz(t, m_t);
u_t = Ac*cos(2*pi*fc*t + 2*pi*kf*intg_m);
plot(t, u_t);
title('Frequency Modulated Signal');
xlabel('Time');
ylabel('Amplitude');

U_f = fft(u_t);
fshift = (-L/2: L/2)*(fs/L);
ushift = fftshift(U_f);
plot(fshift,abs(ushift));
title('Amplitude Spectrum of u(t)');
xlabel('Frequency (Hz)');
ylabel('Magnitude');
```

% Sub.Q3 -- Instantaneous Frequency

```
fi_t = fc + kf*m_t;
bwfi = obw(fi_t,fs);
plot(t,fi_t);
title('Instanteneous Frequency');
xlabel('Time');
ylabel('Amplitude');
```

% Sub.Q4 -- Demodulated Signal

```
cos_angle = acos(u_t);
theta = cos_angle - 2*pi*fc*t;
m_out = diff(theta)/T;
m_out(end+1)=m_out(end);

plot(t,m_out, 'DisplayName','Freq. and Amp.
Modulated sig.');

m_out = envelope(m_out,10,'rms');
plot(t,m_out, 'DisplayName','AM Envelope')

title('Demodulated Signal');
xlabel('Time');
ylabel('Amplitude');
```

% Sub.Q5 -- Demodulated Noisy Signal

```
n_t = sqrt(0.05)*randn(size(t));
y_t = u_t + n_t;
plot(t, y_t);
title('Noisy Received Signal');
xlabel('Time');
ylabel('Amplitude');

cos_angle2 = acos(y_t);
theta2 = real(cos_angle2) - 2*pi*fc*t;
m_out2 = diff(theta2);
m_out2 = m_out2/T;
m_out2(end+1)=m_out2(end);
plot(t,m_out2,'DisplayName','Noisy Freq. & Amp. Modulated sig.');

m_out2 = envelope(m_out2,100,'rms');
plot(t,m_out2,'DisplayName','Noisy signal Envelope')

title('Demodulated Signal');
xlabel('Time');
ylabel('Amplitude');
```