LAB 6

VATTIKUTI SAI ANVITH – IMT2018528

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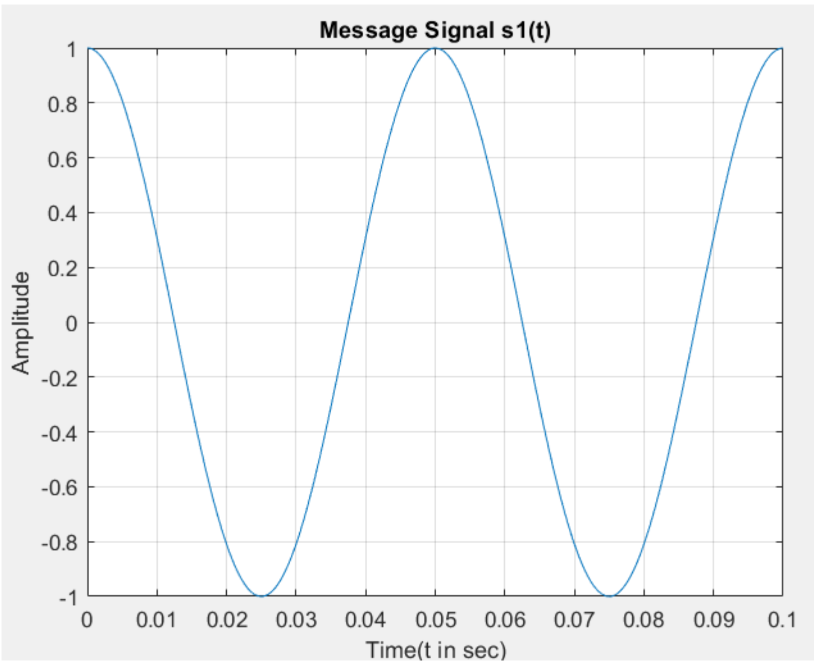
1 QUESTION 1

1. Modulation & demodulation of Frequency Modulated Signal using MATLAB.
a) Generate and plot the sinusoidal waveform $S_1(t)$ with amplitude of 1V and frequency of 20 Hz.
b) Generate and plot the sinusoidal waveform $S_2(t)$ with amplitude of 1V and frequency of 100 Hz.
c) Set the sampling frequency to 1KHz and frequency deviation sensitivity (k_f) of FM modulator as 30Hz/V. Plot the frequency modulated signal, $S_3(t)$.
d) Using Carson's rule, find the FM bandwidth.
e) Now, if frequency deviation sensitivity (k_f) is varied from 10 Hz/V to 50 Hz/V, analyze the significance of this change on power and bandwidth of the FM signal.
f) Demodulate the frequency modulated signal, $S_3(t)$ and plot it (Use k_f=30 Hz/V).
g) Analyze the effect of a frequency offset of 1 Hz, 5 Hz and 10 Hz at the receiving end on the demodulated FM signal.

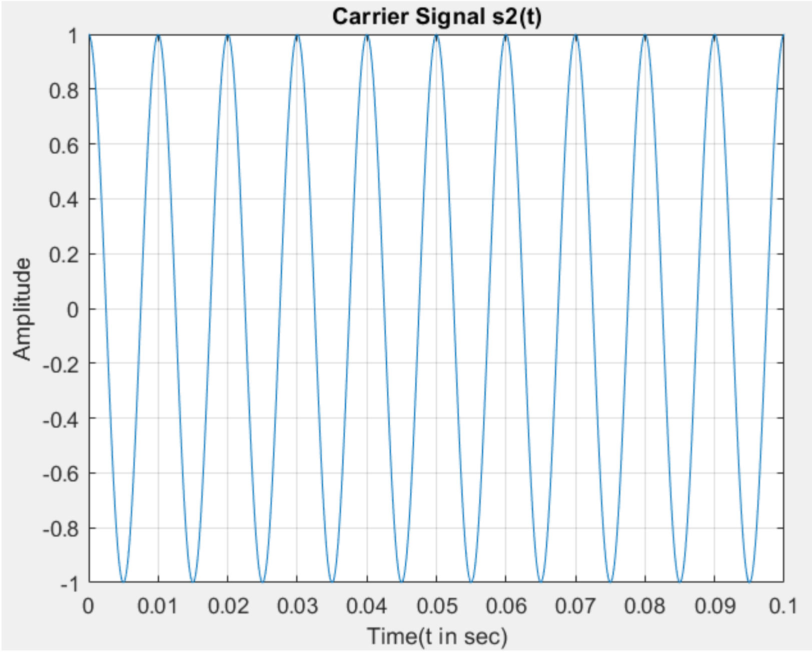
For all the plots a Sampling frequency of 10KHz is used

