International Institute of Information Technology Bangalore

Principles of Communication Systems Lab

EC 303P

Lab 3: Amplitude Modulation and Demodulation

Mohd. Rizwan Shaikh
(IMT2019513)

August 27, 2021

ज्ञानमुत्तमम्

Lab 3: Amplitude Modulation and Demodulation

Mohd. Rizwan Shaikh

August 27, 2021

Abstract

In this Lab report, we study amplitude modulation and demodulation. We plot the message signal, carrier signal and their frequency spectrum. We study amplitude modulation by plotting modulated signal and frequency spectrum for various modulation indices. By replicating the synchronous detector, we demodulate the transmission signal and study its various properties.

1 Introduction

1.1 Question 1

Consider an amplitude modulated signal $s(t) = A_c(1 + k_a m(t))cos(2\pi f_c t)$ with message signal $m(t) = A_m cos(2\pi f_m t)$. Assume $k_a = 1$, $f_m = 100$ Hz and $f_c = 2$ KHz.

(a) Plot the message signal $m(t) = A_m cos(2\pi f_m t)$ for two complete cycles with $A_m = 1$.

(b) Plot the carrier signal $c(t) = A_c cos(2\pi f_c t)$ for a duration equal to the duration of the message signal $m(t)$. Assume $A_c = 1$.

(c) Plot the AM signal for $\mu = 0.5$, 1, 2 and $A_c = 1/\mu$ where μ is the modulation index.

(d) Plot the frequency spectrum of the signals in part (a) and (b) and identify the tones of carrier signal and the message signal.

(e) Demodulate the above AM signal using the synchronous detector discussed in the class for $\mu = 0.5$, 1, 2. Plot the demodulated signal and its spectrum. Assume that the receiver can generate a carrier $c(t) = A_c cos(2\pi f_c t)$.

1.2 Question 2

Consider a multi-tone signal $m(t) = A_1 cos(2\pi f_1 t) + A_2 cos(2\pi f_2 t)$ and a carrier signal $A_c cos(2\pi f_c t)$ with $A_c = A1 = A2 = 1$, $f_1 = 100$ Hz, $f_2 = 200$ Hz and $f_c = 2$ KHz.

(a) Plot the signal $A_1 cos(2\pi f_1 t)$ for complete two cycles.

(b) Plot the signal $A_2 cos(2\pi f_2 t)$ and the carrier signal $A_c cos(2\pi f_c t)$ over the duration of signal $A_1 cos(2\pi f_1 t)$.

(c) Plot the frequency spectrum of the message signal $m(t)$ and the carrier signal $c(t) = A_c cos(2\pi f_c t)$.

(d) Plot the frequency spectrum of the AM signal $s(t) = A_c(1 + m(t))cos(2\pi f_c t)$ and identify the tones of the message signal and the carrier signal.

(e) Demodulate the above AM signal using the synchronous detector discussed in the class and plot the demodulated signal and its spectrum. Assume that the receiver knows the the carrier signal perfectly.

2 Method

2.1 Question 1

To begin with, we first create a time vector followed by message signal vector and carrier signal vector as shown below:

```
fs = 50000;                     %Sampling Frequency
t = [0:fs-1]*1/fs;              %Time vector
m_t = Am*cos(2*pi*fm*t);        %Message Signal
c_t = Ac*cos(2*pi*fc*t);        %Carrier signal
```

Here, we take the sampling frequency as 50 KHz. We plot the message signal and carrier signal using `plot(t, x)` command. To plot the amplitude modulated signal for various modulation indices, we first create an array of modulation indices (`mu = [0.5 1 2]`). Then we create the signal vector s_t as shown below:

```
Ac = 1/mu(i);
s_t = Ac.*c_t.*(1 + mu(i).*m_t/Am);  %Generate the transmission signal
```

Here, we first make A_c as $1/\mu$. Then we use the general formula of amplitude modulated signal which is $s_t(t) = A_c(1 + k_a m(t))cos(2\pi f_c t)$. This is followed by plotting the signal. Using the following piece of code, we calculate the fourier transform of the message and carrier signals:

```
fftM = fftshift(fft(m_t))/length(m_t);      %Find ffts of the signals
fftC = fftshift(fft(c_t))/length(c_t);
f = [-fs/2:fs/2-1]*df;                      %Frequency vector
```

