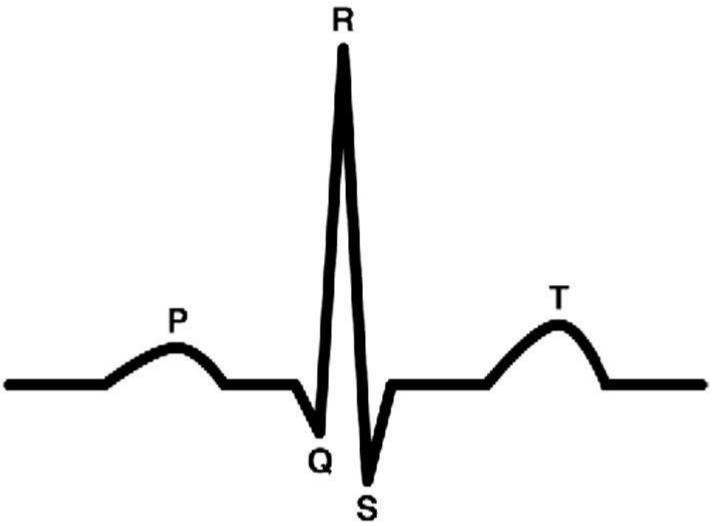
INSTITUTE OF TECHNOLOGY
NAAC ACCREDITED 'A+' GRADE

2EC502
Digital Signal Processing

Report On:
"Electrocardiography Interference Cancellation"



Group - 27
Shabbir Aglodiya - 21BEC006
Pankti Hedau – 21BEC044

ELECTROCARDIOGRAPHY INTERFERENCE CANCELLATION

ABSTRACT:

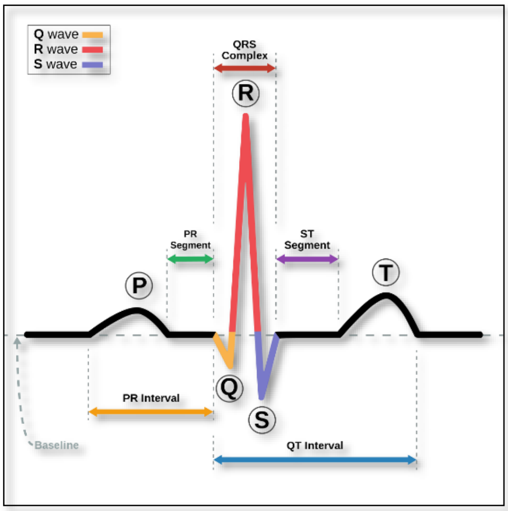
The electrocardiogram (ECG) signals contain many types of noises: Baseline wander, Powerline interference, electromyographic (EMG) noise, electrode motion artifact noise. Baseline wander is a low-frequency noise of around 0.5 to 0.6 Hz. To remove it, a high-pass filter of cut-off frequency 0.5 to 0.6 Hz can be used. Powerline interference (50 or 60 Hz noise from mains supply) can be removed by using a notch filter of 50 or 60 Hz cut-off frequency. EMG noise is a high frequency noise of above 100 Hz and hence may be removed by a low-pass filter of an appropriate cut-off frequency. Electrode motion artifacts can be suppressed by minimizing the movements made by the subject. The filter was tested with MIT-BIH arrhythmia database. This report introduces the types of common noise sources in ECG signals and simple signal processing techniques for removing them, and also presents a section of MATLAB code for the techniques described.

KEYWORDS:

ECG Signal, Baseline wander, Powerline interference, Electrode motion artifacts, EMG noise, IIR filter, FIR filter, high-pass filter, notch filter.

INTRODUCTION:

Electrocardiogram (ECG) is a signal that describes the electrical activity of the heart. The ECG signal is generated by contraction (depolarization) and relaxation (repolarization) of atrial and ventricular muscles of the heart. The ECG signal contains- a P wave (due to atrial depolarization), a QRS complex (due to atrial repolarization and ventricular depolarization) and a T wave (due to ventricular repolarization). A typical ECG signal of a normal subject is shown in (figure 1). In order to record an ECG signal, electrodes (transducers) are placed at specific positions on the human body. Artifacts (noise) are the unwanted signals that are merged with ECG signal and sometimes create obstacles for the physicians from making a true diagnosis. Hence, it is necessary to remove them from ECG signals using proper signal processing methods. There are mainly four types of artifacts encountered in ECG signals: baseline wander, powerline interference, EMG noise and electrode motion artifacts. They are discussed briefly below.



BASELINE WANDER:

Baseline wander or baseline drift is the effect where the base axis (x-axis) of a signal appears to ‘wander’ or move up and down rather than be straight. This causes the entire signal to shift from its normal base. In ECG signal, the baseline wander is caused due to improper electrodes, patient’s movement and breathing (respiration). Figure 1 shows a typical ECG signal affected by baseline wander. The frequency content of the baseline wander is in the range of 0.5 Hz. However, increased movement of the body during exercise or stress test increase the frequency content of baseline wander. Since the baseline signal is a low frequency signal therefore Finite Impulse Response (FIR) high-pass zero phase forward-backward filtering with a cut-off frequency of 0.5 Hz to estimate and remove the baseline in the ECG signal can be used.

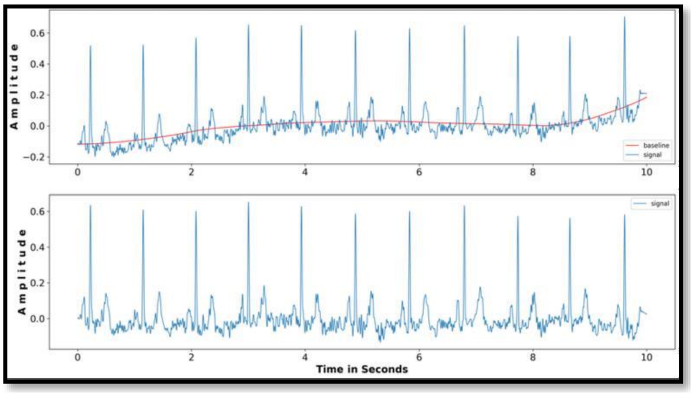


Figure i. ECG signal with Baseline Wander Noise(above) & without baseline wander noise(below).

