FINAL PROJECT

PART-1

VATTIKUTI SAI ANVITH – IMT2018528

7 November 2020

CONTENTS

1 Task 2
2 Designing a receiver that can tune to one of the stations 2
2.1 Time domain plot of voice signal before being frequency modulated . 2
2.2 Time domain plot of music signal before being frequency modulated . 3
2.3 Plot of frequency modulated output after combining both the other signals . . . 3
2.4 Plotting of demodulated output with Fc = 15KHz . . . 5
2.5 Plotting of demodulated output with Fc = 25KHz . . . 5
2.6 Quality of the received signal . . . 5
3 Introducing AWGN channel between the transmitter and receiver 6
3.1 SNR = 5 . . . 6
3.2 SNR = 10 . . . 7
3.3 SNR = 15 . . . 8
4 Plotting the Power Spectra 9
4.1 Power Spectrum of the FM modulated signal at Carrier Frequency of 15KHz . . . 10
4.2 Power Spectrum of the FM modulated signal at Carrier Frequency of 25KHz . . . 10
4.3 Power Spectrum of Combined transmitted signal . . . 11
4.4 Power Spectrum of Received signal . . . 11
4.5 Power Spectrum of Received signal at SNR = 5 . . . 12
4.6 Power Spectrum of Received signal at SNR = 10 . . . 12
4.7 Power Spectrum of Received signal at SNR = 15 . . . 13
4.8 Power Spectrum of Received signal . . . 13
4.9 Power Spectrum of Received signal at SNR = 5 . . . 14
4.10 Power Spectrum of Received signal at SNR = 10 . . . 14
4.11 Power Spectrum of Received signal at SNR = 15 . . . 15
4.12 Power Spectrum after Tuning to 15KHz . . . 15
4.13 Power Spectrum after Tuning to 25KHz . . . 16
4.14 Note . . . 16
5 Mean Opinion Score (MOS) 16
6 Code 17

1 TASK

Goal of the final project to show the impact of jamming on AM and FM radios.

<u>Part I: FM Radio and Study of MOS Score (Due November 4th)</u>

Design a FM broadcast system with at least 2 independent broadcast station each with bandwidth of 10 kHz. Each must transmit an audio signal frequency modulated using carrier frequencies of 15kHz and 25 kHz. Let the modulating frequency be 2 kHz and the modulation index = 1.

1. Design a receiver that can tune to one of these stations. Comment on quality of the received signal.
2. Introduce an AWGN channel between the transmitter and receiver. Analyze the effect of SNR varying from 5 dB to 15 dB (with step size of 5) on the demodulated signal. Write your observation based on the quality of the resultant demodulated signal (both music and voice signal).
3. Plot the power spectrum of the FM modulated signal at each carrier frequency, combined transmitted signal and received signal (with and without noise). Also plot the power spectrum of signal obtained before and after tuning to the stations.

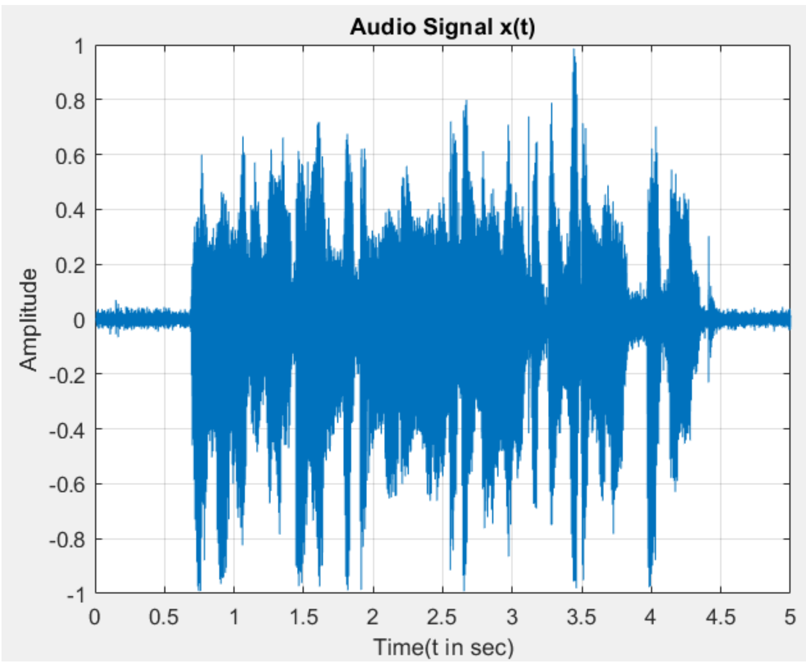
<u>Note:</u> Consider audio signal (.Wav file) for duration of 5 seconds.

<u>MOS score:</u> Write a small note on MOS and estimate the MOS of the received FM signal as SNR changes from 5 to 15 dB.

2 DESIGNING A RECEIVER THAT CAN TUNE TO ONE OF THE STATIONS

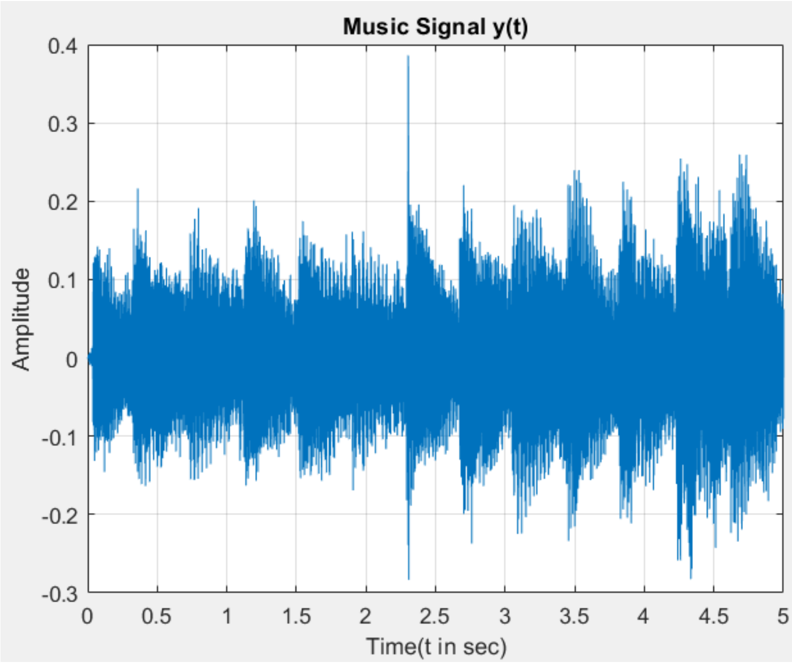
Firstly let us have a look at the signals we are modulating and trying to receive again.