1.1 Plotting of message signal s1(t)



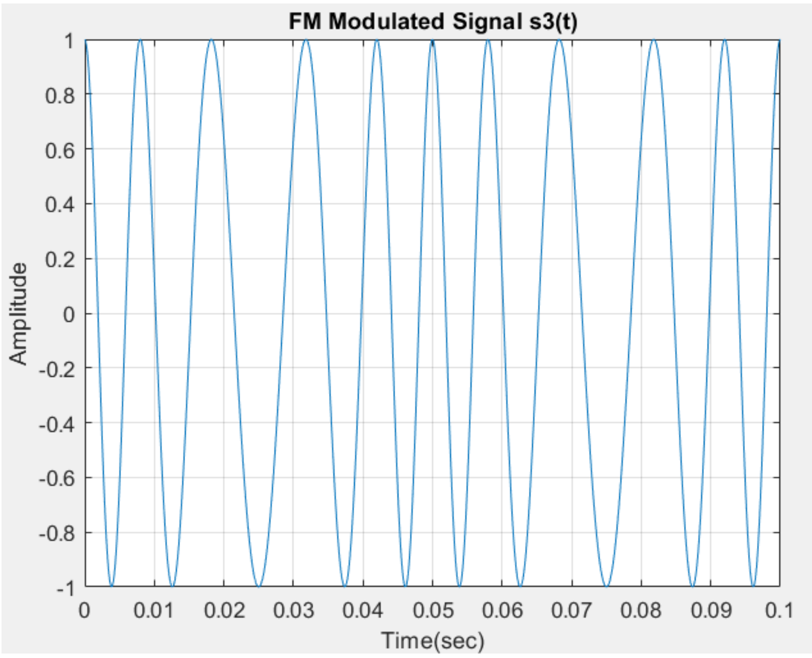
This plot shows 2 cycles of the signal s1(t) = 1*cos(2*pi*20*t).
This is a sinusoidal wave with frequency 20Hz(Time period = 0.05s). It has maximum amplitudes of +1, -1.

1.2 Plotting of carrier signal s2(t)



This plot shows 10 cycles of the signal s2(t) = cos(2*pi*100*t).
This is a sinusoidal wave with frequency 100Hz(Time period = 0.01s). It has maximum amplitudes of +1, -1.

