International Institute of Information Technology
Bangalore

Principles of Communication Systems Lab

ECE303P

Lab 6: Angle Modulation and Demodulation

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Abstract

In this Lab report, we study angle modulation and demodulation. We plot the message signal, carrier signal and their frequency spectrum. We study both frequency and phase modulation by plotting modulated signal and frequency spectrum. We also demodulate the transmission signal and study its various properties.

1 Introduction

1.1 Question 1

Consider an information signal $m(t) = A_m cos(2\pi f_m t)$ with $A_m = 1$ V and $f_m = 50$ Hz, and a carrier signal $c(t) = A_c cos(2\pi f_c t)$ with $A_c = 2$ V and $f_c = 250$ Hz.

(a) Plot m(t) for 5 complete cycles, and plot c(t) over the duration of m(t).

(b) Consider frequency sensitivity $k_f = 12.5$ Hz/Volt and plot the frequency modulated signal $\phi_{FM}(t) = A_c cos(2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(\alpha)d\alpha)$ and its spectrum. Also calculate the bandwidth of the modulated signal.

(c) Consider frequency sensitivity $k_f = 100$ Hz/Volt and plot the frequency modulated signal $\phi_{FM}(t) = A_c cos(2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(\alpha)d\alpha)$ and its spectrum. Also calculate the bandwidth of the modulated signal.

(d) Vary k_f from 12.5 Hz/V to 100 Hz/V and analyze its effect on power and bandwidth of the FM signal.

(e) Demodulate the frequency modulated signal and plot the demodulated signal (take $k_f = 100$ Hz/Volt).

1.2 Question 2

Consider an information signal $m(t) = A_m cos(2\pi f_m t)$ with $A_m = 1$ V and $f_m = 50$ Hz, and a carrier signal $c(t) = A_c cos(2\pi f_c t)$ with $A_c = 2$ V and $f_c = 250$ Hz.

(a) Plot m(t) for 5 complete cycles, and plot c(t) over the duration of m(t).

(b) Consider phase sensitivity $k_p = 0.25$ rad/Volt and plot the phase modulated signal $\phi_{PM}(t) = A_c cos(2\pi f_c t + 2\pi k_p m(t))$ and its spectrum. Also calculate the bandwidth of the modulated signal.

(c) Consider phase sensitivity $k_p = 2$ rad/Volt and plot phase modulated signal $\phi_{PM}(t) = A_c cos(2\pi f_c t + 2\pi k_p m(t))$ and its spectrum. Also calculate the bandwidth of the modulated signal.

(d) Vary k_p from 0.25 rad/V to 2 rad/V and analyze its effect on power and bandwidth of the FM signal.

(e) Demodulate the phase modulated signal and plot the demodulated signal (take $k_p = 2$ rad/-Volt).

1.3 Question 3

Plot the frequency modulated and phase modulated signal in the same plot using subplots. Compare the two plots and write your observation.

2 Method

2.1 Question 1

First we create the required signals as follows:

```
clear all; close all; clc;

Am = 1;          Ac = 2;     %Parameters
fm = 50;         fc = 250;
fs = 5000;       df = 1;
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
phi_t = Ac*fmmod(mt, fc, fs, kf*Am); %FM signal
```

We plot the message signal, carrier signal and FM modulated signal using `plot(t, x)` command.

```
f = [-fs/2:fs/2-1]*df;                          %Frequency vector
fftphi = fftshift(fft(phi_t))/length(phi_t);    %FFT of FM signal
```

Using the above code, we get the fft of the signal.

```
mt = fmdemod(phi_t, fc, fs, kf*Am)          %Demodulate FM signal
```

Using the above command, we demodulate the FM modulated signal.

2.2 Question 2

We follow the same procedure as above to solve this question. However, we use `pmmod` and `pmdemod` command to do phase modulation and demodulation.

2.3 Question 3

We follow the same procedure as question 1. We plot the phase and frequency modulated signal and compare the plots.

3 Results and Analysis

3.1 Question 1

First we find the message signal vector, carrier signal vector and frequency modulated signal vector as follows:

```
Am = 1;          Ac = 2;      %Parameters
fm = 50;         fc = 250;
fs = 5000;       df = 1;
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
phi_t = Ac*fmmod(mt, fc, fs, kf*Am); %FM signal
```

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

```
%≤===== 1(a) ======>
subplot(2, 1, 1);             %Plot the message signal
plot(t, m_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('1(a) Message Signal: A_mcos(2\pif_mt)');
xlim([0 0.1]);  ylim([-2 2]);
grid on;

subplot(2, 1, 2);             %Plot the carrier signal
plot(t, c_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> c(t)');
title('1(a) Carrier Signal: A_ccos(2\pif_ct)');
xlim([0 0.1]);  ylim([-3 3]);
grid on;
```

The plot of m(t) for 5 complete cycles and c(t) is as follows:

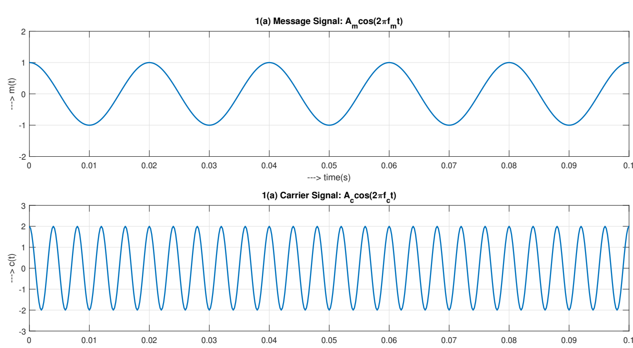

Figure 1: Message signal and carrier signal

The MATLAB code to plot $\phi_{FM}(t)$ and its frequency spectrum for $k_f = 12.5$ Hz/Volt (part(b)) is as follows:

```
%<===== 1(b) ======>
mt = Am*cos(2*pi*fm*t);
phi_t = Ac*fmmod(mt, fc, fs, kf*Am);

subplot(2, 1, 1);            %Plot the frequency modulated signal
plot(t, phi_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> \phi_{FM}(t)');
title('1(b) Frequency modulated signal \phi_{FM}(t)');
xlim([0 0.1]);  ylim([-3 3]);
grid on;

f = [-fs/2:fs/2-1]*df;
fftphi = fftshift(fft(phi_t))/length(phi_t);

subplot(2,1,2);             %Plot spectrum of frequency modulated signal
plot(f, real(fftphi), 'LineWidth', 1.7);
xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{FM}(f)');
title('1(b) Frequency spectrum of \phi_{FM}(t)');
xlim([-500 500]); ylim([-0.2 1.1]);
grid on;
```

The plot of $\phi_{FM}(t)$ and its spectrum for $k_f = 12.5$ Hz/Volt is as follows:

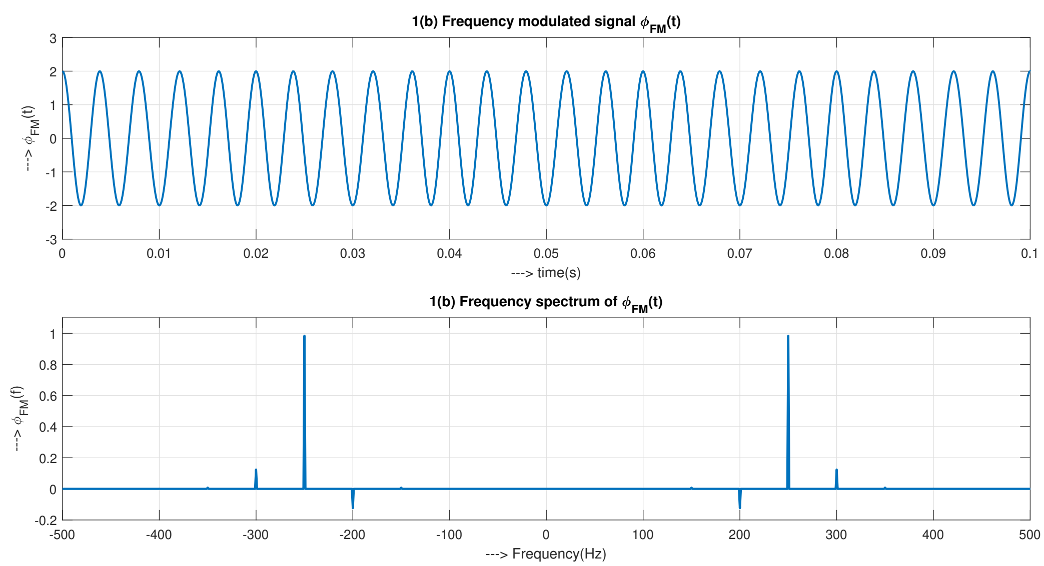

Figure 2: $\phi_{FM}(t)$ for $k_f = 12.5$ Hz/Volt

Here we see that the bandwidth of the frequency modulated signal is 100 Hertz.

The MATLAB code to plot $\phi_{FM}(t)$ and its frequency spectrum for $k_f = 100$ Hz/Volt (part(c)) is as follows:

```
%<===== 1(c) ======>
mt = Am*cos(2*pi*fm*t);
```

```
phi_t = 2*fmmod(mt, fc, fs, kf*Am);

subplot(2, 1, 1);           %Plot the frequency modulated signal
plot(t, phi_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> \phi_{FM}(t)');
title('1(c) Frequency modulated signal \phi_{FM}(t)');
xlim([0 0.1]);  ylim([-3 3]);
grid on;

f = [-fs/2:fs/2-1]*df;
fftphi = fftshift(fft(phi_t))/length(phi_t);

subplot(2,1,2);
plot(f, real(fftphi), 'LineWidth', 1.7);
xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{FM}(f)');
title('1(c) Frequency spectrum of \phi_{FM}(t)');
xlim([-600 600]); ylim([-0.7 0.7]);
xticks(-800:100:800);
grid on
```