2.1 Time domain plot of voice signal before being frequency modulated



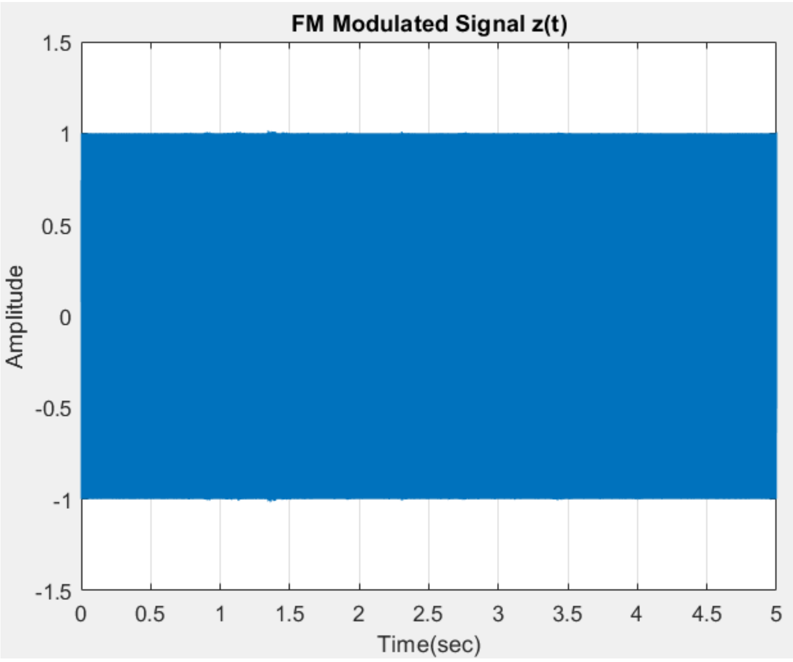
This audio is my voice saying, "My name is V Sai Anvith and my roll number is IMT2018528"

2.2 Time domain plot of music signal before being frequency modulated



This audio is an excerpt taken from the popular classic, Beethoven's Moonlight Sonata played on Piano. Here we clearly observe each note of piano in the plot as individual trapezoid blocks.

2.3 Plot of frequency modulated output after combining both the other signals



The observed plot is the output of adding FM modulated voice signal with carrier frequency at 15KHz and FM modulated music signal with carrier frequency at 25KHz.

Below is the code snippet explaining the above output

```
% changing audio length to 5sec as asked
x = x(1:5*fs);
y = y(1:5*fs);
% Increasing sampling rate
fs = 2*fs;
x = resample(x,2,1);
y = resample(y,2,1);
% soundsc(x,fs);%->to play the audio
t = (0:1/fs:(length(y)-1)/fs);

fm = 2000;
m = 1;

x1 = fmmod(x,15000,fs,m*fm);
y1 = fmmod(y,25000,fs,m*fm);

z = x1 + y1;
```

Firstly in the code we see, I limited the audio signal to 5 seconds as asked.
But the sampling frequency is too small(approximately equal) when compared with carrier frequencies. So I have doubled it.
Now we see the frequency modulated output(z) is sum of the other two modulated outputs(x1 + y1).

Now to demodulate this we simply select a carrier frequency of our choice and use fmdemod function to get the desired output.
Below is the code snippet explaining the demodulated output

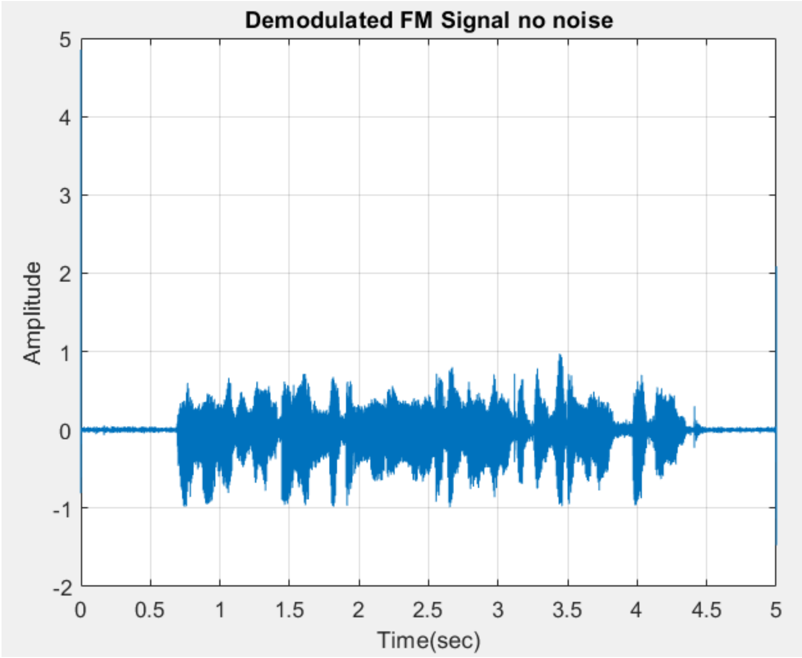
```
z = bandpass(z, [Fc-5000, Fc+5000], fs);
z_demod = fmdemod(z,Fc,fs,m*fm);
% soundsc(z_demod,fs);%->to play the audio
```

We choose a band pass filter to let only the required section be demodulated. We chose that range because in question it's given each station has bandwidth of 10KHz.
As mentioned earlier now we choose required Fc to tune to the channel.

This how we design a receiver that can tune to any one of the stations.

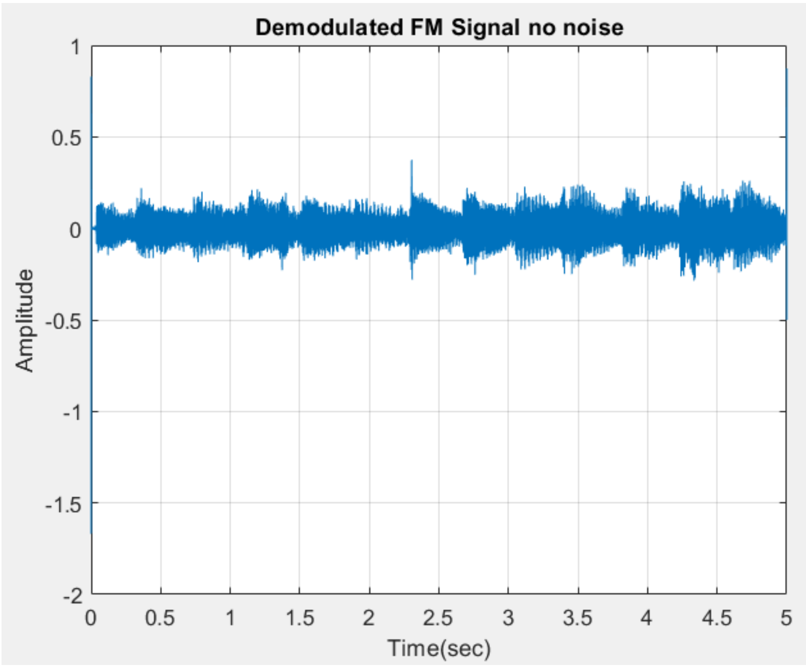
Now let's test this by choosing Fc = 15KHz, 25KHz. We expect to receive the voice signal and music signal being transmitted on that channels respectively. Let's verify that now

2.4 Plotting of demodulated output with Fc = 15KHz



This looks same like the voice signal we saw earlier.

2.5 Plotting of demodulated output with Fc = 25KHz



This looks same like the music signal we saw earlier.