To demodulate the transmission signal, we use the concepts of synchronous detector. First we multiply the transmission signal by $A_c cos(2\pi f_c t)$. Then we pass it through a low pass filter. Then we subtract $A_c^2/2$ from the signal. Finally, we divide the signal by $A_c^2/2 * \mu$ to get the original signal. The code for this process is shown below:

```
Ac = 1/mu(i);
s_t = Ac.*c_t.*(1 + mu(i).*m_t/Am);     %Transmission signal
x_t = s_t.*Ac.*c_t;                     %Multiply with Ac*Cos(2*pi*fc*t)
m1t = lowpass(x_t, 150, fs);            %Pass through low pass filter
m1t = m1t - (Ac*Ac)/2;                  %Subtract Ac^2/2
m1t = m1t/(mu(i)*Ac^2/2);               %Divide the signal by Ac^2/2*mu
```

2.2 Question 2

We follow the same steps as question 1 to get the desired results.

3 Results and Analysis

3.1 Question 1

To solve the question, we create message signal and carrier signal vector as shown below:

```
ka = 1;                          %Parameters
fm = 100;       fc = 2000;
Am = 1;         Ac = 1;
fs = 50000;                      %Sampling Frequency
df = 1;                          %frequency gap
t = [0:fs-1]*1/fs;               %Time vector

m_t  = Am*cos(2*pi*fm*t);        %Message Signal
c_t  = Ac*cos(2*pi*fc*t);        %Carrier signal
```

The MATLAB code to plot message and carrier signal (part (a) and part (b)) is as follows:

```
%≤===== 1(a) ======>
subplot(2, 1, 1);               %Plot the message signal
plot(t, m_t);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('1(a) Message Signal: A_mcos(2\pif_mt)');
xlim([0 0.02]);
grid on;

%≤===== 1(b) ======>
subplot(2, 1, 2);               %Plot the carrier signal
plot(t, c_t);
xlabel('---> time(s)');    ylabel('---> c(t)');
title('1(b) Carrier Signal: A_ccos(2\pif_ct)');
xlim([0 0.02]);
grid on;
```

The plot of message and carrier signal (part (a) and part (b)) is as follows:

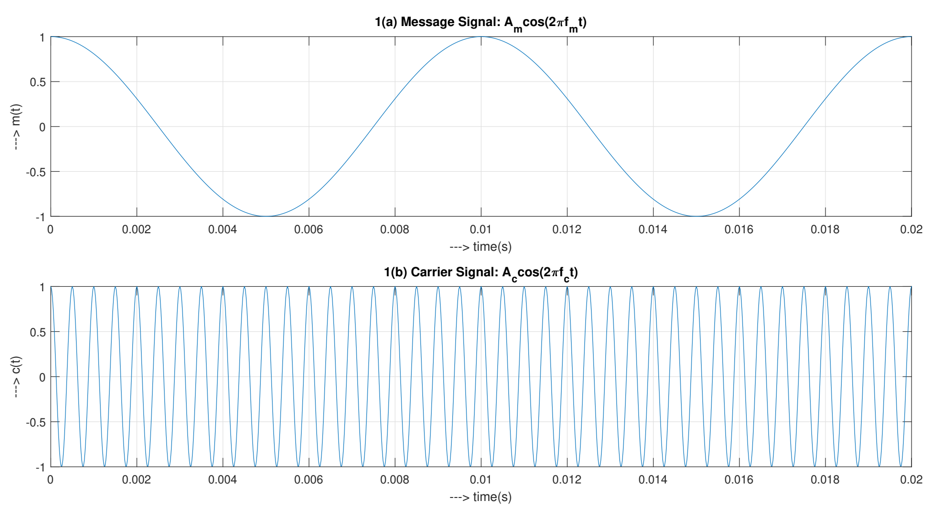

Figure 1: The message and the carrier signal.