POWERLINE INTERFERENCE:

Electromagnetic fields caused by a powerline represent a common noise source in the ECG, as well as to any other bioelectrical signal recorded from the body surface. Such noise is characterized by 50 or 60 Hz sinusoidal interference, possibly accompanied by a number of harmonics. Such narrowband noise renders the analysis and interpretation of the ECG more difficult. It is necessary to remove powerline interference from ECG signals as it completely superimposes the low frequency ECG waves like P wave and T wave. (Figure 2) shows an ECG signal typically affected by a powerline interference. So, to remove the power line interference, we can design a notch filter however it removes the noise at specific frequencies. We will design notch filter with cut-off frequency of 50Hz or 60Hz which will remove the noise.

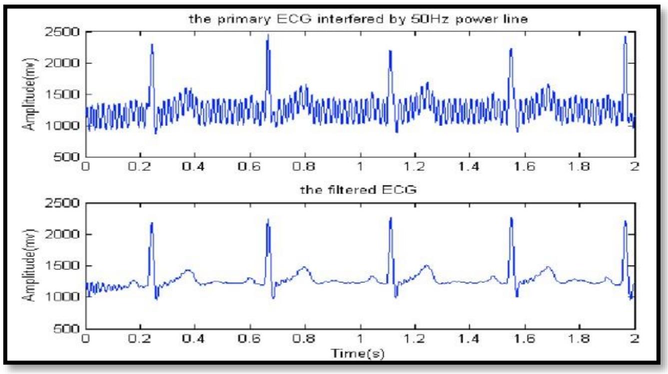


Figure ii. ECG signal with Powerline Interference (above) & without Powerline Interference (below).

EMG NOISE:

The presence of muscle noise represents a major problem in many ECG applications, especially in recordings acquired during exercise, since low amplitude waveforms may become completely obscured. Muscle noise is, in contrast to baseline wander and 50/60 Hz interference, not removed by narrowband filtering, but presents a much more difficult filtering problem since the spectral content of muscle activity considerably overlaps that of the PQRST complex. Since the ECG is a repetitive signal, techniques can be used to reduce muscle noise in a way similar to the processing of evoked potentials. Successful noise reduction by ensemble averaging is, however, restricted to one particular QRS morphology at a time and requires that several beats be available. Hence, there is still a need to develop signal processing techniques which can reduce the influence of muscle noise. Figure (3) shows an ECG signal interfered by an EMG noise.

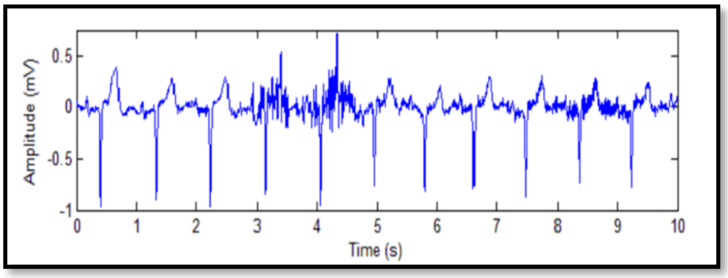


Figure iii. ECG signal with EMG Noise.

ELECTRODE MOTION ARTIFACTS:

Electrode motion artifacts are mainly caused by skin stretching which alters the impedance of the skin around the electrode. Motion artifacts resemble the signal characteristics of baseline wander, but are more problematic to combat since their spectral content considerably overlaps that of the PQRST complex. They occur mainly in the range from 1 to 10 Hz. In the ECG, these artifacts are manifested as large-amplitude waveforms which are sometimes mistaken for QRS complexes. Electrode motion artifacts are particularly troublesome in the context of ambulatory ECG monitoring where they constitute the main source of falsely detected heartbeats. A typical ECG signal affected by electrode motion artifact is shown in figure (4).

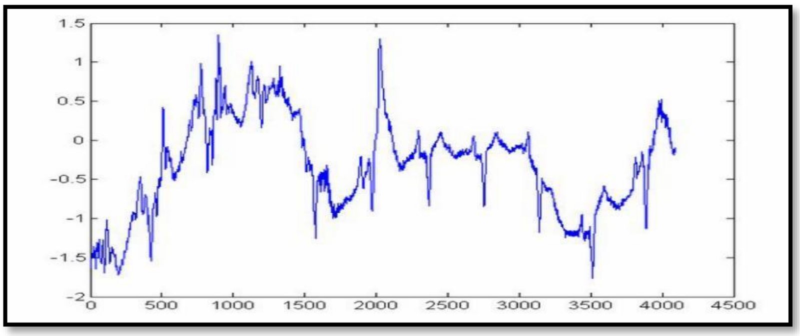
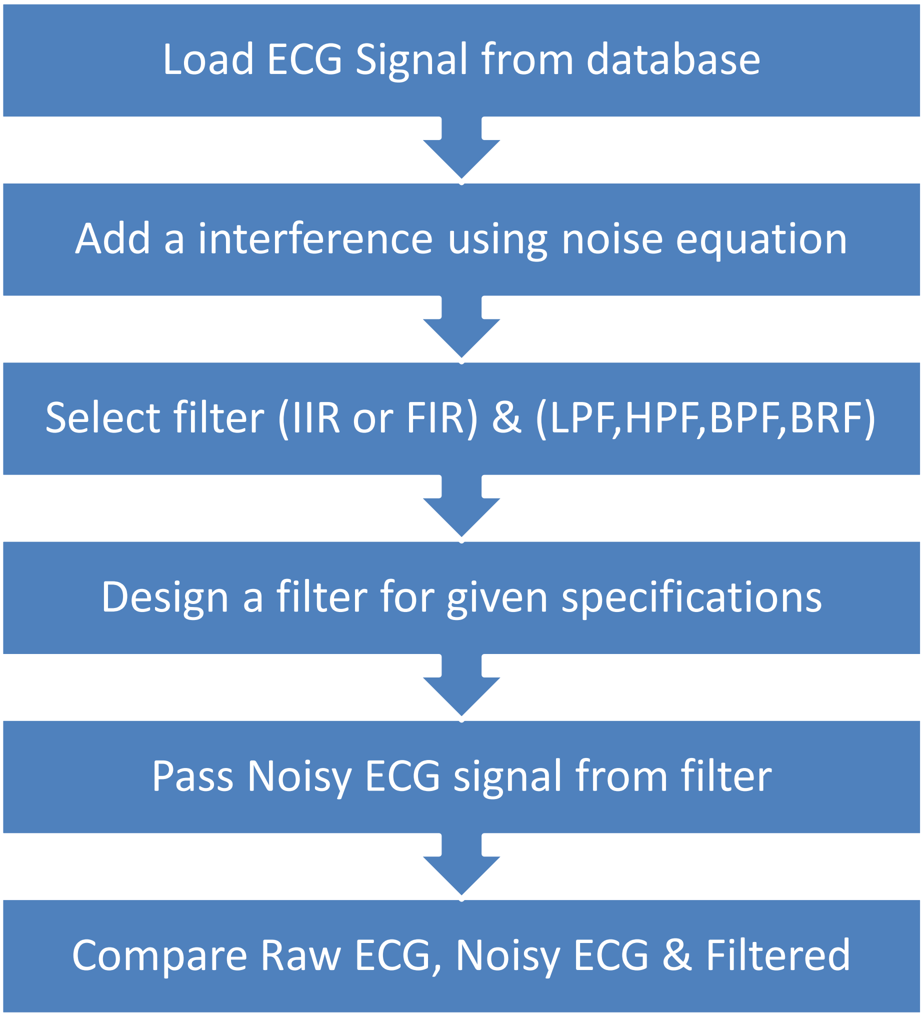