2.6 Quality of the received signal

In both cases I found the quality of the received signal to be exactly the same as the original audio. I however noticed a minor decrease(not really a noticeable difference) in loudness in received signal. The voice and quality is perfect and hence I'd give an MOS of 5 for both the received audios.

3 INTRODUCING AWGN CHANNEL BETWEEN THE TRANSMITTER AND RECEIVER

Here we shall see the impact of SNR(Signal to Noise Ratio) on the output demodulated signal.

To add a noise channel between the transmitter and receiver, we write -

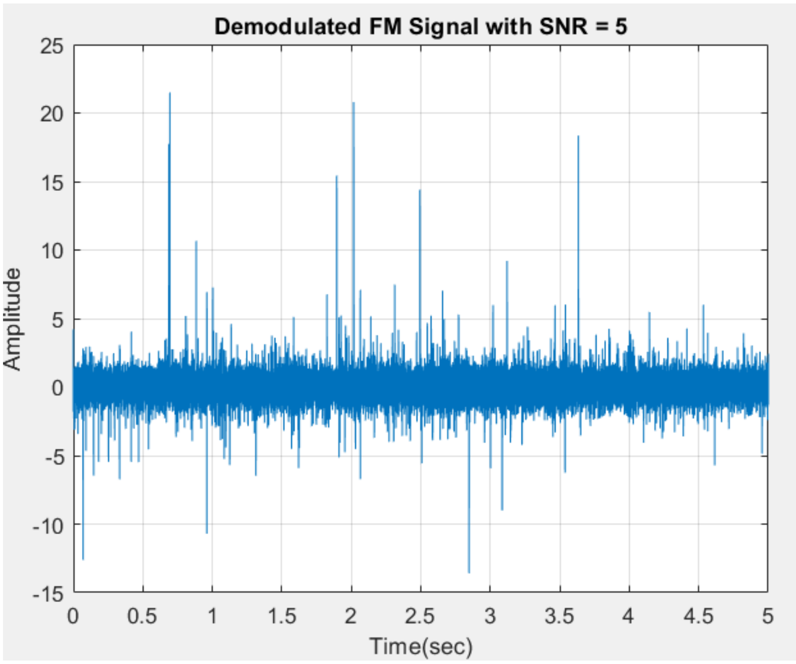
```
SNR = 5;
z_noise = awgn(z, SNR);
```

Here z is the modulated output after combining both the other signals. We then choose the desired SNR to get the output plots. In the question we are asked to use SNR = 5, 10, 15. Let's plot the outputs for the asked SNR values for both the channels and analyze the quality of output.

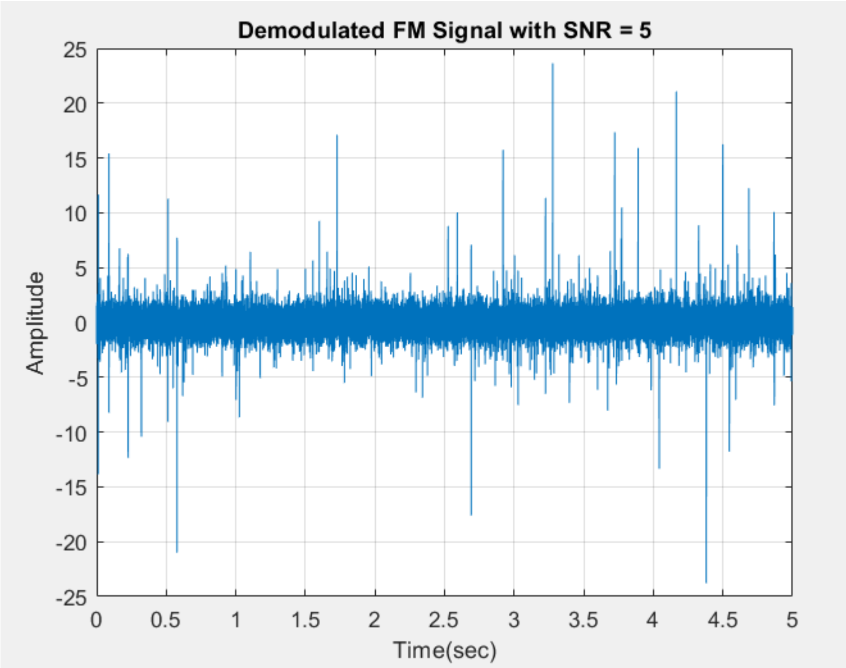
Please note that the following MOS scores are just my individual observations and I haven't considered opinion scores from anyone else.