1.3 Plotting of FM Modulated signal, s31(t)

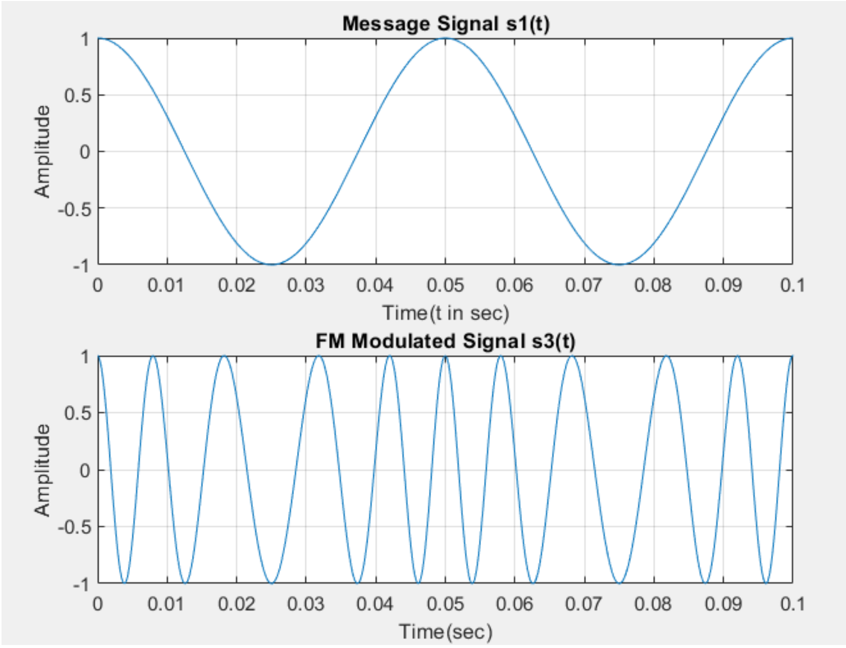


This is the plot of message signal after it is Frequency modulated.
The signal with 100Hz(s2) acts as the carrier signal.
This plot is basically also the outcome of the following equation

Modulated wave $$\varphi_{FM}(t) = A_C\left[\cos\left(\omega_C t + \frac{k_f A_m}{f_m}\sin(\omega_m t)\right)\right]$$

or $$\varphi_{FM}(t) = A_C\left[\cos(\omega_C t + \beta\sin(\omega_m t))\right]$$

1.4 Comparing FM signal with Message signal



Here we see that the Modulated signal is dense(closely packed) at the time instance where the message signal is around maximum value. It is because the the output modulated signal depends on frequency at the instance of time.

1.5 Carson's rule to find Bandwidth

Carson's rule: Add up estimates for narrowband and wideband FM

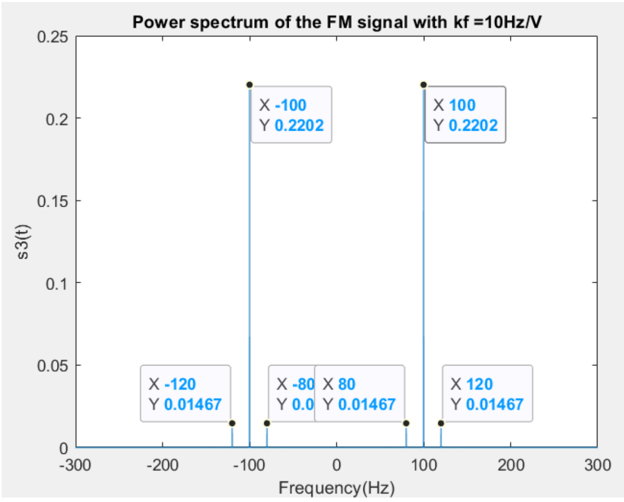
$$B_{FM} \approx 2B + 2\Delta f_{max} = 2B(\beta + 1)$$

$\beta = \Delta f_{max}/B$ **FM modulation index or deviation ratio**

As seen above,
B is the bandwidth of message signal = fm (Here given fm = 20).
Δfmax = kf*Am (Here kf is given 30Hz/V, Am = 1V)
So, solving we write Bfm = 2*20 + 2*30
=> Bfm = 100Hz
Therefore, Bandwidth of FM signal using carson's rule is found to be 100Hz.

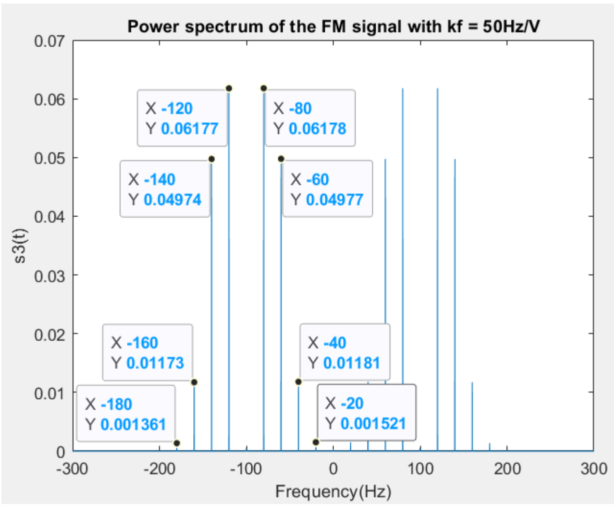
1.6 Varying frequency deviation sensitivity (kf) from 10Hz/V to 50Hz/V