The plot of $\phi_{FM}(t)$ and its spectrum for $k_f = 100$ Hz/Volt is as follows:

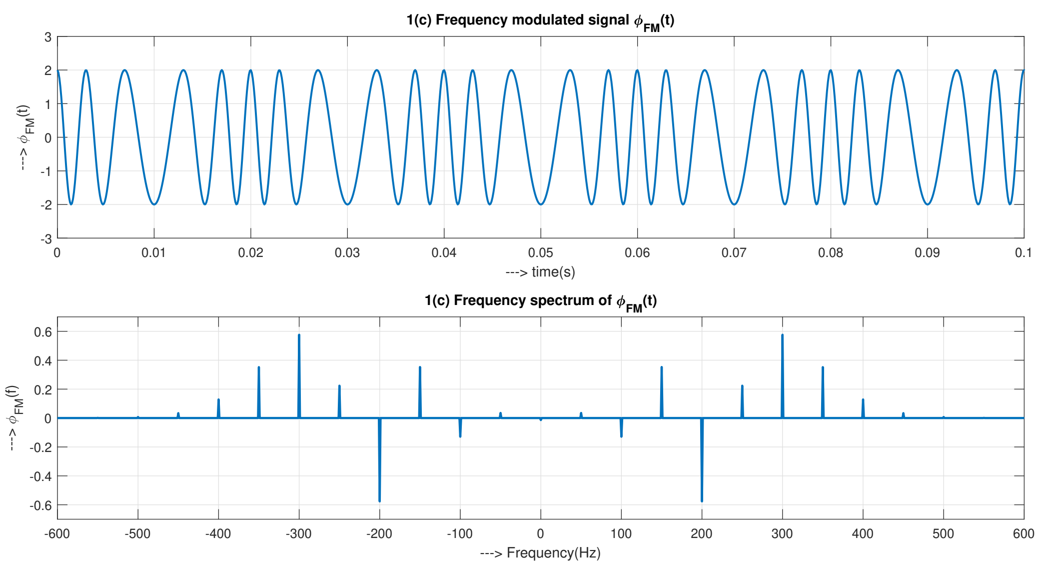

Figure 3: $\phi_{FM}(t)$ for $k_f = 100$ Hz/Volt

Here, we see that the bandwidth of the frequency modulated signal is 400 Hertz.

Theoretically, the bandwidth of the frequency modulated signal is given by $B.W. = 2(\beta + 1)f_m$ where $\beta = \frac{K_f A_m}{f_m}$ (Carson's rule). On putting the values, we get the theoretical value of bandwidth as 300 Hz.

The MATLAB code to plot $\phi_{FM}(t)$ and its frequency spectrum for various values of k_f (part(d)) is given below. We consider K_f values of 12.5, 41.66, 70.83 and 100 to for the same.

```
%<===== 1(d) ======>
kfs = [12.5 41.66 70.83 100];

```

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

    plotNo = 1;
    for i=1:4
        phi_t = Ac*fmmod(Am*cos(2*pi*fm*t), fc, fs, kfs(i)*Am);
        subplot(4,2,plotNo);
        plot(t, phi_t, 'LineWidth', 1.7);
        xlabel('---> Time(s)');    ylabel('---> \phi_{FM}(t)');
        title(sprintf('1(d) phi_{FM}(t) for k_f = %.2f', kfs(i)));
        xlim([0 0.1]);  ylim([-3 3]);
        grid on;
        plotNo = plotNo + 1;
        fftphi = fftshift(fft(phi_t))/length(phi_t);
        subplot(4,2,plotNo);
        plot(f, real(fftphi), 'LineWidth', 1.7);
        xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{FM}(f)');
        title(sprintf('1(d) Frequency spectrum of phi_{FM}(t) for k_f = %.2f', ...
            kfs(i)));
        xlim([-500 500]);
        xticks(-800:50:800);  yticks(-1:0.5:1);
        if i == 1
            ylim([-0.5 1.25]);
        elseif i == 2
            ylim([-0.5 1]);
        elseif i == 3
            ylim([-0.75 0.75]);
        else
            ylim([-1 1]);
        end
        grid on
        plotNo = plotNo + 1;
    end
```

The plot of frequency modulated signal and its spectrum for various K_f values is shown below:

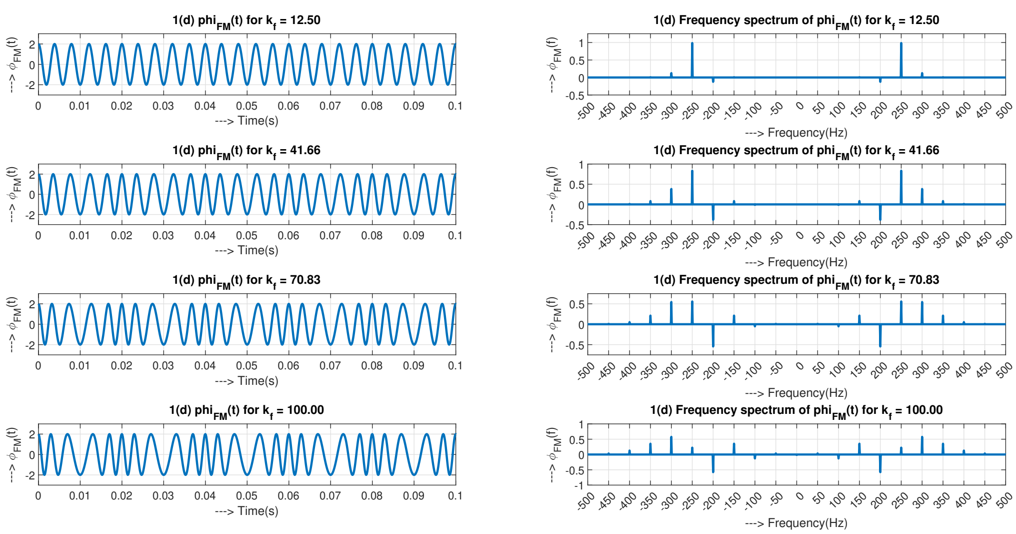

Figure 4: Frequency modulated signal for various K_f values.

Here, we see that when $K_f = 12.5$ and 41.66, the modulated signal is narrow band FM. Whereas, for $K_f = 70.83$ and 100 the signal is wide band FM.

The table given below shows the bandwidth obtained from the plots, the bandwidth according to Carlson's rule and the power of the signal for various K_f values.

Table 1: Power and bandwidth of signal for various K_f values

K_f	Power	B.W.(From plot)	B.W. (From Carlson's rule)
12.50	2.065/R	100	-
41.66	2.6889/R	200	-
70.83	2/R	300	241.66
100.00	2/R	400	300

The MATLAB code to demodulate the signal (part(e)) is shown below:

```
%<===== 1(e) ======>
mt = fmdemod(phi_t, fc, fs, kf*Am)

plot(t, mt, 'LineWidth', 1.7);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('1(e) Demodulated signal');
xlim([0 0.1]);  ylim([-2 2]);
grid on;
```

The plot of the demodulated signal is shown below:

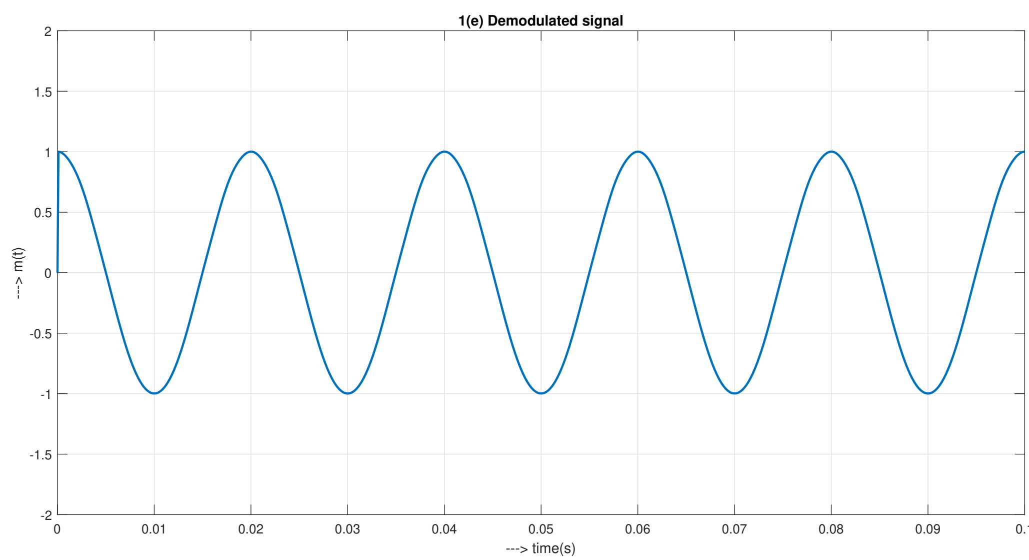

Figure 5: Demodulated signal

3.2 Question 2

First we find the message signal vector, carrier signal vector and phase modulated signal vector as follows:

```
Am = 1;         Ac = 2;      %Parameters
fm = 50;        fc = 250;
fs = 5000;      df = 1;
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
phi_t = Ac*pmmod(Am*cos(2*pi*fm*t), fc, fs, kp*Am); %PM signal
```

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