3.1 SNR = 5

3.1.1 *Demodulated output when tuned to 15KHz frequency*



3.1.2 *Demodulated output when tuned to 25KHz frequency*

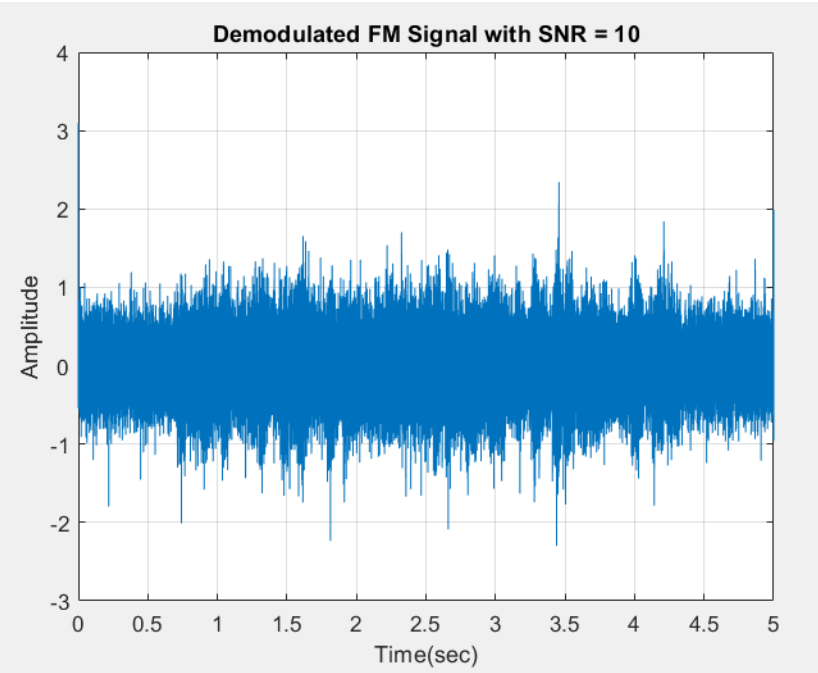


3.1.3 *Quality of received signal*

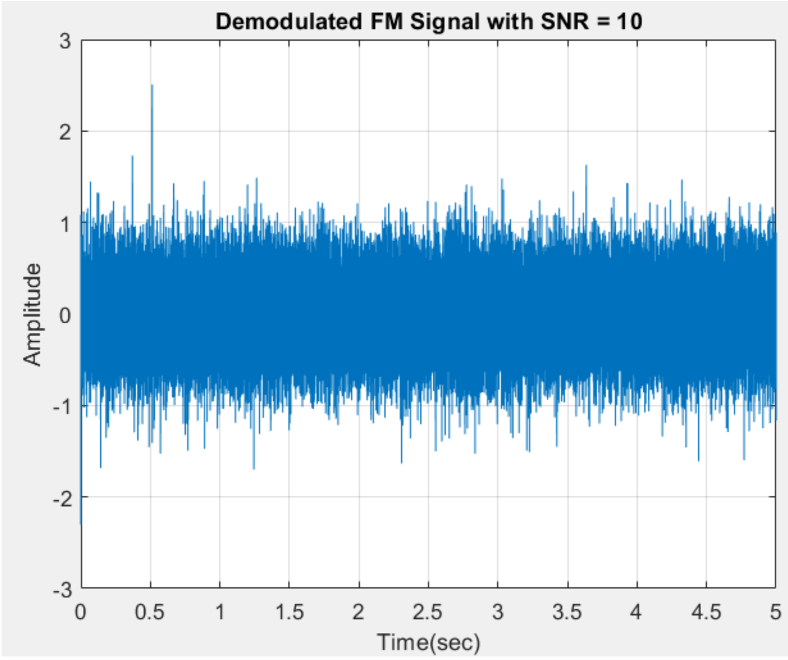
Having low SNR means having higher noise. In both the channels, I observed heavy disturbance due to the noise. Although I could barely hear the output, the noise makes it hard to understand. Hence I'd give the both outputs an MOS of 2.

3.2 SNR = 10

3.2.1 *Demodulated output when tuned to 15KHz frequency*



3.2.2 *Demodulated output when tuned to 25KHz frequency*

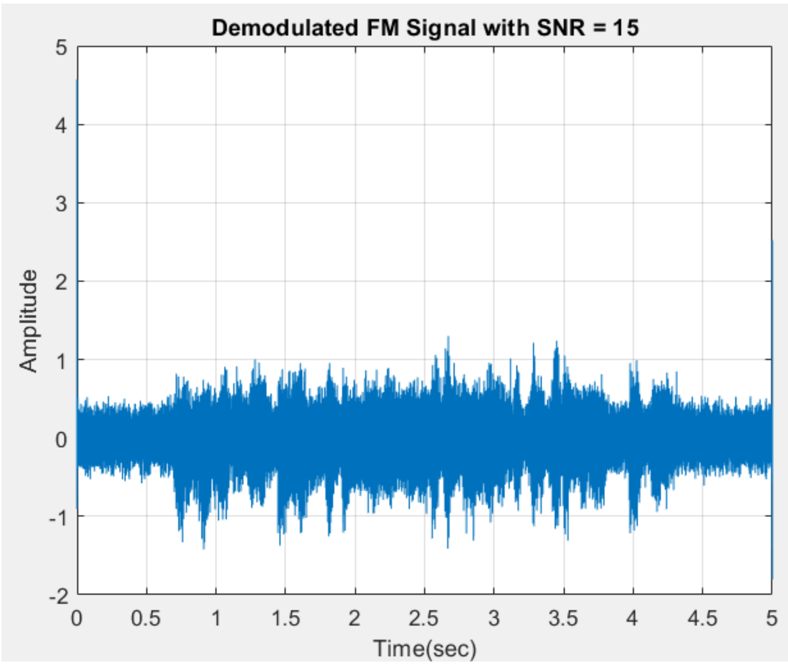


3.2.3 *Quality of received signal*

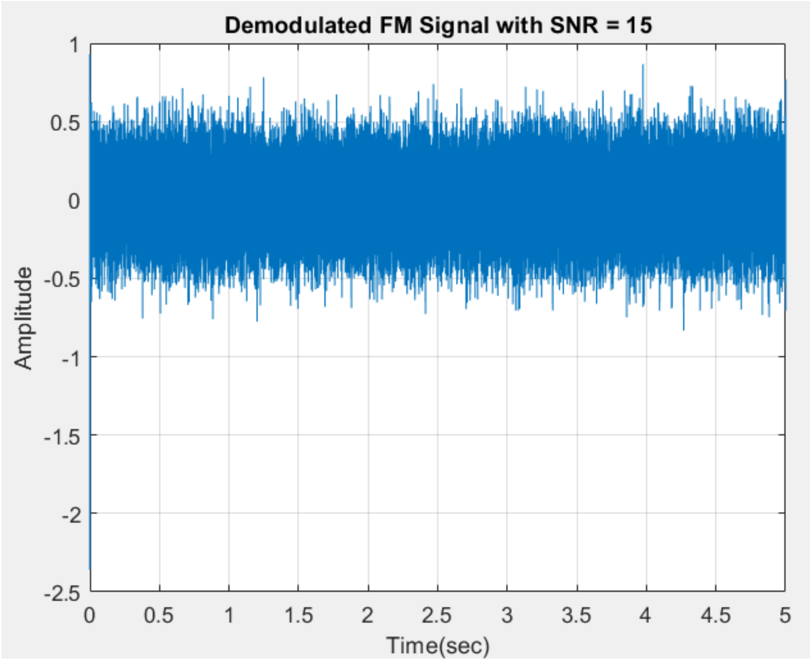
In both the channels, I observed heavy disturbance due to the noise. Unlike the earlier case, now I observed the message signal to be clear although there is continuous background noise. Also the notes of piano are more distinct from before case. Hence I'd give the both outputs an MOS of 3.

3.3 SNR = 15

3.3.1 *Demodulated output when tuned to 15KHz frequency*



3.3.2 *Demodulated output when tuned to 25KHz frequency*



3.3.3 *Quality of received signal*

In both the channels, I observed heavy disturbance due to the noise. I haven't seen any noticeable difference from earlier case. So I'd give the both outputs an MOS of 3 again as the noise is still too loud to give it a better MOS score.

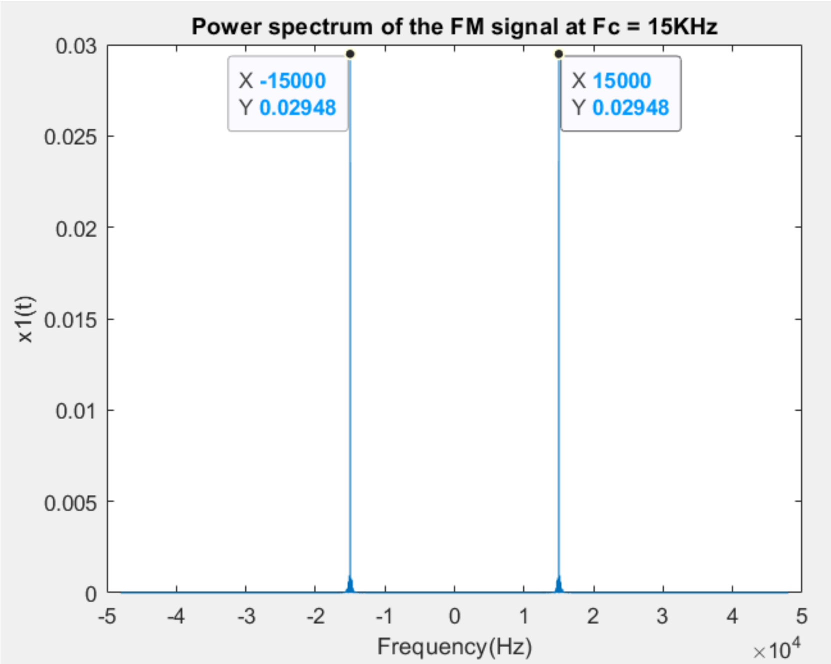
4 PLOTTING THE POWER SPECTRA

To plot the power spectra, I've written the following function code block to return me the magnitude and frequency components of the spectrum -