The MATLAB code to plot Amplitude Modulated signal (part (c)) is as follows:

```
%<===== 1(c) ======>
mu = [0.5 1 2];

for i=1:length(mu)
    Ac = 1/mu(i);
    s_t = Ac.*c_t.*(1 + mu(i).*m_t/Am);  %Generate the transmission signal
    subplot(length(mu), 1, i);           %Plot the signal
    plot(t, s_t);
    xlabel('---> time(s)');    ylabel('---> s(t)');
    xlim([0 0.02]);
    title(sprintf('1(c) Amplitude Modulated Signal for mu = %.1f', mu(i)));
    grid on;
end
```

The plot of amplitude modulated signal (part (c)) is as follows:

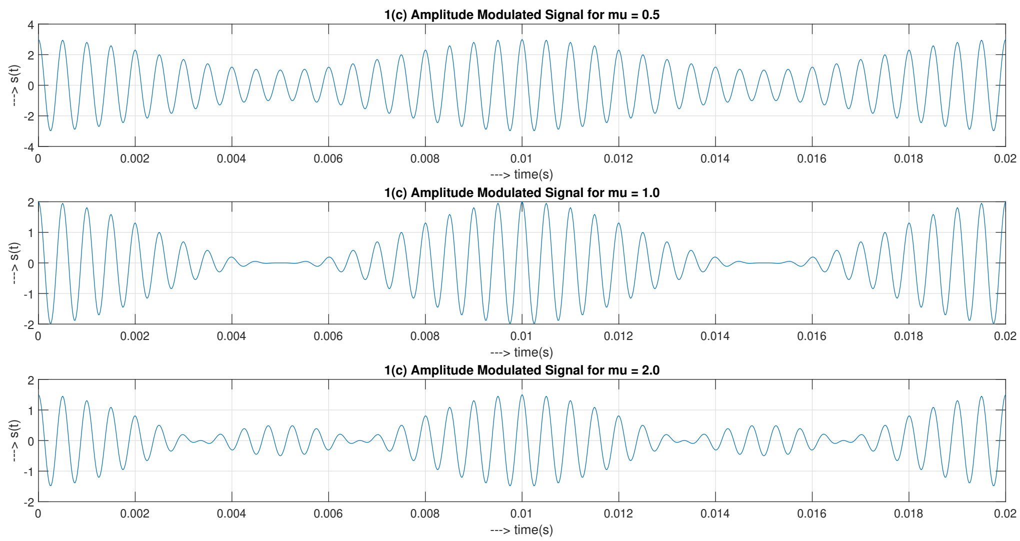

Figure 2: Amplitude modulated signal for various values of μ

Here, a noteworthy observation is of maximum and minimum amplitude of the signal.

- For $\mu = 0.5$, the maximum amplitude is 3 and minimum amplitude is 1.5. This is a case of under modulation.
- For $\mu = 1$, the maximum amplitude is 2 and minimum amplitude is 0. This is a case of critical modulation.
- For $\mu = 2$, the maximum amplitude is 1.5 and minimum amplitude is -0.5. This is a case of over modulation.

The formula for maximum amplitude is given by $A_{max} = A_c(1 + \mu)$. For $A_c = 1/\mu$, $A_{max} = 1/\mu + 1$.

Similarly, the formula for minimum amplitude is given by $A_{min} = A_c(1-\mu)$. For $A_c = 1/\mu$, $A_{min} = 1/\mu - 1$.

The maximum and minimum amplitude of the plotted signals are in agreement with the corresponding formulae.

The MATLAB code to plot the frequency spectrum of the signals (part (d)) is as follows:

```
%<===== 1(d) ======>
fftM = fftshift(fft(m_t))/length(m_t);       %Find ffts of the signals
fftC = fftshift(fft(c_t))/length(c_t);

f = [-fs/2:fs/2-1]*df;

subplot(2, 1, 1);                            %Plot frequency spectrum
plot(f, abs(fftM));
xlabel('---> Frequency(Hz)');    ylabel('---> M(f)');
title('1(d) Frequency Spectrum of Message Signal');
text(130, 0.3, 'Tone at 100 Hz');
xlim([-500 500]);
grid on;

subplot(2, 1, 2);                            %Plot frequency spectrum
plot(f, abs(fftC));
xlabel('---> Frequency(Hz)');    ylabel('---> C(f)');
title('1(d) Frequency Spectrum of Carrier Signal');
text(2100, 0.3, 'Tone at 2000 Hz');
xlim([-3000 3000]);
grid on;
```

The plot of the frequency spectrum is as follows:

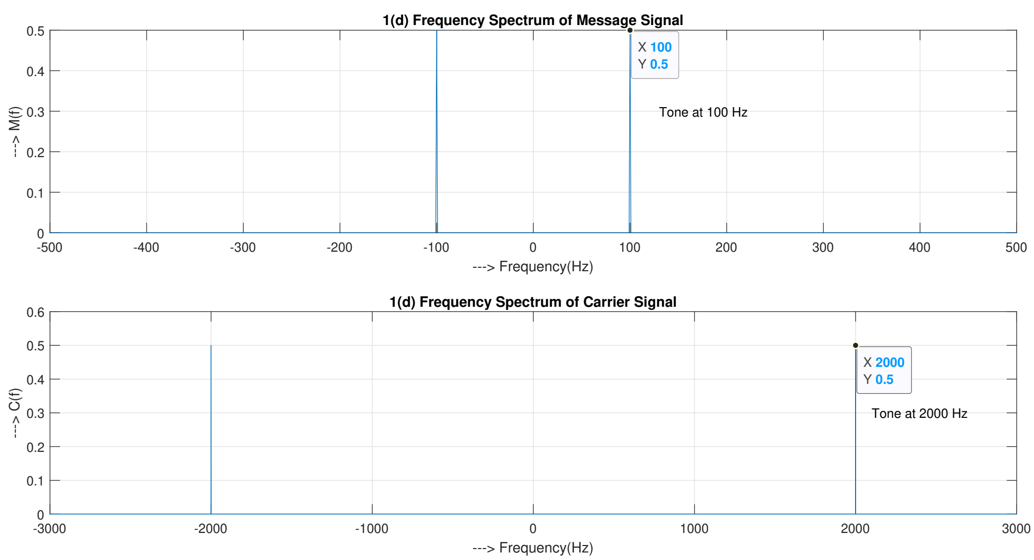

Figure 3: Frequency Spectrum of message and carrier signals.

For message signal, the tone is at 100 Hz. This is a single tone signal. For carrier signal, the tone is at 2000 Hz.

The MATLAB code to demodulate the transmission signal (part (e)) is as follows:

```
%≤===== 1(e) ======>
mu = [0.5 1 2];
plotNo = 1;
for i = 1:length(mu)
    Ac = 1/mu(i);
    s_t = Ac.*c_t.*(1 + mu(i).*m_t/Am);    %Transmission signal
    x_t = s_t.*Ac.*c_t;                    %Multiply with Ac*Cos(2*pi*fc*t)
    m1t = lowpass(x_t, 150, fs);           %Pass through low pass filter
    m1t = m1t - (Ac*Ac)/2;                 %Subtract Ac^2/2
    m1t = m1t/(mu(i)*Ac^2/2);              %Divide the signal by Ac^2/2*mu
    subplot(3, 2, plotNo);                 %Plot the demodulated signal
    plot(t, m1t);
    xlabel('---> time(s)');    ylabel('---> m(t)');
    title(sprintf('1(e) Demodulated Signal for mu = %.1f', mu(i)));
    xlim([0 0.02]);
    grid on;
    plotNo = plotNo + 1;

    fftS = fftshift(fft(m1t))/length(m1t); %Find fft of the signal
    f = [-fs/2:fs/2-1]*df;
    subplot(3, 2, plotNo);                 %Plot frequency spectrum
    plot(f, abs(fftS));
    xlim([-250 250]);
    xlabel('---> Frequency(Hz)');    ylabel('---> M(f)');
    title(sprintf('1(e) Frequency Spectrum of the Signal for mu = %.1f', ...
        mu(i)));
    grid on;
    text(115,0.35, 'Tone at 100 Hz');
    plotNo = plotNo + 1;
end
```

The plot of demodulated signal and its frequency spectrum is as follows:

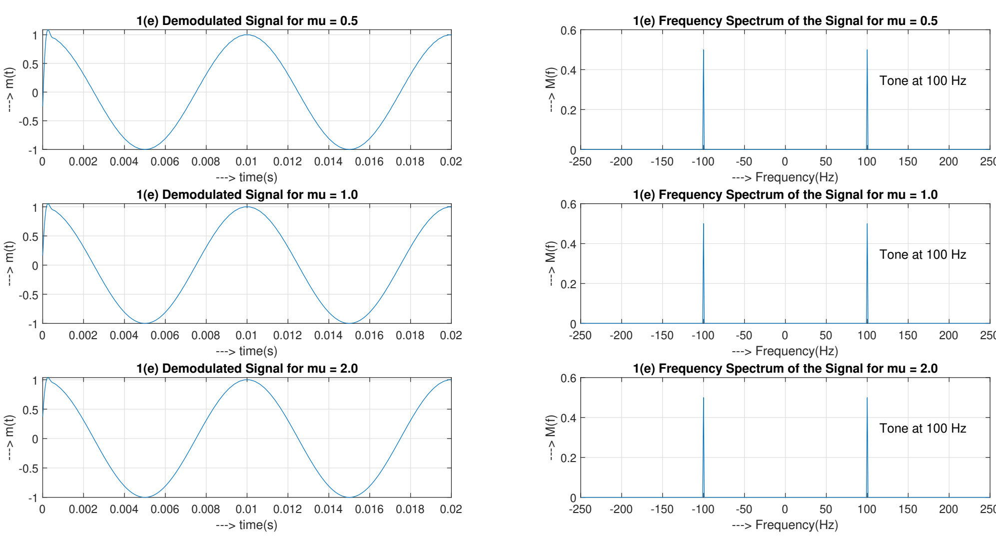

Figure 4: Demodulated signal and its frequency spectrum for various values of μ.

Here, we see that the demodulated signal matches with the original message signal for all given values of μ. The frequency spectrum of the demodulated signals have tone at 100 Hz.

3.2 Question 2

To begin with, we first create the carrier signal vector and message signal vector as follows:

```
Ac = 1; A1 = 1; A2 = 1;
f1 = 100;   f2 = 200;   fc = 2000;   df = 1;
fs = 50000;                 %Sampling Frequency
t = [0:fs-1]*1/fs;          %Time vector

m1 = A1*cos(2*pi*f1*t);     m2 = A2*cos(2*pi*f2*t);
m_t = m1 + m2;
c_t = Ac*cos(2*pi*fc*t);
```

The given message signal and carrier signal is shown below:

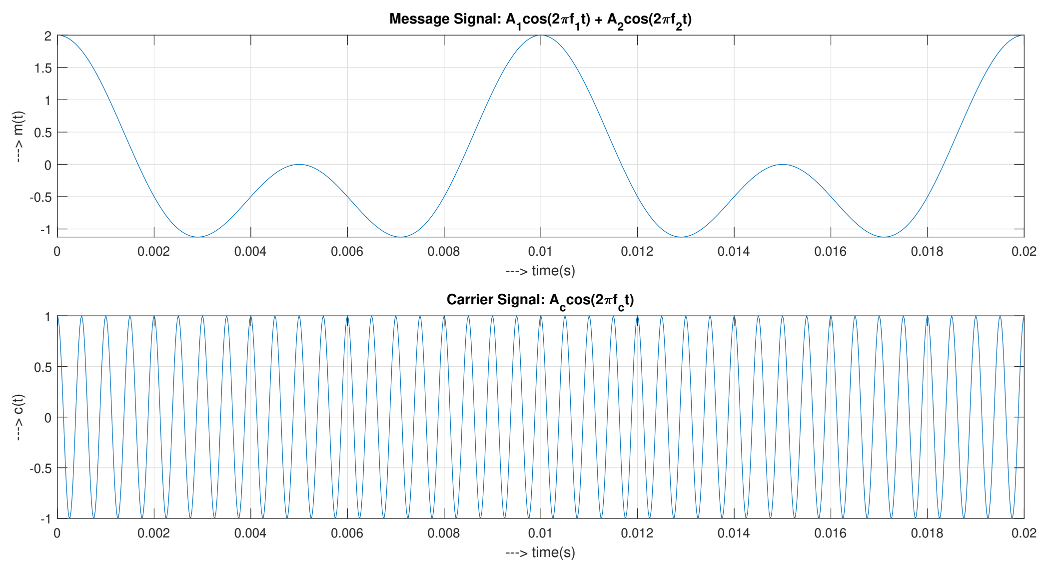

Figure 5: Message signal and Carrier signal

The MATLAB code to plot $A_1cos(2\pi f_1t)$, $A_2cos(2\pi f_2t)$ and carrier signal $A_ccos(2\pi f_ct)$ (part (a) and (b)) is as follows:

```
%<===== 2(a) ======>
subplot(3, 1, 1);   plot(t, m1);        %Plot the signals
xlabel('---> time(s)');    ylabel('---> Signal');
title('2(a) A_1cos(2\pif_1t) signal');
xlim([0 0.02]);
grid on;

%<===== 2(b) ======>
subplot(3, 1, 2);   plot(t, m2);
xlabel('---> time(s)');    ylabel('---> Signal');
title('2(b) A_2cos(2\pif_2t) signal');
xlim([0 0.02]);
grid on;

subplot(3, 1, 3);   plot(t, c_t);
```

```
    xlabel('---> time(s)');    ylabel('---> Signal');
    title('2(b) Carrier signal: A_ccos(2\pif_ct)');
    xlim([0 0.02]);
    grid on;
```

The plots of $A_1cos(2\pi f_1t)$, $A_2cos(2\pi f_2t)$ and $A_ccos(2\pi f_ct)$ is as follows:

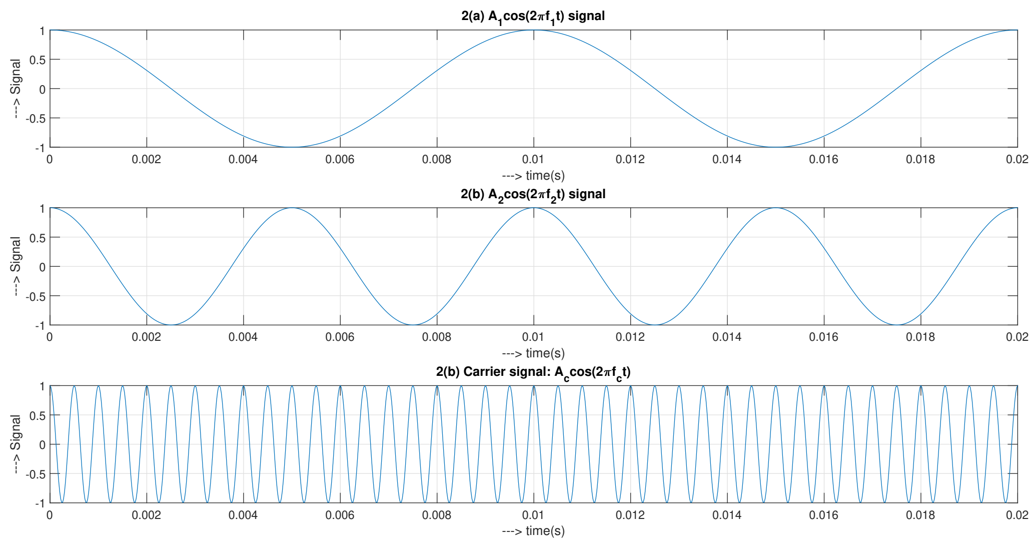

Figure 6: $A_1cos(2\pi f_1t)$, $A_2cos(2\pi f_2t)$ and $A_ccos(2\pi f_ct)$ signals.

The MATLAB code to plot the frequency spectrum of message and carrier signal (part (c)) is as follows:

```
    %<===== 2(c) ======>
    fftM = fftshift(fft(m_t))/length(m_t);      %Calculate fft of the signals
    fftC = fftshift(fft(c_t))/length(c_t);

    f = [-fs/2:fs/2-1]*df;

    subplot(2, 1, 1);                   %Plot the frequency spectrum
    plot(f, abs(fftM));
    xlabel('---> Frequency(Hz)');    ylabel('---> M(f)');
    title('2(c) Frequency Spectrum of Message Signal');
    xlim([-500 500]);
    grid on;

    subplot(2, 1, 2);                   %Plot the frequency spectrum
    plot(f, abs(fftC));
    xlabel('---> Frequency(Hz)');    ylabel('---> C(f)');
    title('2(c) Frequency Spectrum of Carrier Signal');
    xlim([-3000 3000]);
    grid on;
```

The plot of the frequency spectrum of message and carrier signal is as follows:

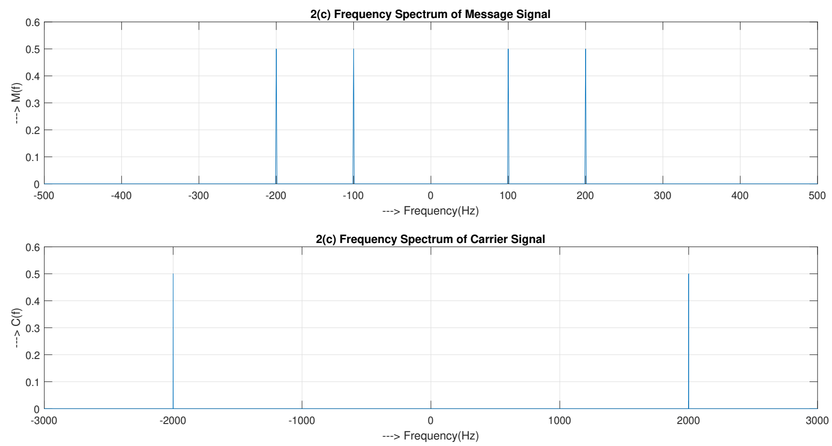

Figure 7: Frequency spectrum of message and carrier signal

Here, we observe that the tone of the message signal is at 100 and 200 Hz. It is a multi-tone signal. The tone of the carrier signal is at 2000 Hz.

The MATLAB code to plot the frequency spectrum of amplitude modulated signal (part (d)) is as follows:

```
%≤===== 2(d) ======>
AM = c_t.*(1+m_t);
fftAM = fftshift(fft(AM))/length(AM);   %Find fft
f = [-fs/2:fs/2-1]*df;

plot(f, abs(fftAM));          %Plot the frequency spectrum
xlabel('---> Frequency(Hz)');    ylabel('---> |s(t)|');
title('2(d) Frequency spectrum of amplitude modulated signal');
xlim([-4000 4000]);     grid on;
text(2100, 0.5, 'Tone of carrier signal at 2000 Hz');
text(2100, 0.35, 'Tone of message signal at 1800, 1900, 2100 and 2200 Hz');
```

The plot of the frequency spectrum of amplitude modulated signal is as follows:

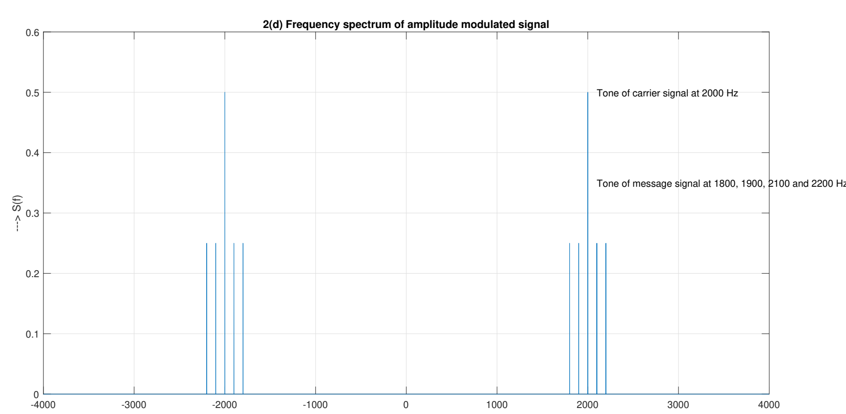

Figure 8: Frequency spectrum of amplitude modulated signal

Here, the tone of the carrier signal is at 2000 Hz. The tone of the message signal is at 1800, 1900, 2100 and 2200 Hz. In the frequency spectrum, the amplitude of the carrier signal is 0.5 which is in agreement with the theoretical value of $A_c/2$. Similarly for message signal, the amplitude is 0.25 at 1800, 1900, 2100 and 2200 Hz. This value corresponds to the theoretical value of $A_c^2/4 * K_a$.