Figure iv. ECG signal with Electrode Motion Artifacts Interference

PROBLEM STATEMENT:

The problem of ECG interference cancellation revolves around the development and implementation of effective techniques and algorithms to remove unwanted interference from ECG signals. The primary challenges to be addressed include: Noise Types: Identification and characterization of the various types of interference commonly encountered in ECG signals, such as baseline wander (0.5-0.6Hz), powerline noise (50/60 Hz), electromyographic (EMG) artifacts, electrode motion artifacts(1-10Hz), etc.

FLOW CHART:



REMOVAL OF POWERLINE INTERFERENCE:

Power line interference is modeled as sinusoids. Characteristics of model include the amplitude and frequency content of the signal. The amplitude can vary up to 50 percent of the peak to peak of ECG signal. We have modelled noise by the equation below,

$$\boxed{N(t) = 0.1\cos(2\pi f_1 t)}$$

Where f1 is the frequency of power line interference.

Now we will see 2 methods to eliminate the noise

- Using IIR Notch Filter
- Using FIR Notch Filter
- Using FIR Notch using Hamming Window

Here we will design a notch filter with the given specifications:

Notch Frequency (F1) = 50 Hz / 60Hz
3 dB Bandwidth = ±5 Hz
Sampling Frequency (Fs) = 360 Hz (Given in .info file)

By using relation of analog and digital frequency,

$$\boxed{F = \frac{w}{\pi} \times \frac{F_s}{2}}$$

For 50Hz,

Digital Notch Frequency = $w_o = 0.278\pi$
Digital 3 dB Bandwidth = $\Delta w = 0.0278\pi$

F = 60Hz,
Digital Notch Frequency = $w_o = 0.333\pi$
Digital 3 dB Bandwidth = $\Delta w = 0.0278\pi$

IIR NOTCH FILTER DESIGNING:

Generalized Equation for 2nd Order IIR Notch Filter,

$$\boxed{H(e^{jw}) = \frac{1+\alpha}{2}\left(\frac{1 - 2\beta z^{-1} + z^{-2}}{1 - \beta(1+\alpha)z^{-1} + \alpha z^{-2}}\right)}$$

$$\beta = \cos(w_o)$$

$$cos(\Delta w) = \frac{2\alpha}{1 + \alpha^2}$$

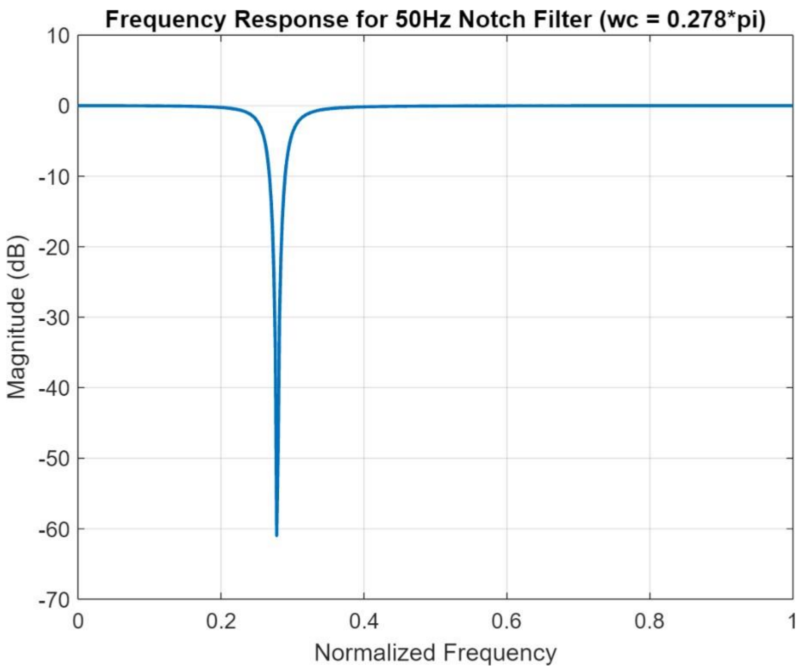
For F = 50Hz,

Digital Notch Frequency = $w_o = 0.278\pi$
Digital 3 dB Bandwidth = $\Delta w = 0.0278\pi$

By substituting values in above eq.

$$\beta = 0.6422$$
$$\alpha = 0.914$$

$$\boxed{H(e^{jw}) = 0.957\left(\frac{1 - 1.2844z^{-1} + z^{-2}}{1 - 1.2291z^{-1} + 0.914z^{-2}}\right)}$$