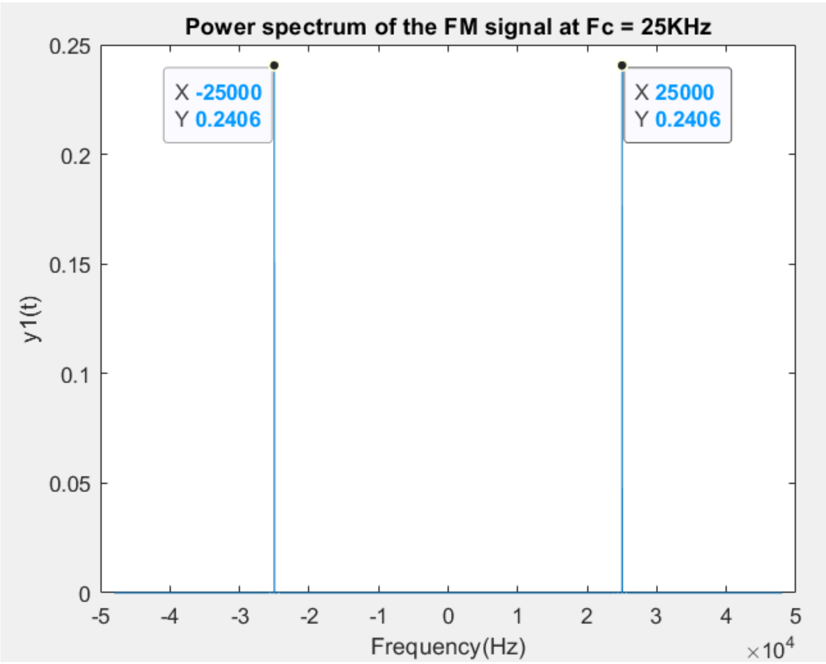
```
%% function to return power spectrum
function [freq, Gn] = powerspectrum(s3, fs)
    s3_fts =fftshift((fft(s3)));
    N = length(s3_fts);
    freq = -fs/2: fs/length(s3_fts): fs/2-fs/length(s3_fts);
    Gn=(abs(s3_fts/N).^2);
end
```

Now below are the plots asked for in the question -

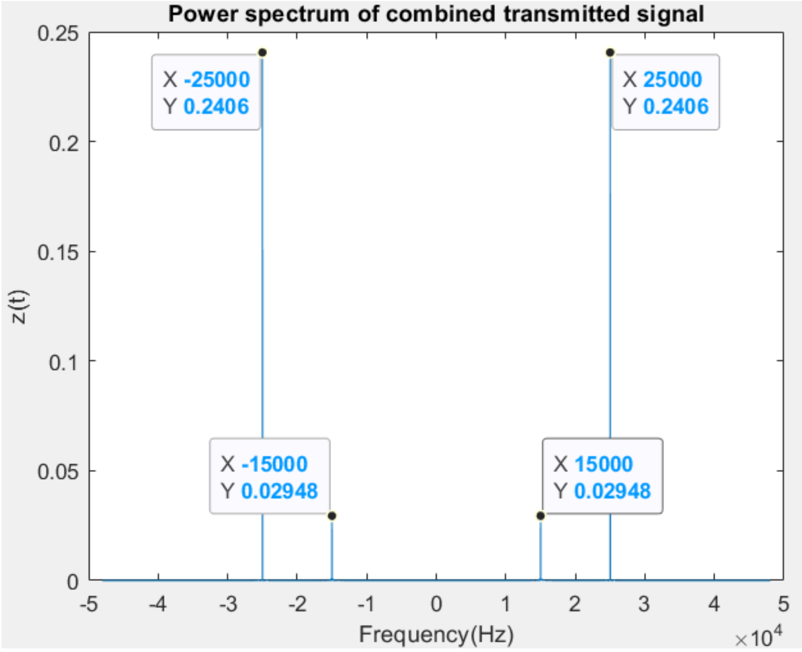
4.1 Power Spectrum of the FM modulated signal at Carrier Frequency of 15KHz



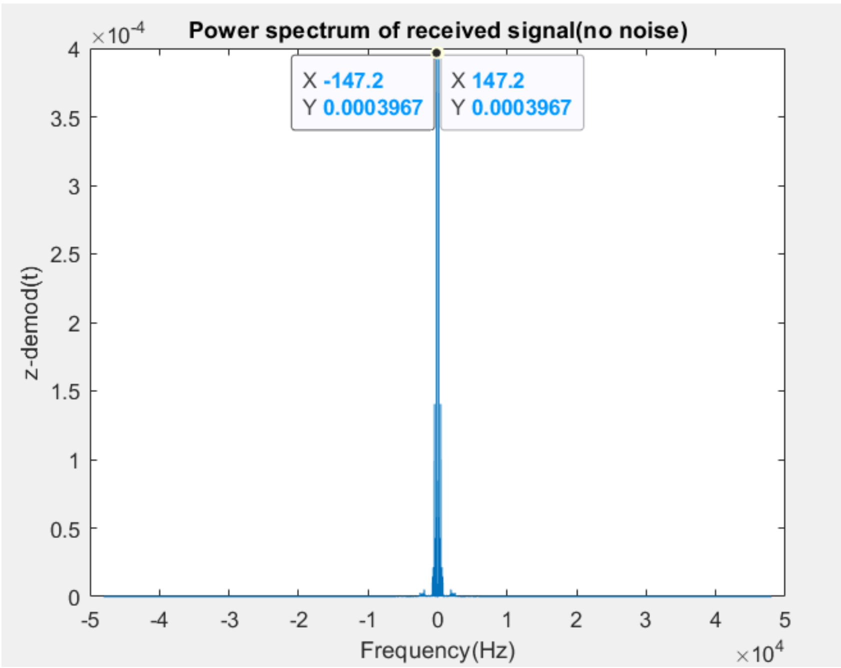
4.2 Power Spectrum of the FM modulated signal at Carrier Frequency of 25KHz