1.6.1 *Using kf = 10Hz/V*

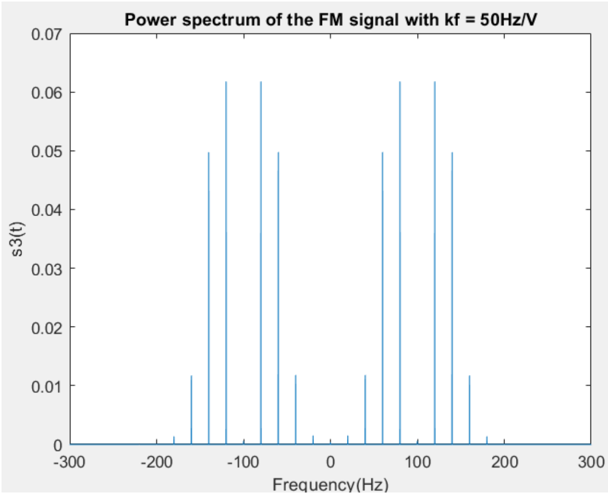


From the graph we see the total power of FM signal(sum of individual peaks) = 0.49908 watts
Using Carson's rule, Bandwidth of FM signal = 2*(20 + 10)Hz
So the bandwidth of FM signal with kf =10Hz/V is 60Hz

1.6.2 *Using kf = 50Hz/V*



A cleaner version of same plot -

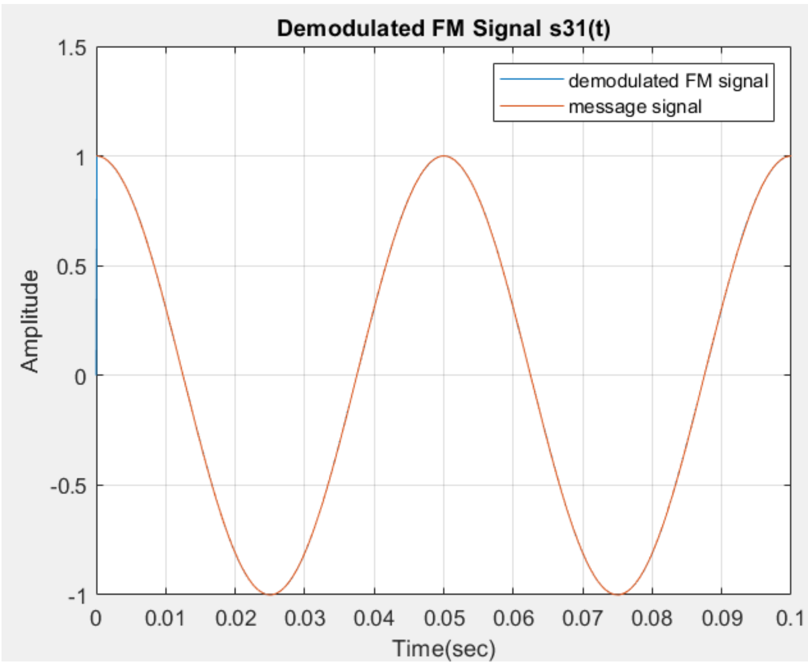


From the graph we see the total power of FM signal(sum of individual peaks) = 0.498964 watts
Using Carson's rule, Bandwidth of FM signal = 2*(20 + 50)Hz
So the bandwidth of FM signal with kf = 50Hz/V is 140Hz