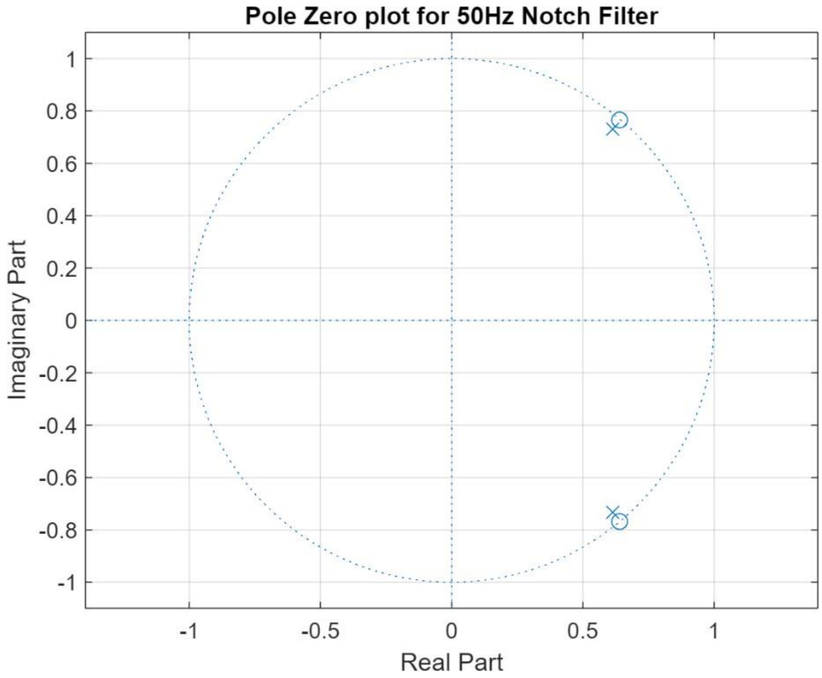


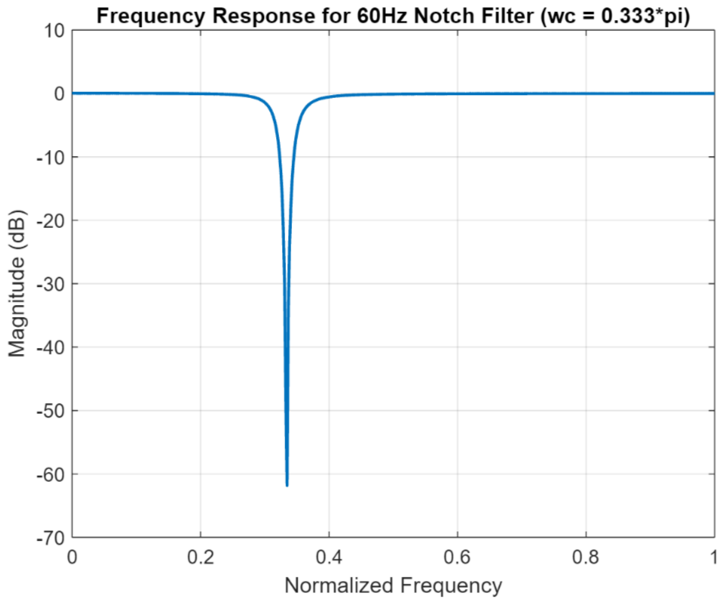
Figure v. Above plot shows the frequency response and pole zero plot for 50Hz IIR Notch Filter.

Similarly For F = 60Hz,

Digital Notch Frequency = $w_o = 0.333\pi$
Digital 3 dB Bandwidth = $\Delta w = 0.0278\pi$

$$\beta = 0.500$$
$$\alpha = 0.914$$

$$\boxed{H(e^{jw}) = 0.957\left(\frac{1 - z^{-1} + z^{-2}}{1 - 0.958z^{-1} + 0.914z^{-2}}\right)}$$



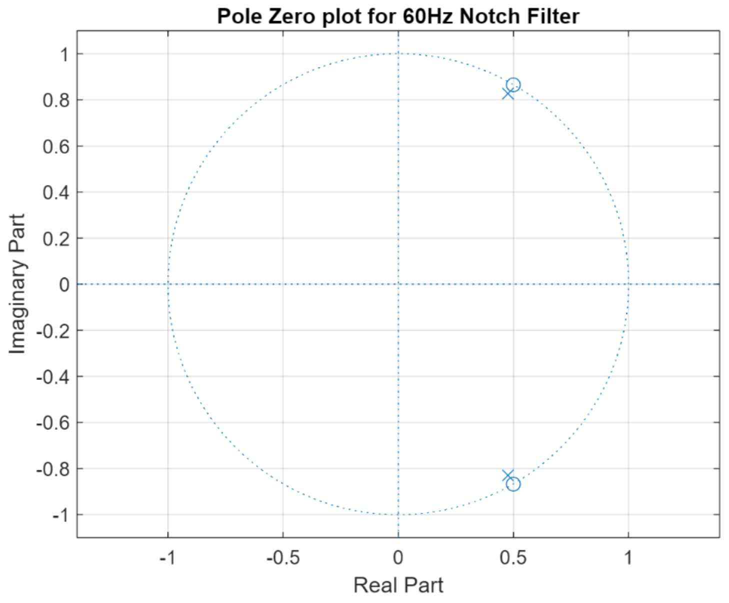


Figure vi. Above plot shows the frequency response and pole zero plot for 60Hz IIR Notch Filter.

The pole-zero plots and frequency responses for both the 50 Hz and 60 Hz notch filters reveal that the filters are stable, as indicated by poles residing inside the unit circle. This stability assures reliable filter performance. These filters effectively attenuate the specified frequencies (50 Hz and 60 Hz), making them suitable for the task of removing these unwanted components from the input signal.

FIR NOTCH FILTER DESIGNING:

Here we will design the FIR Notch filter having **cutoff frequency 60Hz**. We know that the general equation for FIR filter (Den = 1) as shown below,

$$\boxed{\boldsymbol{H(z) = (z - z_1)(z - z_2)(z - z_3) \ldots \ldots . . (z - z_N)}}$$

From relation of analog and digital frequency,

(Fs = 200Hz)

$$\boxed{F = \frac{w}{\pi} \times \frac{F_s}{2}}$$

$$w = 1.88\, rads$$

Location of zeros,

$$\cos(w) \pm jsin(w)$$

Z1 = 0.500 + j0.8659
Z2 = 0.500 - j0.8659

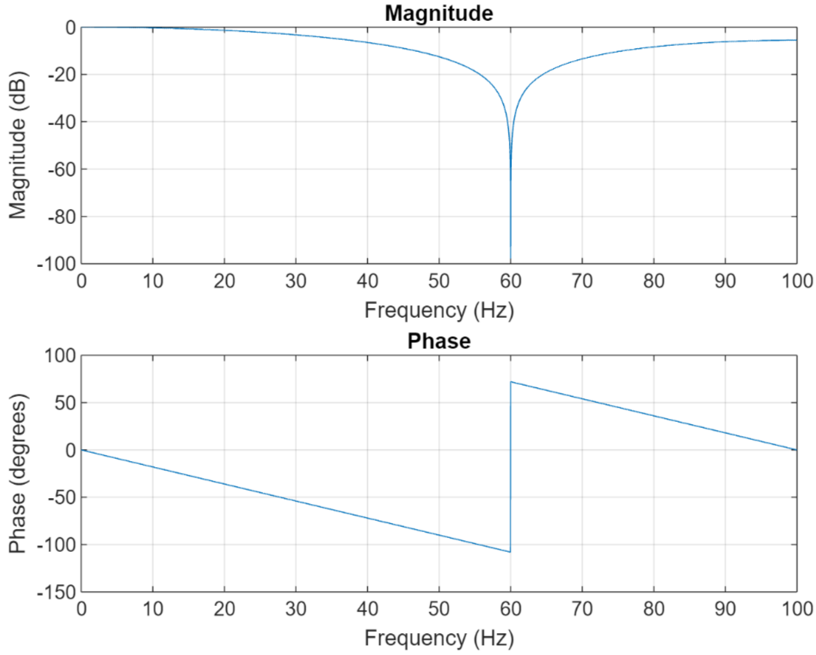
Hence there are two zeros and poles are at origin therefore the order is 2.