4.3 Power Spectrum of Combined transmitted signal

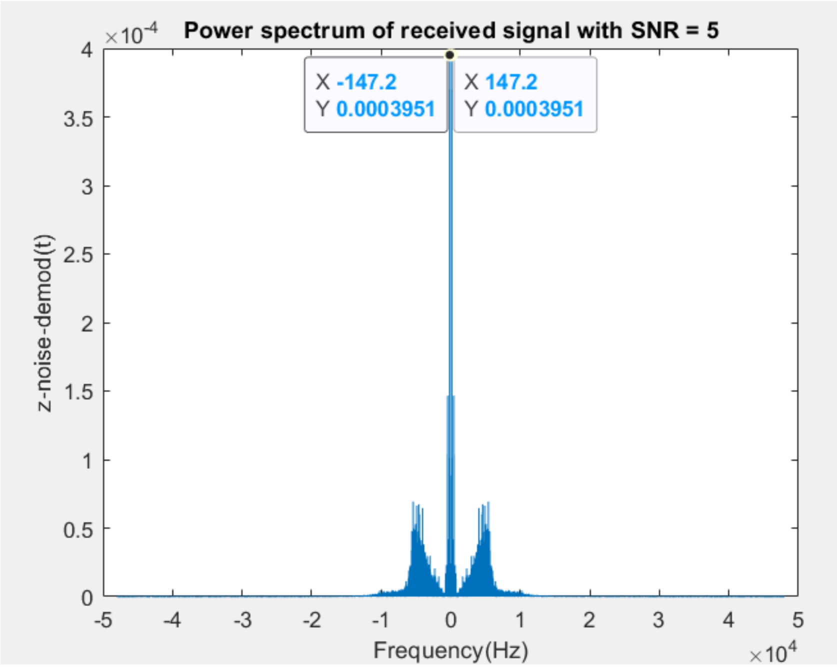


4.4 Power Spectrum of Received signal



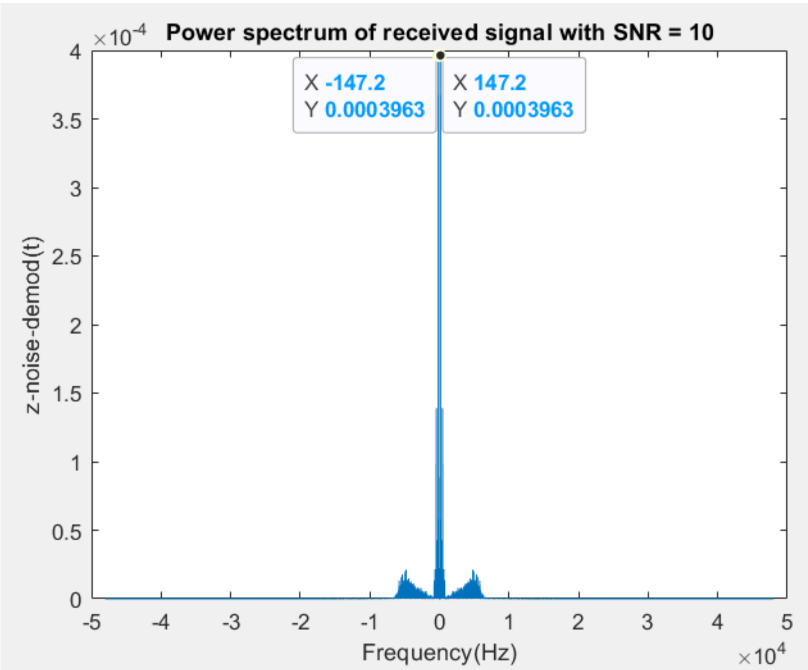
Fc = 15KHz in above case.

4.5 Power Spectrum of Received signal at SNR = 5



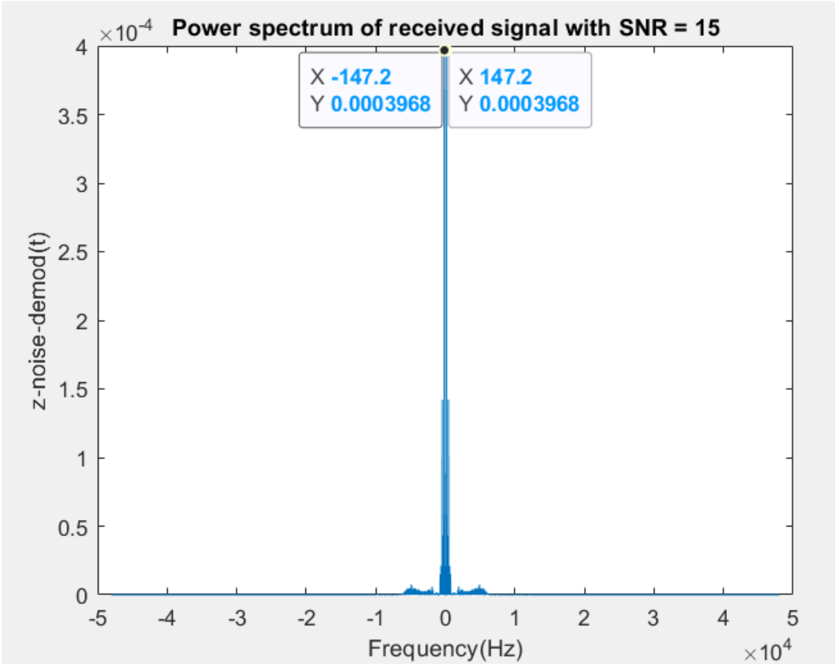
Fc = 15KHz in above case.

4.6 Power Spectrum of Received signal at SNR = 10

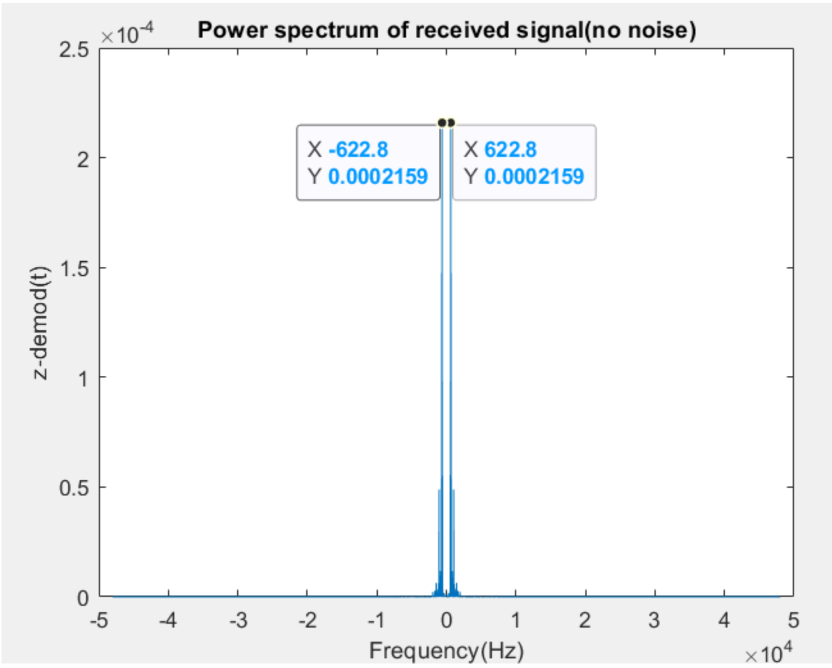


Fc = 15KHz in above case.