The MATLAB code to demodulate the amplitude modulated signal (part (e)) is as follows:

```
%<===== 2(e) ======>
s_t = c_t.*(1 + m_t);                   %Transmission signal
x_t = s_t.*Ac.*c_t;                     %Multiply with Ac*Cos(2*pi*fc*t)
m1t = lowpass(x_t, 200, fs);            %Pass through low pass filter
m1t = m1t - (Ac*Ac)/2;                  %Subtract Ac^2/2
m1t = m1t/(Ac^2/2);                     %Divide the signal by Ac^2/2
subplot(2, 1, 1);
plot(t, m1t);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('2(e) Demodulated Signal');
xlim([0 0.02]);
grid on;

fftS = fftshift(fft(m1t))/length(m1t); %Find fft of the signal
f = [-fs/2:fs/2-1]*df;
subplot(2, 1, 2);                       %Plot frequency spectrum
plot(f, abs(fftS));
xlim([-250 250]);
xlabel('---> Frequency(Hz)');    ylabel('---> M(f)');
title('2(e) Frequency Spectrum of the Demodulated Signal');
grid on;
text(110, 0.17, 'Tone at 100 Hz');
text(202, 0.17, 'Tone at 200 Hz');
```

The plot of the demodulated signal along with its frequency spectrum (part (e)) is shown below:

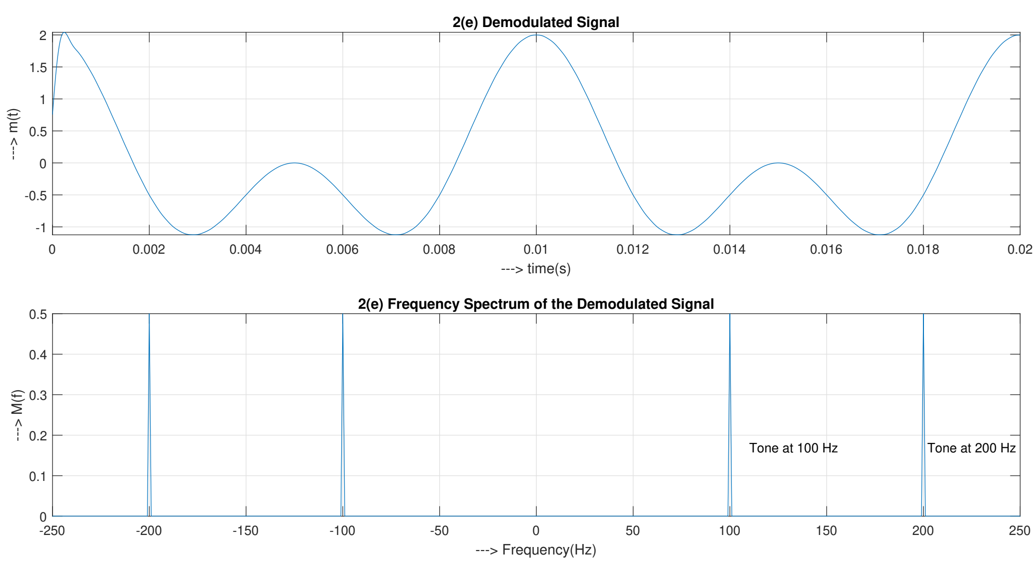

Figure 9: Demodulated signal and its frequency spectrum

Here, we observe that we get back the original signal by passing the transmission signal through synchronous detector. The demodulated signal has tone at 100 and 200 Hz.

4 Discussion and Conclusion

4.1 Question 1

We plotted the message and carrier signal along with its frequency spectrum. We also plotted the amplitude modulated signal for various modulation indices. Finally, we replicated the function of synchronous detector to demodulate the transmission signal and plotted the signal with its frequency spectrum.

Some of the noteworthy observations are as follows:

- The given message signal is a single tone signal.
- The maximum and minimum amplitude of the amplitude modulated signal was dependent on its modulation index.
- The tone of the message signal is at 100 Hz and that of the carrier signal is at 2 KHz.
- Using synchronous detector, we were able to get back the original signal from the transmission signal.

4.2 Question 2

For this question too, we plotted the message signal, the carrier signal and the amplitude modulated signal along with its frequency spectrum. We also demodulated the transmission signal and plotted its frequency spectrum.

Some of the observations are as follows:

- The given message signal is a multi tone signal.
- In the frequency spectrum of message signal, the tones are at 100 and 200 Hz. Similarly, for carrier signal, the tone is at 2 KHz.
- In amplitude modulated signal, the tone of the carrier signal is at 2 KHz and tones of message signal are at 1800, 1900, 2100 and 2200 Hz.
- Using synchronous detector, we were able to get back the original signal from the transmission signal.

References

[1] Low Pass filter signals,
https://in.mathworks.com/help/signal/ref/lowpass.html