1.6.3 *Observation*

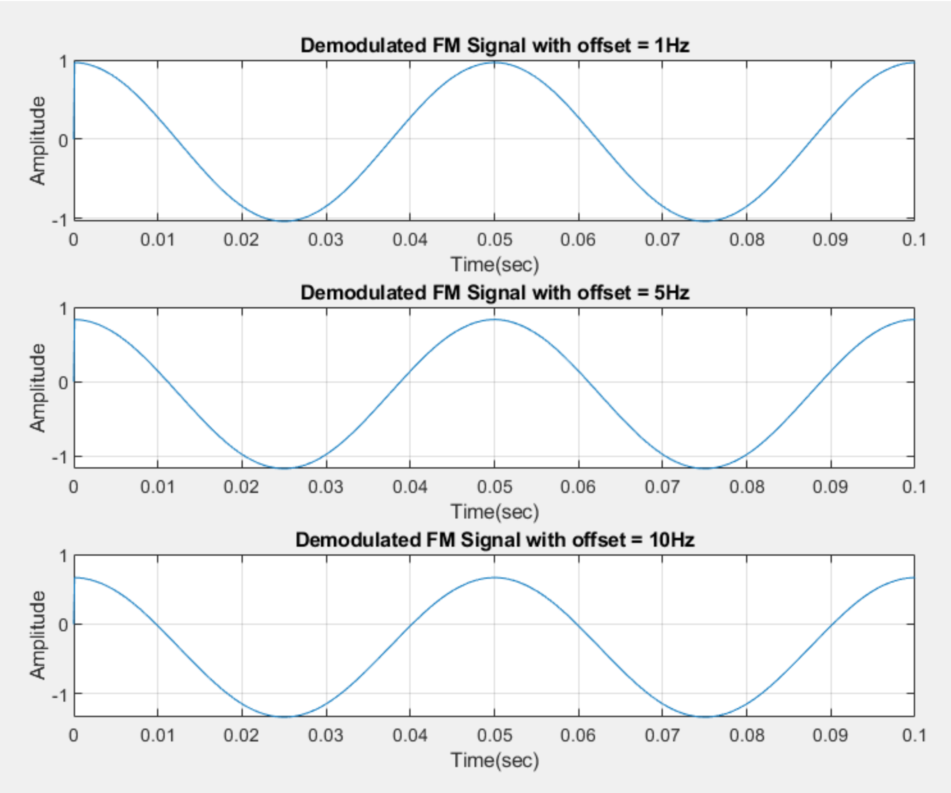
From this we observe that changing kf value doesn't have any impact on power.
Power = Am*Am/2. Am is amplitude of message signal. So this doesn't change with variation in kf.
But from Carson's rule we write, BW = 2*(fm + Ac*kf) so as kf increases, Bandwidth of FM signal also increases.

1.7 Plotting the demodulated FM signal, s31(t)



After demodulation, we get back the original message signal. This demodulated signal except the few initial milliseconds is exactly the same as the signal s1.

1.8 Effect of Frequency Offset while demodulating an FM signal



After demodulation, we get back the original message signal in all three cases. But we observe that the demodulated signal shifts down as the frequency offset increases.
From phase we write message signal as -

$$m(t) = \frac{1}{2\pi k_f} \cdot \frac{d\theta(t)}{dt}$$

So when theta changes, it is affected in the differentiation and causes addition of DC component to the final message signal. That is why we see downward shift as offset increases

1.9 Code

```
close all; clc;

fs = 10000;
kf = 30;

t = 0:1/fs:10-1/fs;

Am = 1;        fm = 20;
s1 = Am*cos(2*pi*fm*t);
Ac = 1;        fc = 100;
s2 = Ac*cos(2*pi*100*t);

s3 = fmmod(s1,fc,fs,kf*Am);
```

```
s31 = fmdemod(s3,fc,fs,kf*Am);

s3_fts =fftshift((fft(s3)));
N = length(s3_fts);
freq = -fs/2: fs/length(s3_fts): fs/2-fs/length(s3_fts);
Gn=(abs(s3_fts/N).^2);

s31_1 = fmdemod(s3,fc + 1,fs,kf*Am);
s31_5 = fmdemod(s3,fc + 5,fs,kf*Am);
s31_10 = fmdemod(s3,fc + 10,fs,kf*Am);
%% plot of s1(t)
figure
plot(t,s1)
title('Message Signal s1(t)')
xlabel('Time(t in sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of s2(t)
figure
plot(t,s2)
title('Carrier Signal s2(t)')
xlabel('Time(t in sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of FM signal, s3(t)
figure
plot(t,s3)
title('FM Modulated Signal s3(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of demodulated FM signal, s31(t)
figure
plot(t,s31)
title('Demodulated FM Signal s31(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
hold on
plot(t,s1)
hold off
legend('demodulated FM signal','message signal')
%% Plot of power spectrum of the FM signal, s3(t)
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('s3(t)')
title ('Power spectrum of the FM signal with kf = 50Hz/V')
xlim([-300 300])
%% Effect of offset in demodulation
figure
subplot(3,1,1)
```

```
plot(t,s31_1)
title('Demodulated FM Signal with offset = 1Hz')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
subplot(3,1,2)
plot(t,s31_5)
title('Demodulated FM Signal with offset = 5Hz')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
subplot(3,1,3)
plot(t,s31_10)
title('Demodulated FM Signal with offset = 10Hz')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
```