4.7 Power Spectrum of Received signal at SNR = 15

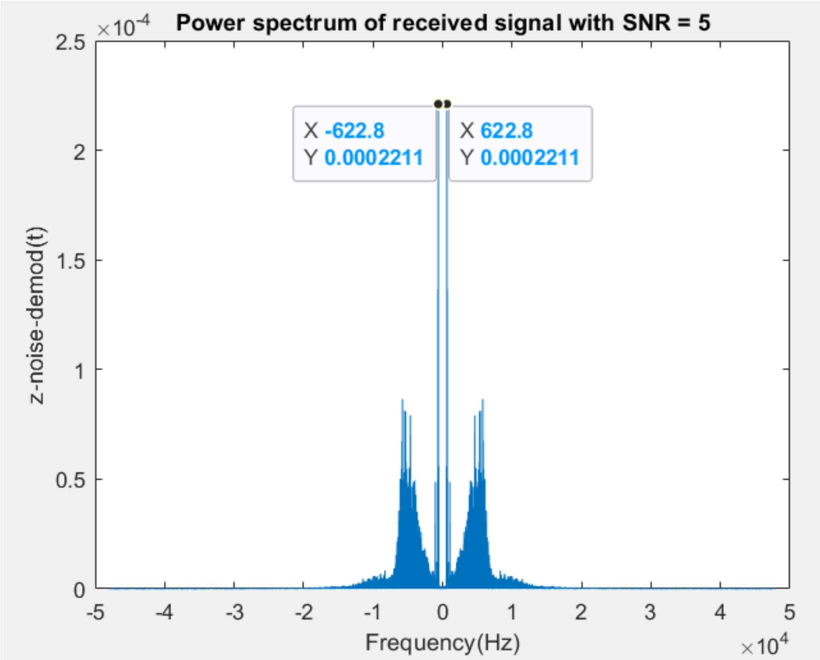


4.8 Power Spectrum of Received signal



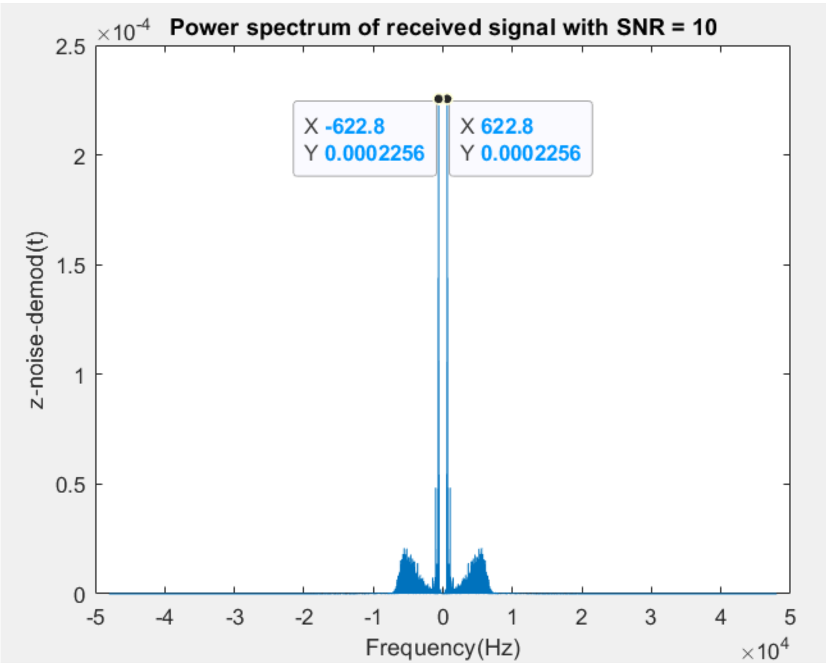
Fc = 25KHz in above case.

4.9 Power Spectrum of Received signal at SNR = 5



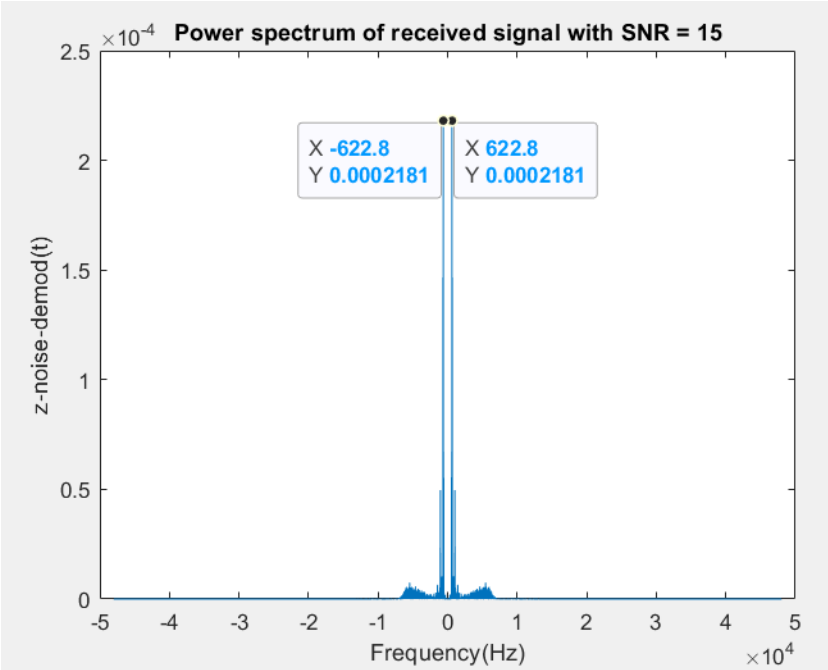
Fc = 25KHz in above case.

4.10 Power Spectrum of Received signal at SNR = 10



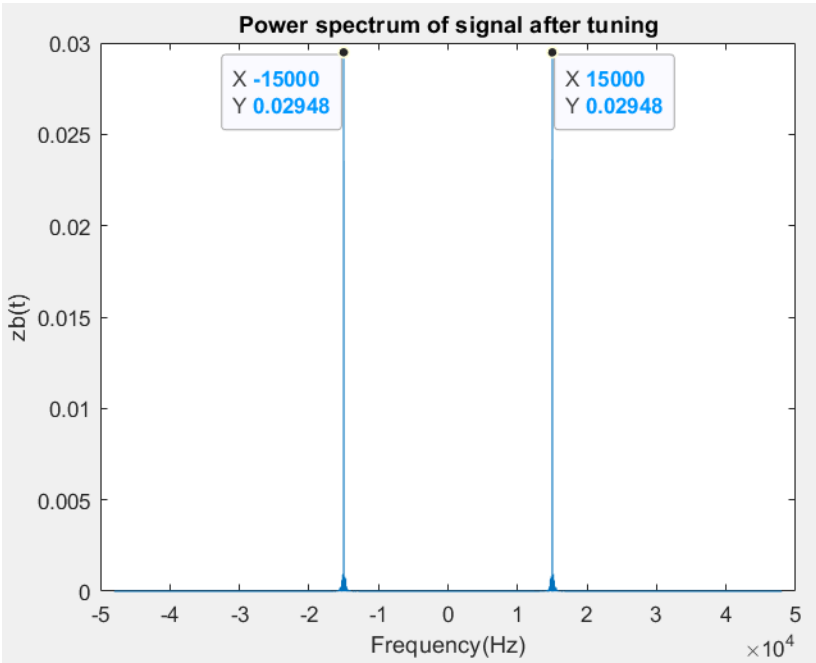
Fc = 25KHz in above case.