Putting z1 & z2 in above equation,

$$\boxed{H(z) = (1 + 0.618z^{-1} + z^{-2})}$$

Dividing by 2.618 to make DC gain = 1 (i.e., at z = 1)

$$H(z) = \frac{(1 + 0.618z^{-1} + z^{-2})}{2.618}$$



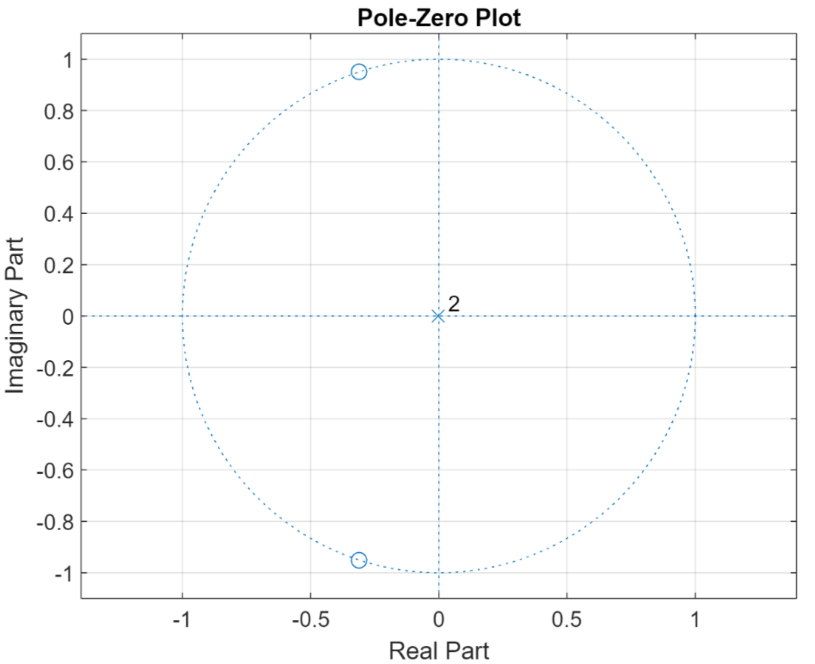
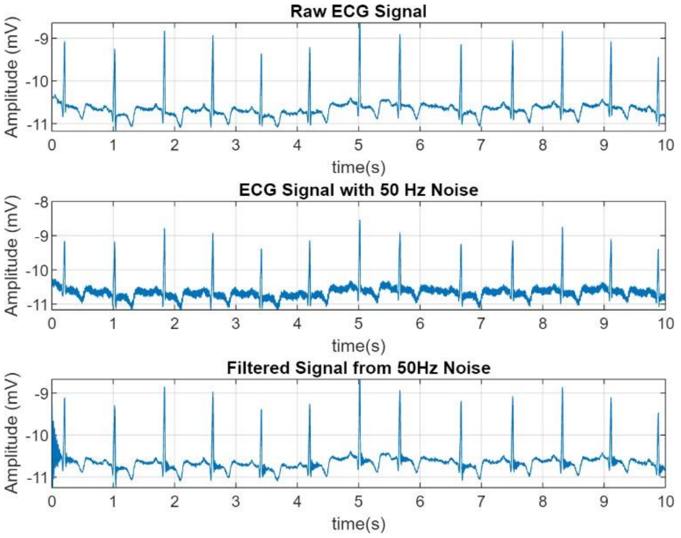


Figure vii. Above plot shows the frequency response and pole zero plot for 60Hz FIR Notch Filter.

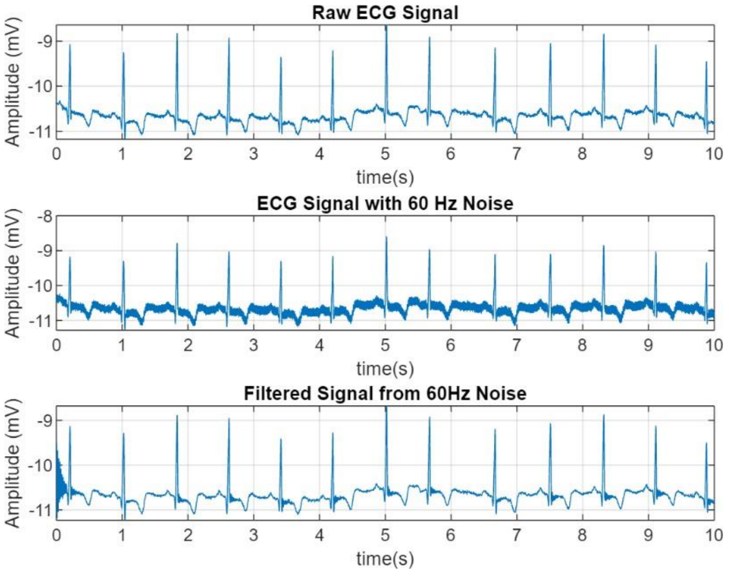
The above figure shows the Magnitude Spectrum, Phase Spectrum & pole-zero plot for FIR Notch filter. From the above spectrum we can see that the filter has cutoff frequency of 60Hz & and also the phase response is also linear. From the pole zero plot it can be concluded that the filter is system because poles lie inside unit circle.