```
%<====== 2(a) ======>
subplot(2, 1, 1);           %Plot the message signal
plot(t, m_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('2(a) Message Signal: A_mcos(2\pif_mt)');
xlim([0 0.1]);  ylim([-2 2]);
grid on;

subplot(2, 1, 2);           %Plot the carrier signal
plot(t, c_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> c(t)');
title('2(a) Carrier Signal: A_ccos(2\pif_ct)');
xlim([0 0.1]);  ylim([-3 3]);
grid on;
```

The plot of m(t) for 5 complete cycles and c(t) is as follows:

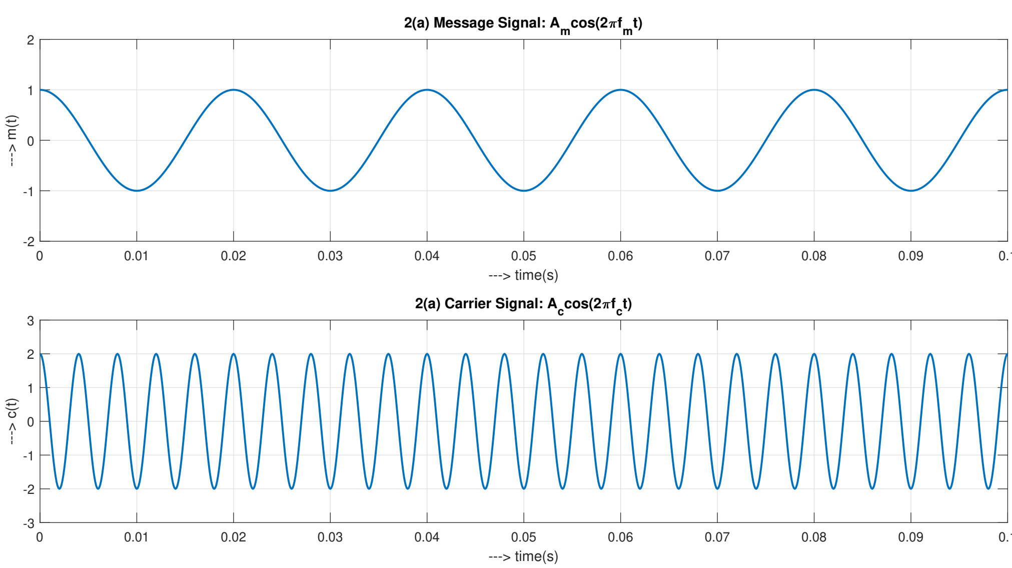

Figure 6: Message signal and carrier signal

The MATLAB code to plot $\phi_{PM}(t)$ and its frequency spectrum for $k_p = 0.25$ rad/Volt (part(b)) is as follows:

```
%<===== 2(b) ======>
subplot(2, 1, 1);            %Plot the phase modulated signal signal
plot(t, phi_t, 'LineWidth', 1.5);
xlabel('---> time(s)');    ylabel('---> \phi_{PM}(t)');
title('2(b) Phase modulated signal \phi_{PM}(t)');
xlim([0 0.1]);  ylim([-3 3]);
grid on;

f = [-fs/2:fs/2-1]*df;
fftphi = fftshift(fft(phi_t))/length(phi_t);

subplot(2,1,2);              %Plot spectrum of phase modulated signal
plot(f, real(fftphi), 'LineWidth', 1.7);
xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{PM}(f)');
title('2(b) Frequency spectrum of \phi_{PM}(t)');
xlim([-500 500]); ylim([-0.2 1.1]);
grid on
```

The plot of $\phi_{PM}(t)$ and its spectrum for $k_p = 0.25$ rad/Volt is as follows:

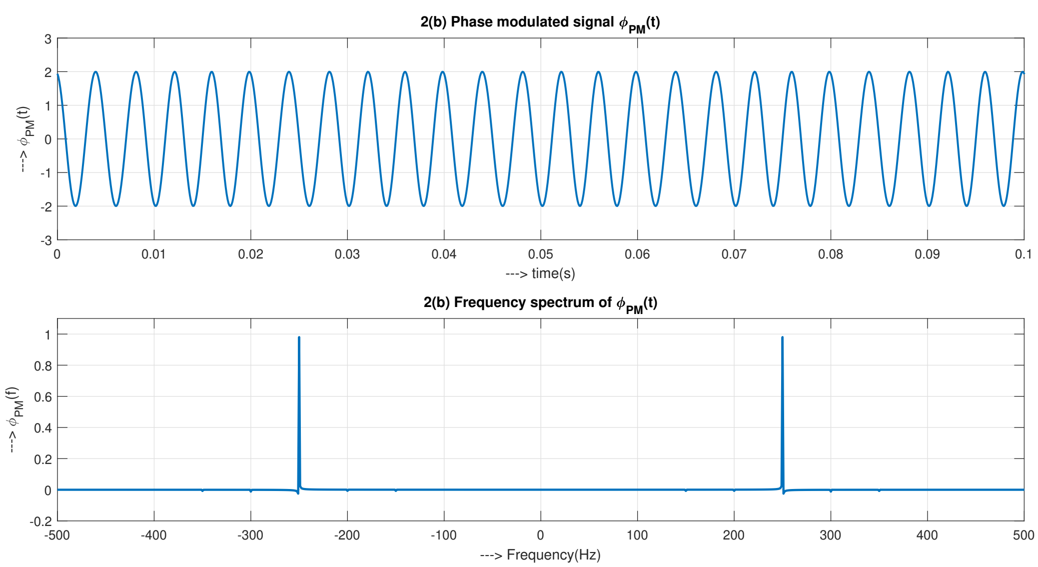

Figure 7: $\phi_{PM}(t)$ for $k_p = 0.25$ rad/Volt

Here, we see that the bandwidth of the modulated signal is 100 Hz.

The MATLAB code to plot $\phi_{PM}(t)$ and its frequency spectrum for $k_p = 2$ rad/Volt (part(c)) is as follows:

```
%<===== 2(c) ======>
phi_t = Ac*pmmod(Am*cos(2*pi*fm*t), fc, fs, kp*Am);

subplot(2, 1, 1);            %Plot the phase modulated signal
plot(t, phi_t, 'LineWidth', 1.5);
```

```
    xlabel('---> time(s)');    ylabel('---> \phi_{PM}(t)');
    title('2(c) Phase modulated signal \phi_{PM}(t)');
    xlim([0 0.1]);  ylim([-3 3]);
    grid on;

    f = [-fs/2:fs/2-1]*df;
    fftphi = fftshift(fft(phi_t))/length(phi_t);

    subplot(2,1,2);             %Plot frequency spectrum of phase modulated signal
    plot(f, real(fftphi), 'LineWidth', 1.7);
    xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{PM}(f)');
    title('2(c) Frequency spectrum of \phi_{PM}(t)');
    xlim([-500 500]); ylim([-0.4 0.4]);
    xticks(-800:50:800);       yticks(-0.5:0.1:0.5);
    grid on
```

The plot of $\phi_{PM}(t)$ and its spectrum for $k_p = 2$ rad/Volt is as follows:

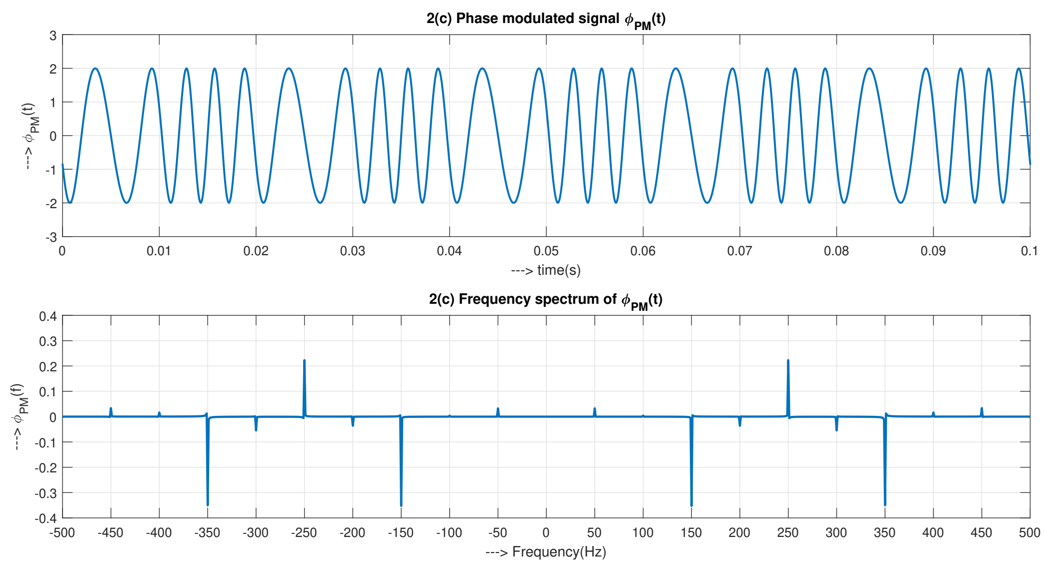

Figure 8: $\phi_{PM}(t)$ for $k_p = 2$ rad/Volt

Here, we see that the bandwidth of the modulated signal is 400 Hz. Theoretically, the bandwidth of the phase modulated signal is given by $B.W. = 2(\beta + 1)f_m$ where $\beta = K_p A_m$ (Carson's rule). On putting the values, we get the theoretical value of bandwidth as 300 Hz.

The MATLAB code to plot $\phi_{PM}(t)$ and its frequency spectrum for various values of k_p (part(d)) is given below. We consider K_p values of 0.25, 0.83, 1.42 and 2 for the same.