2 QUESTION 2

2. Modulation & demodulation of Phase Modulated Signal using MATLAB.

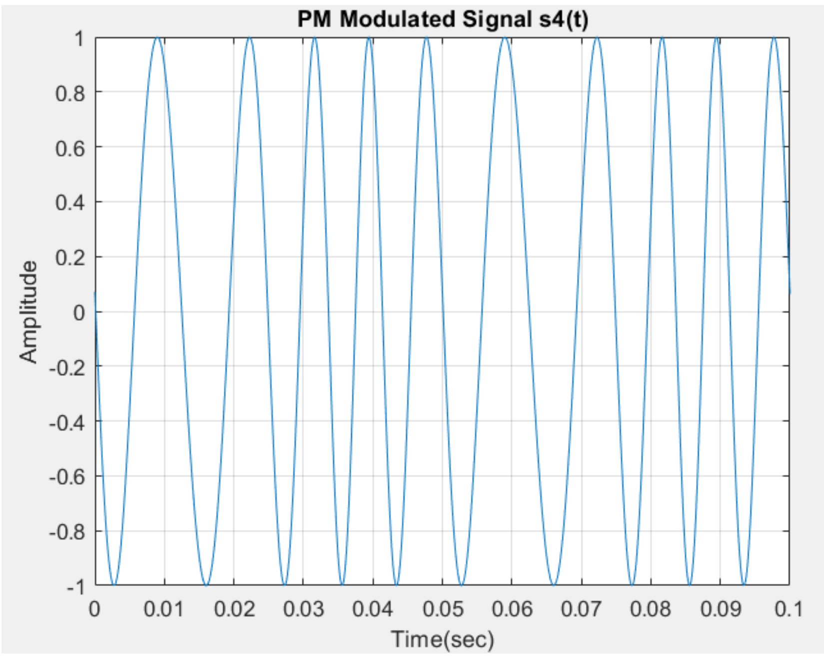
a) Set phase deviation sensitivity (k_p) to 1.5 rad/V & plot the phase modulated signal, S_4(t) using modulating signal, S_1(t) and carrier signal, S_2(t) as mentioned in part 1.

b) Demodulate the phase modulated signal, S_4(t) and plot it.

c) Using Carson's rule, find the PM bandwidth.

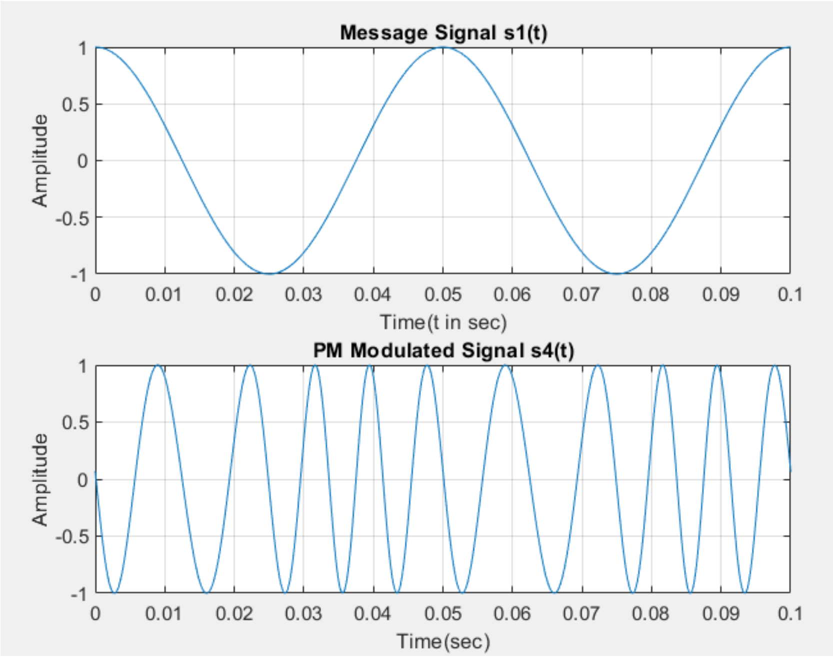
For all the plots a Sampling frequency of 10KHz is used