EXPERIMENTS AND RESULTS:

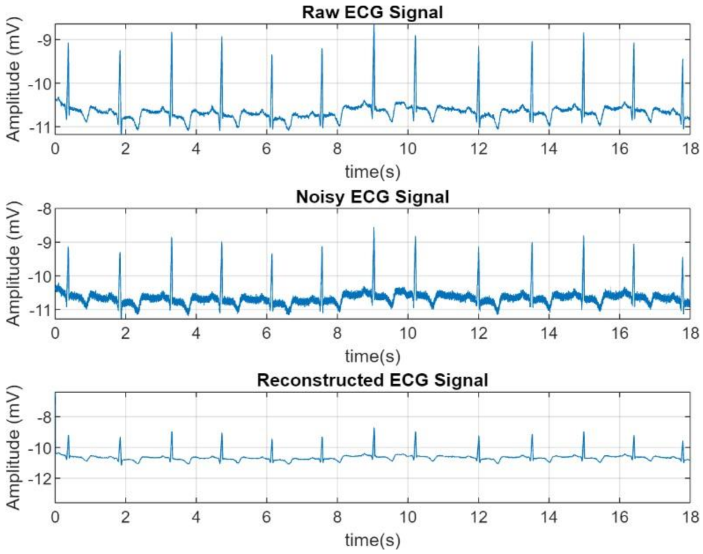
First, MATLAB program is developed to read the ECG signal from the database. Then, the power line interference for 50 Hz and 60 Hz is modeled using noise equation. The ECG signal is superimposed with noise. Then the filters were designed to eliminate the power line interference from ecg signal.



ECG Signal "100'' from database (1st Row), ECG signal superimposed with 50Hz noise (2nd Row), ECG Filtered signal with 50Hz IIR Notch filter (3rd Row)



ECG Signal "100'' from database (1st Row), ECG signal superimposed with 60Hz noise (2nd Row), ECG Filtered signal with 60Hz IIR Notch filter (3rd Row)



ECG Signal "100'' from database (1st Row), ECG signal superimposed with 60Hz noise (2nd Row), ECG Filtered signal with 60Hz FIR Notch filter (3rd Row)

In summary, the figure illustrates that passing a noisy ECG signal through a filter effectively eliminates interference and noise, resulting in an interference-free output. This observation leads to the conclusion that the information contained within the ECG signal remains intact. Through this signal processing technique, the essential ECG data is preserved while undesirable elements are removed, ensuring the accuracy and reliability of the output for clinical or diagnostic purposes.

REMOVAL OF ELECTRODES MOTION ARTIFACTS:

The ECG signal has a wandering baseline (low frequency artifacts). So, to remove that low frequency signal we have to design a filter that removes low frequency component and allow high frequencies to pass. i.e., **High Pass Filter**

So here to remove it we will design Butterworth High pass filter with the specifications as mentioned,

$$Fs = 360Hz$$
$$Fc = 5Hz$$
$$N = 2$$

Now using inbuilt function of MATLAB,

$$\boxed{[B,A] = butter(N,Wn,'high')}$$

B = Coefficient of Numerators
A = Coefficient of Denominator
N = Order
Wn = digital cutoff frequency

For us,

```
[b,a] = butter(n,fc/(Fs/2),'high');
```

By this we got b & a and hence we can get the transfer function of the filter,

```
t1 =

  0.9402 z^2 - 1.88 z + 0.9402
  ----------------------------
     z^2 - 1.877 z + 0.8839

Sample time: 0.0027778 seconds
Discrete-time transfer function.
```

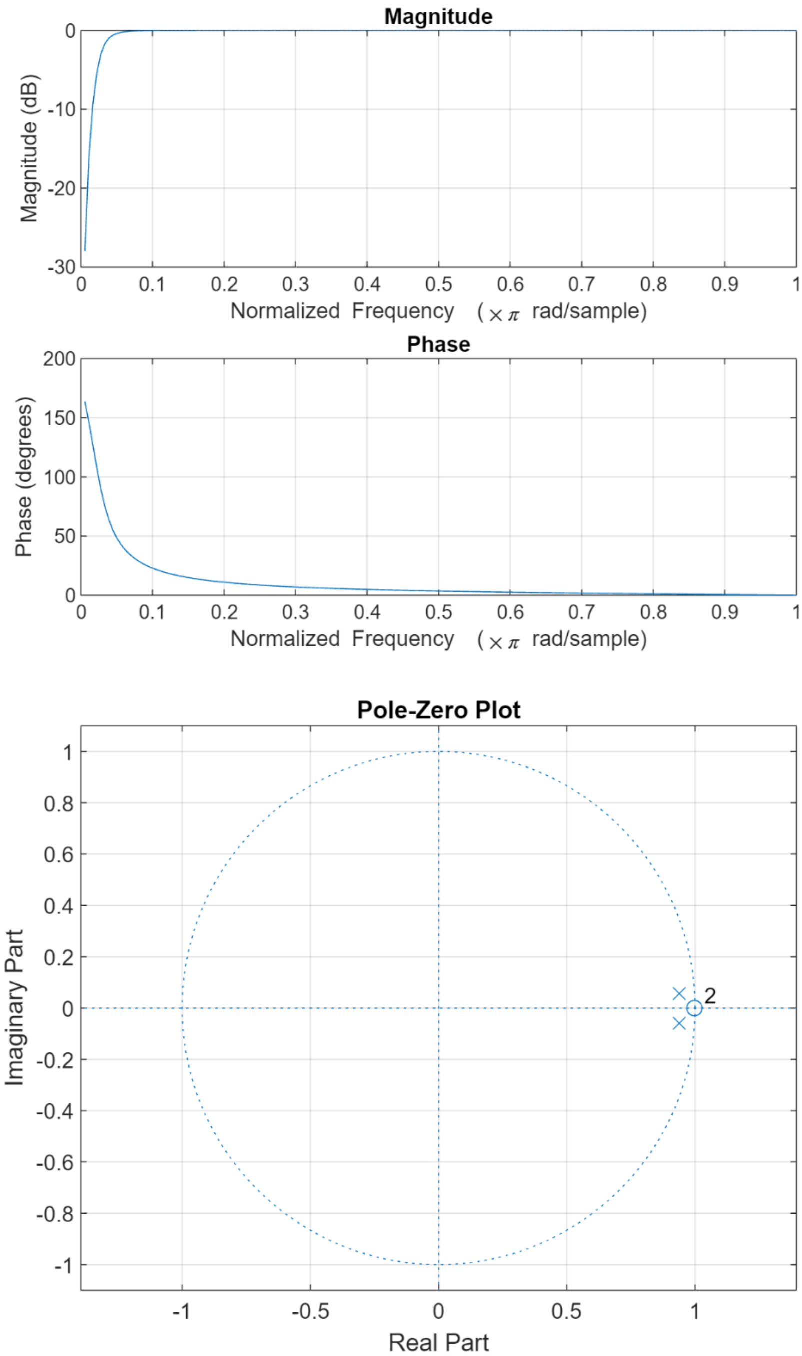
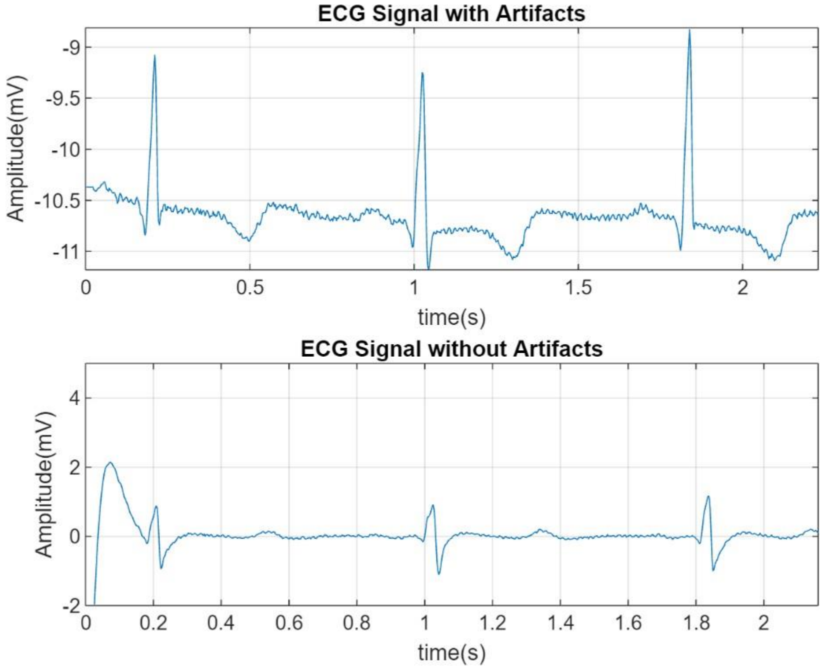