```
    %<===== 2(d) =====>
    kps = [0.25 0.83 1.42 2];
    f = [-fs/2:fs/2-1]*df;
    plotNo = 1;
    for i=1:4
        phi_t = Ac*pmmod(Am*cos(2*pi*fm*t), fc, fs, kps(i)*Am);
        subplot(4,2,plotNo);
        plot(t, phi_t, 'LineWidth', 1.7);
        xlabel('---> Time(s)');    ylabel('---> \phi_{PM}(t)');
```

```
        title(sprintf('2(d) phi_{PM}(t) for k_p = %.2f', kps(i)));
        xlim([0 0.1]);  ylim([-3 3]);
        grid on;
        plotNo = plotNo + 1;


        fftphi = fftshift(fft(phi_t))/length(phi_t);
        subplot(4,2,plotNo);
        plot(f, real(fftphi), 'LineWidth', 1.7);
        xlabel('---> Frequency(Hz)');    ylabel('---> \phi_{PM}(f)');
        title(sprintf('2(d) Frequency spectrum of phi_{PM}(t) for k_p = %.2f', ...
            kps(i)));
        xlim([-500 500]);
        xticks(-800:50:800);  yticks(-1:0.5:1);
        if i == 1
            ylim([-0.25 1.25]);
        elseif i == 2
            ylim([-0.25 1]);
        elseif i == 3
            ylim([-0.5 0.75]);
        else
            ylim([-0.5 0.5]);
        end
        grid on
        plotNo = plotNo + 1;
    end
```

The plot of phase modulated signal and its spectrum for various K_p values is shown below:

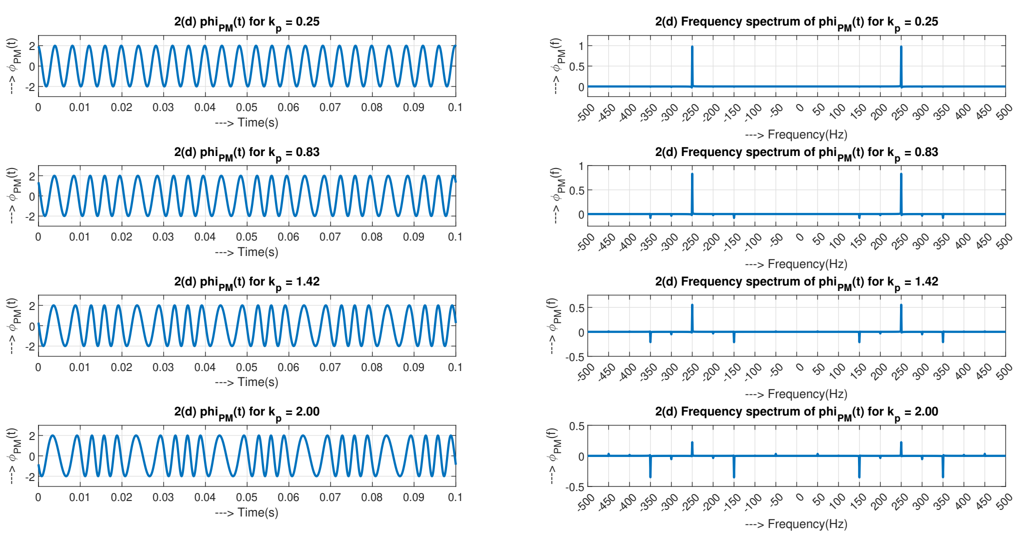

Figure 9: Phase modulated signal for various K_p values.

Here, we see that when $K_p = 0.25$ and 0.83 the modulated signal is narrow band PM. Whereas, for $K_p = 1.42$ and 2 the signal is wide band PM.

The table given below shows the bandwidth obtained from the plots, the bandwidth according to Carlson's rule and the power of the signal for various K_p values.

Table 2: Power and bandwidth of signal for various K_p values

K_p	Power	B.W.(From plot)	B.W. (From Carlson's rule)
0.25	2.065/R	100	-
0.83	2.6889/R	200	-
1.42	2/R	200	242
2.00	2/R	400	300

The MATLAB code to demodulate the signal (part(e)) is shown below:

```
%<===== 2(e) ======>
phi_t = Ac*pmmod(Am*cos(2*pi*fm*t), fc, fs, kp*Am);
mt = pmdemod(phi_t, fc, fs, kp*Am);

plot(t, mt, 'LineWidth', 1.7);
xlabel('---> time(s)');    ylabel('---> m(t)');
title('2(e) Demodulated signal');
xlim([0 0.1]);  ylim([-2 2]);
grid on;
```

The plot of the demodulated signal is shown below:

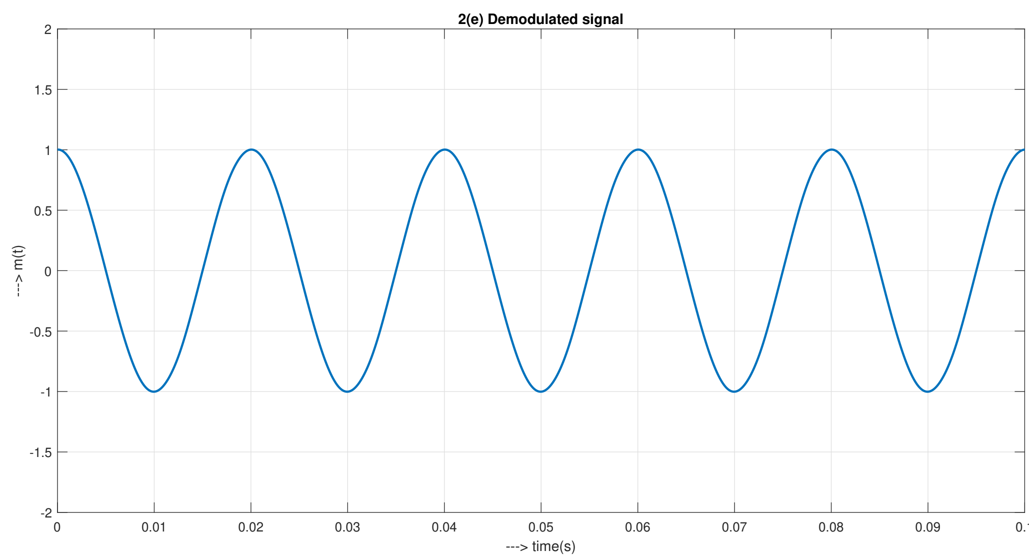

Figure 10: Demodulated signal

3.3 Question 3

The MATLAB code to plot frequency modulated and phase modulated signal for various values of k_f and k_p is shown below:

```
%<===== 3 ======>
```

```
kfs = [12.5 41.66 70.83 100];
kps = [0.25 0.83 1.42 2];
plotNo = 1
for i=1:4
    phi_ft = Ac*fmmod(Am*cos(2*pi*fm*t), fc, fs, kfs(i)*Am);
    phi_pt = Ac*pmmod(Am*cos(2*pi*fm*t), fc, fs, kps(i)*Am);
    subplot(4,2,plotNo);
    plot(t, phi_ft, 'LineWidth', 1.5);
    xlabel('---> time(s)');    ylabel('---> \phi_{FM}(t)');
    title(sprintf('3) phi_{FM}(t) for k_f = %.2f', kfs(i)));
    xlim([0 0.1]);  ylim([-3 3]);
    grid on;
    plotNo = plotNo + 1;

    subplot(4,2,plotNo);
    plot(t, phi_pt, 'LineWidth', 1.5);
    xlabel('---> time(s)');    ylabel('---> \phi_{PM}(t)');
    title(sprintf('3) phi_{PM}(t) for k_p = %.2f', kps(i)));
    xlim([0 0.1]);  ylim([-3 3]);
    grid on;
    plotNo = plotNo + 1;
end
```

The plot of various FM and PM signal is shown below:

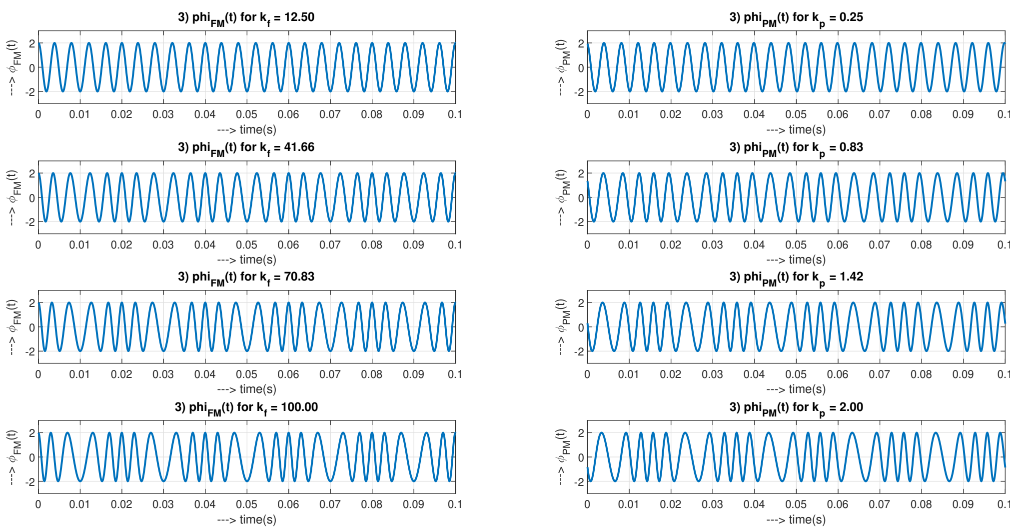

Figure 11: Frequency and phase modulated signal for various values of k_f and k_p

The plots on the left side are frequency modulated signals and those on the right side are phase modulated signals. Here, we see that the plots obtained on the left side are almost identical to those on the right side.

We can even see this similarity in the modulation index of the corresponding signals as shown below:

Table 3: Modulation index for FM and PM signal

k_f for FM signal	β for FM signal	k_p for PM signal	β for PM signal
12.50	0.25	0.25	0.25
41.66	0.83	0.83	0.83
70.83	1.42	1.42	1.42
100	2.00	2.00	2.00

4 Discussion and Conclusion

4.1 Question 1 and 2

Here, we plotted all the relevant signals and analyzed the effect of changing k_f/k_p values on the modulated signal. We also demodulated the signal to get back the original signal.

4.2 Question 3

Here we see that the plots obtained are almost identical in nature.