4.11 Power Spectrum of Received signal at SNR = 15

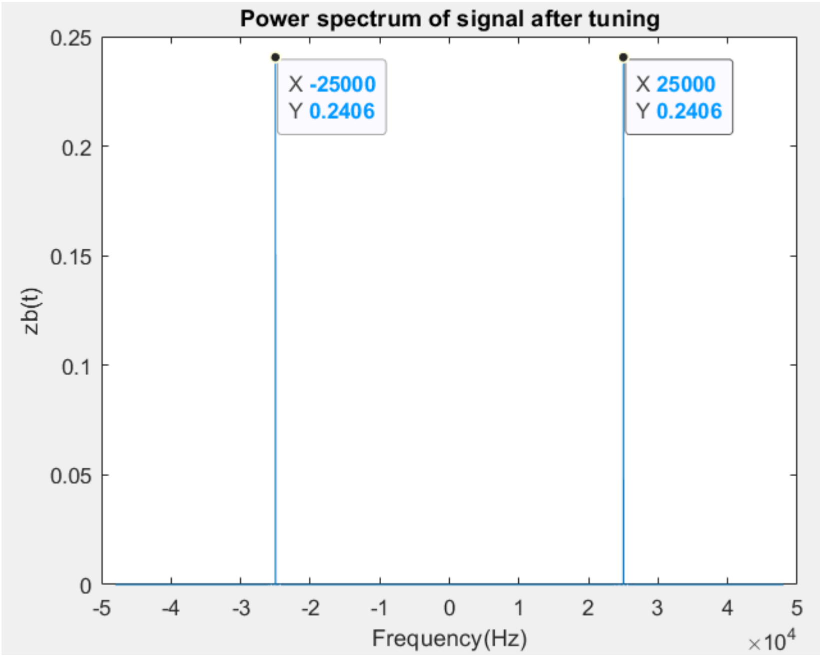


Fc = 25KHz in above case.

4.12 Power Spectrum after Tuning to 15KHz



4.13 Power Spectrum after Tuning to 25KHz



4.14 Note

The plots before tuning are not mentioned because they are the same as the plot of Combined Transmitted Signal.

The plots after tuning to specified frequency might look similar to the plots for signals at the same specified frequency. But they are not because, the FM signal in the former case mentioned here, contains overlapping parts of other channels. But in the latter case we have only pure signal. So there is a difference between both the plots.

In combined transmitted plot we see 2 impulses due to the 2 frequency carriers combination.

In plots with noise, we see the noise reduces as the SNR increases.

5 MEAN OPINION SCORE (MOS)

A Mean Opinion Score (MOS) is a numerical measure of the human-judged overall quality of an event or experience. In telecommunications, a Mean Opinion Score is a ranking of the quality of voice and video sessions.

Most often judged on a scale of 1 (bad) to 5 (excellent), Mean Opinion Scores are the average of a number of other human-scored individual parameters. Originally Mean Opinion Scores were derived from surveys of expert observers.

We can assign our own MOS scores on the given basis :
Score 5 : Same audio quality as original signal, as if without interference. Excellent
Score 4 : Some interference but audio intelligible 70 - 80 percent of the time. Good
Score 3 : Audio intelligible for greater than thirty percent of the time. Fair
Score 2 : Audio intelligible for less than thirty percent of the. Poor
Score 1 : Audio unintelligible. Bad

The MOS scores for each audio with their noise is mentioned near their respective plot diagrams.

6 CODE

```
close all; clc;

Fc = 25000; %Change this to tune to required station

[x,fs]=audioread('audio.wav');
[y,fs]=audioread('music.wav');
% All have same fs due to same recording source.
x = x(:,1);
y = y(:,1);
% changing audio length to 5sec as asked
x = x(1:5*fs);
y = y(1:5*fs);
% Increasing sampling rate
fs = 2*fs;
x = resample(x,2,1);
y = resample(y,2,1);
% soundsc(y,fs);%-->to play the audio
t = (0:1/fs:(length(y)-1)/fs);

fm = 2000;
m = 1;

x1 = fmmod(x,15000,fs,m*fm);
y1 = fmmod(y,25000,fs,m*fm);

z = x1 + y1;
SNR = 5;
z_noise = awgn(z, SNR);

zb = bandpass(z, [Fc-5000, Fc+5000], fs);
z_demod = fmdemod(zb,Fc,fs,m*fm);
% soundsc(z_demod,fs);%-->to play the audio

z_noiseb = bandpass(z_noise, [Fc-5000, Fc+5000], fs);
z_noise_demod = fmdemod(z_noiseb,Fc,fs,m*fm);
% soundsc(z_noise_demod,fs);%-->to play the audio

%% plot of audio signal x(t)
figure
plot(t,x)
title('Audio Signal x(t)')
xlabel('Time(t in sec)')
ylabel('Amplitude')
grid on
%% plot of music signal y(t)
figure
plot(t,y)
title('Music Signal y(t)')
```

```
xlabel('Time(t in sec)')
ylabel('Amplitude')
grid on
%% plot of FM signal, z(t)
figure
plot(t,z)
title('FM Modulated Signal z(t)')
xlabel('Time(sec)')
ylabel('Amplitude')
grid on
%% plot of demodulated FM signal, z_demod(t)
figure
plot(t,z_demod)
title('Demodulated FM Signal no noise')
xlabel('Time(sec)')
ylabel('Amplitude')
grid on
%% plot of demodulated noisy FM signal, z_noise_demod(t)
figure
plot(t,z_noise_demod)
title('Demodulated FM Signal with SNR = 5')
xlabel('Time(sec)')
ylabel('Amplitude')
grid on
%% plot of power spectrum at Fc = 15KHz
[freq, Gn] = powerspectrum(x1, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('x1(t)')
title ('Power spectrum of the FM signal at Fc = 15KHz')
%% plot of power spectrum at Fc = 25KHz
[freq, Gn] = powerspectrum(y1, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('y1(t)')
title ('Power spectrum of the FM signal at Fc = 25KHz')
%% plot of power spectrum of combined transmitted signal
[freq, Gn] = powerspectrum(z, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('z(t)')
title ('Power spectrum of combined transmitted signal')
%% plot of power spectrum of received signal
[freq, Gn] = powerspectrum(z_demod, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('z-demod(t)')
title ('Power spectrum of received signal(no noise)')
%% plot of power spectrum of received signal with noise
[freq, Gn] = powerspectrum(z_noise_demod, fs);
figure
plot(freq,Gn)
```

```
xlabel('Frequency(Hz)')
ylabel('z-noise-demod(t)')
title ('Power spectrum of received signal with SNR = 5')
%% plot of power spectrum of signal after tuning to station
[freq, Gn] = powerspectrum(zb, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('zb(t)')
title ('Power spectrum of signal after tuning(no noise)')
%% plot of power spectrum of signal after tuning to station with noise
[freq, Gn] = powerspectrum(z_noiseb, fs);
figure
plot(freq,Gn)
xlabel('Frequency(Hz)')
ylabel('z-noiseb(t)')
title ('Power spectrum of signal after tuning(SNR = 5)')
%% function to return power spectrum
function [freq, Gn] = powerspectrum(s3, fs)
    N = length(s3);
    s3_fts = fftshift((fft(s3)))/N;
    freq = -fs/2: fs/N: fs/2-fs/N;
    Gn = (abs(s3_fts).^2);
end
```