2.1 Plotting the Phase modulated signal s4(t)



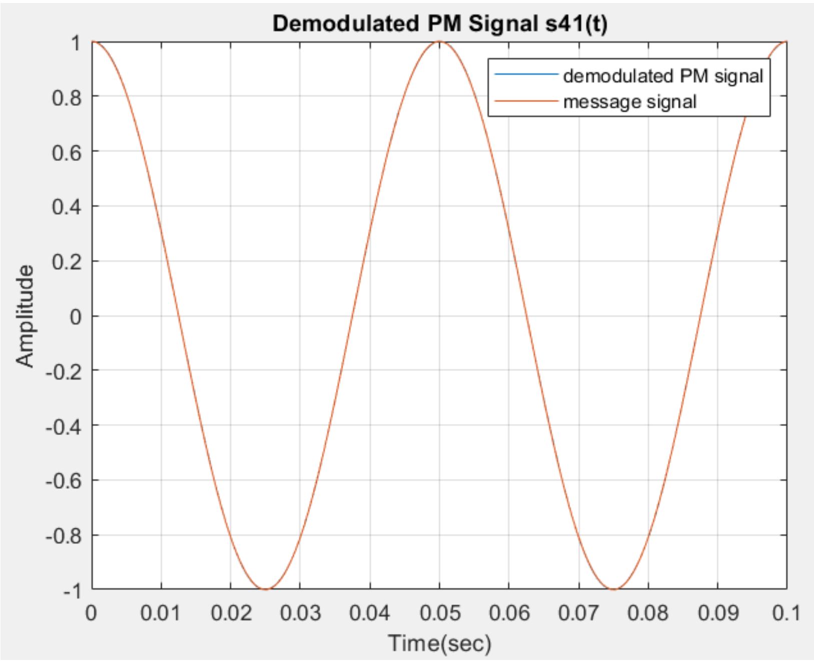
This plot is of Phase modulated signal for the message signal s1(t) = 1*cos(2*pi*20t) with carrier s2(t) = 1*cos(2*pi*100t).

2.2 Comparing PM signal with Message signal



Here we see that the Modulated signal is dense(closely packed) at the time instance where the message signal is changing its phase from negative to positive. It is because the the output modulated signal depends on phase change at the instance of time.

2.3 Plotting the demodulated output of the Phase modulated signal



After demodulation we got back the original message signal s1(t).

2.4 Bandwidth using Carson's rule

PM:

- For tone modulation: Modulation index, $b = k_p A_m$
- $BW = 2(k_p A_m + 1) f_m$

Am is amplitude of message signal
fm is frequency of message signal
Hence we write Band width of PM signal = 2*(1.5*1 + 1)*20 = 100Hz
Therefore bandwidth of PM signal is 100Hz.

2.5 Code

```
close all; clc;

fs = 10000;
kp = 1.5;

t = 0:1/fs:10-1/fs;

Am = 1;      fm = 20;
s1 = Am*cos(2*pi*fm*t);
Ac = 1;      fc = 100;
s2 = Ac*cos(2*pi*100*t);

s4 = pmmod(s1,fc,fs,kp*Am);
s41 = pmdemod(s4,fc,fs,kp*Am);
%% plot of s1(t)
figure
plot(t,s1)
title('Message Signal s1(t)')
xlabel('Time(t in sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of PM signal, s4(t)
figure
plot(t,s4)
title('PM Modulated Signal s4(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of demodulated PM signal, s41(t)
figure
plot(t,s41)
title('Demodulated PM Signal s41(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
hold on
plot(t,s1)
hold off
```