Figure viii. Above plot shows the frequency responseand pole zero plot for 5Hz IIR High pass Filter.

The pole-zero plot for IIR High pass filter is shown in above figure. Also, the frequency response of filter is shown. From the pole-zero diagram we can say that the poles lie inside the unit circle, it can be concluded that the filter is stable and filter is working properly.

EXPERIMENTS AND RESULTS FOR ARTIFACT NOISE:



ECG Signal "100'' from database (1st Row), ECG Filtered signal with 5 Hz IIR HPF (2nd Row)

Here we can see that the raw ecg signal has a low frequency component considered as electrode motion artifacts. In the above figure we can see that the signal is getting distorted and getting affected a lot and as smooth type of signal is not observed. But in the second figure after passing, it through a filter the signal gets a little smooth and hence the effect of low frequency is being removed and also a signal has gained some amplitude as result in increase of power of signal.

CONCLUSION:

In computer-based ECG systems, removing power line interference and electrode motion artifacts is crucial for accurate diagnoses. This report discussed about various types of noise due to which ECG signal can be distorted or the information can be lost and discussed few methods to remove some of them. Modeling of power line interference is done and using digital notch IIR and FIR filter the interference is removed. The electrode motion artifact noise is also removed using a IIR High pass filter. The filter worked reasonably well, preserving important ECG information (like P-waves, QRS complexes, and T-waves). In above all the various filter designing method for powerline interference it can be concluded that the IIR filter has order 2 which is as same as FIR filter's order and on observing the phase plot for both it can be said that the FIR filter has linear phase so it is always stable and IIR are not stable and can be made stable using some operations like shifting. It can be concluded that FIR filter gives the best interference cancellation. Further to remove the artifacts noise high pass filter is designed which eliminates the frequency component of 5Hz. Now after eliminating noise thesignal can be proceeded further for other operations or analysis.

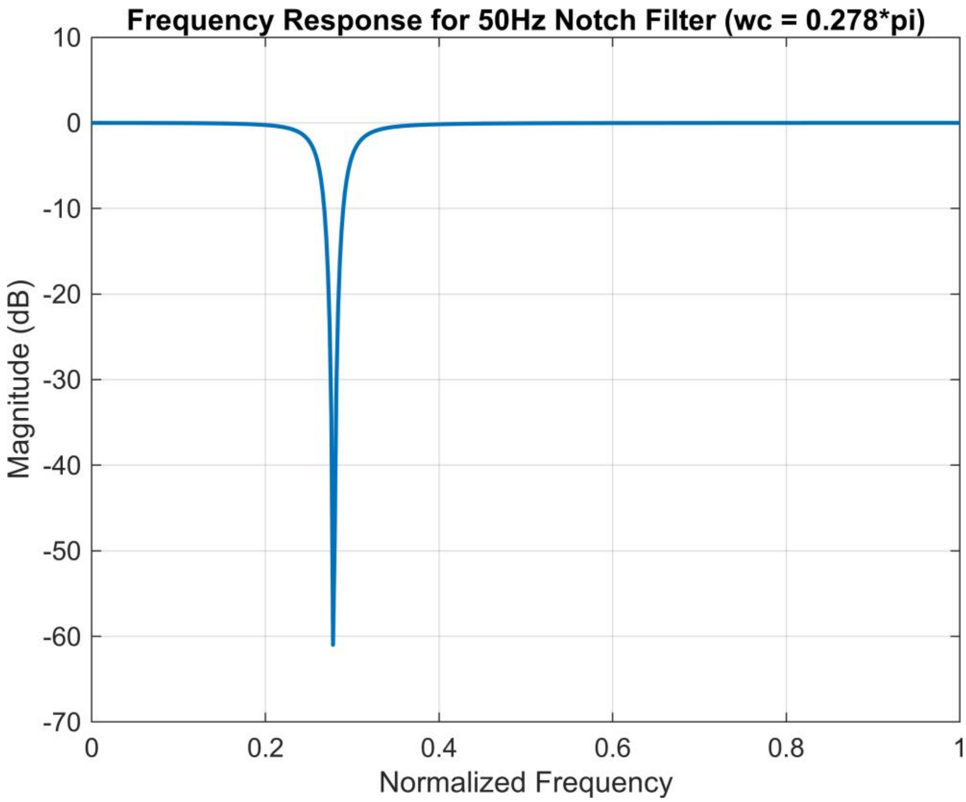
MATLAB CODES (GROUP 27_21BEC006_21BEC044)