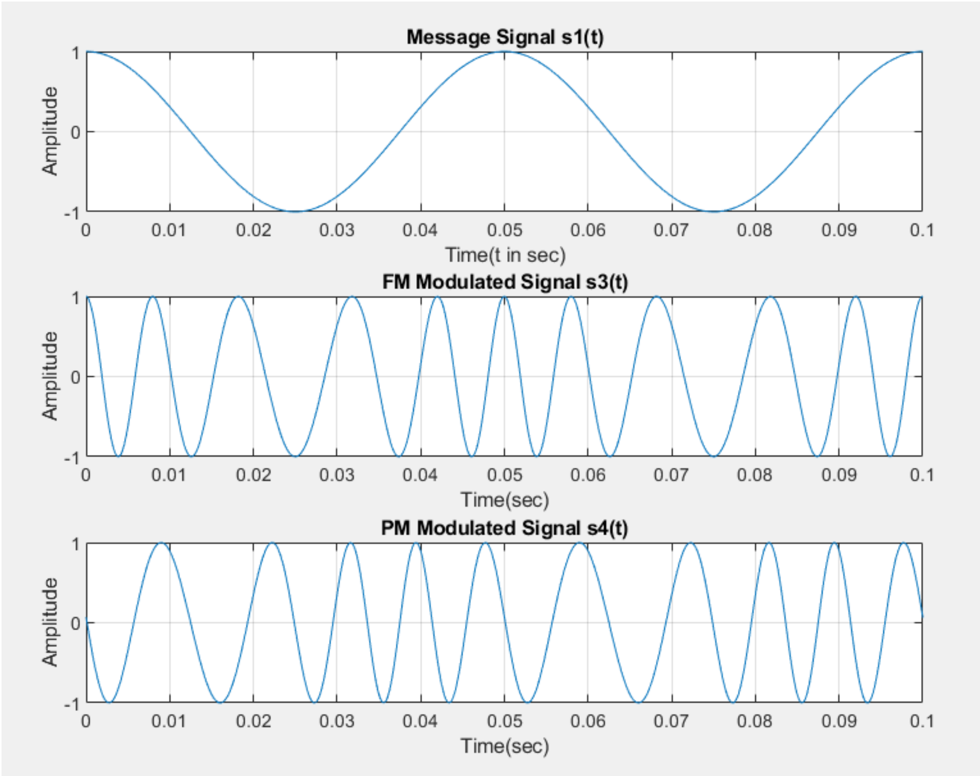
```
legend('demodulated PM signal','message signal')
```

3 QUESTION 3

3. Plot the frequency modulated signal, $S_3(t)$ and phase modulated signal, $S_4(t)$ in the same plot using subplots. Compare the two plots and write your observation.

For all the plots a Sampling frequency of 10KHz is used

3.1 Plotting both FM and AM signals along with message signal



3.2 Observations

For FM we see that the Modulated signal is dense(closely packed) at the time instance where the message signal is around maximum value. It is because the the output modulated signal depends on frequency at the instance of time.

For PM we see that the Modulated signal is dense(closely packed) at the time instance where the message signal is changing its phase from negative to positive. It is because the the output modulated signal depends on phase change at the instance of time.

Also if this is a running graph we couldn't easily say which is FM and which is PM because they vary only a little in phase.

3.3 Code

```
close all; clc;

fs = 10000;
```

```
kf = 30;
kp = 1.5;

t = 0:1/fs:10-1/fs;

Am = 1;      fm = 20;
s1 = Am*cos(2*pi*fm*t);
Ac = 1;      fc = 100;
s2 = Ac*cos(2*pi*100*t);

s3 = fmmod(s1,fc,fs,kf*Am);
s4 = pmmod(s1,fc,fs,kp*Am);

%% plot of s1(t)
figure
subplot(3,1,1)
plot(t,s1)
title('Message Signal s1(t)')
xlabel('Time(t in sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of FM signal, s3(t)
subplot(3,1,2)
plot(t,s3)
title('FM Modulated Signal s3(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
%% plot of PM signal, s4(t)
subplot(3,1,3)
plot(t,s4)
title('PM Modulated Signal s4(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
xlim([0 0.1])
grid on
```