Removing Power Line Interference of 50Hz Using IIR Notch Filter

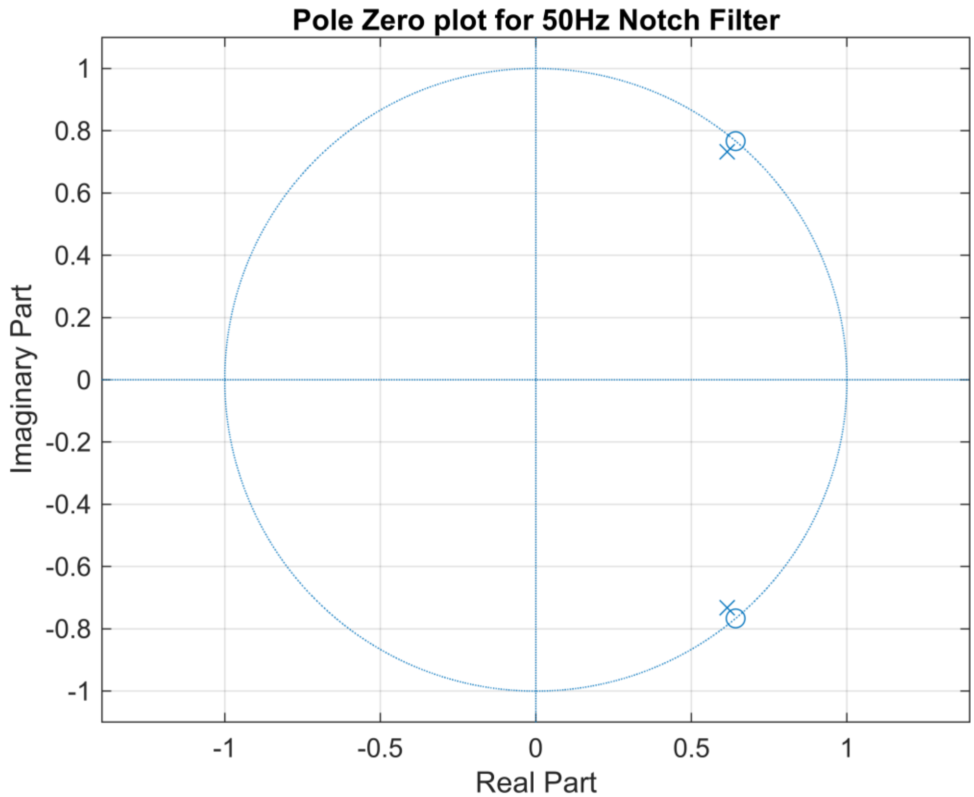
```
clc;
clear all;
close all;

%Loaded ECG Signal
load('100m.mat')

%Removing the Base and Gain from ECG Signal
ECGsignal_original = (val -1024)/100;
Fs = 360;

%Frequency of PowerLine Interference
f1 = 50;

t = (0:length(ECGsignal_original)-1)/Fs;

%Generating Noise for f1 = 50 Hz
N= 0.1*cos (2*pi*f1*t);

%Adding Noise to ECG signal
ECG_Noise = ECGsignal_original + N;

% Designing_IIR_Notch_Filter_using_coefficient
num = 0.957*[1 -1.2844 1];
den = [1 -1.2291 0.914];
sys = tf(num,den);
[Z,P,K] = tf2zp(num,den)
```

```
Z = 2×1 complex
   0.6422 + 0.7665i
   0.6422 - 0.7665i
P = 2×1 complex
   0.6146 + 0.7323i
   0.6146 - 0.7323i
K = 0.9570
```

```
%Freq response of filter
[H,w]=freqz(num,den);
plot(w/max(w),20*log(abs(H)),LineWidth=1.5)
xlabel('Normalized Frequency')
ylabel('Magnitude (dB)')
title('Frequency Response for 50Hz Notch Filter (wc = 0.278*pi)')
grid on
```

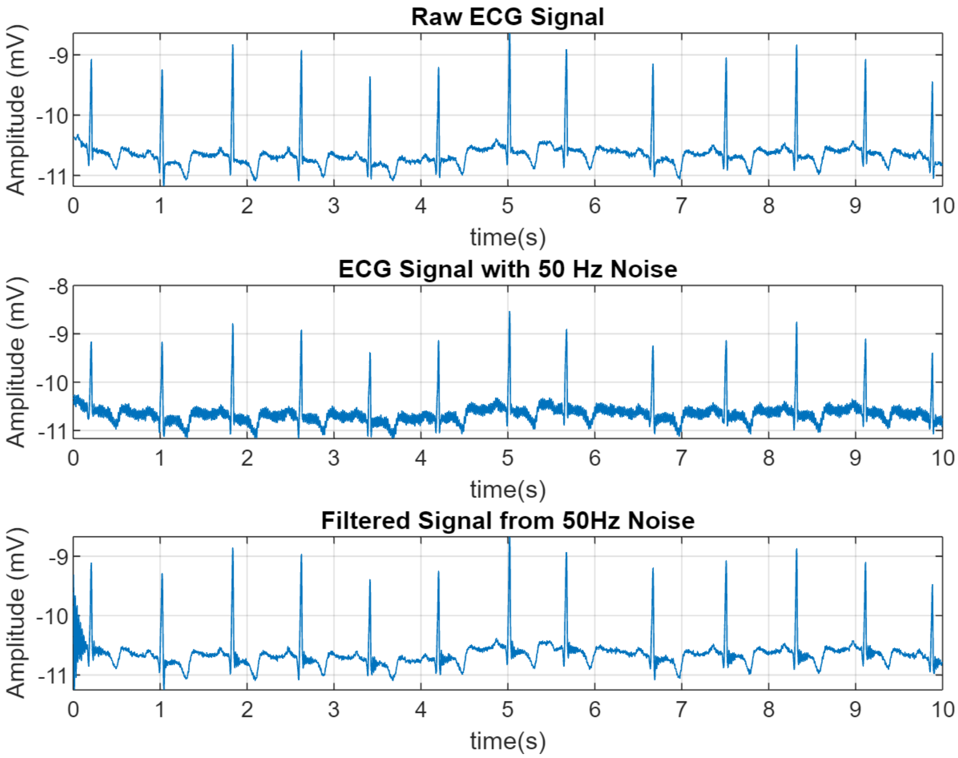



```
%Pole Zero plot of filter
zplane(num,den);
title('Pole Zero plot for 50Hz Notch Filter')
grid on
```




```
%Reconstructed ECG Signal using Filter 1
ecg_recons = filter(num,den,ECG_Noise);
```

```
subplot(3,1,1)
plot(t,ECGsignal_original)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('Raw ECG Signal')
grid on
subplot(3,1,2)
plot(t,ECG_Noise)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('ECG Signal with 50 Hz Noise')
grid on
subplot(3,1,3)
plot(t,ecg_recons)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('Filtered Signal from 50Hz Noise')
grid on
```

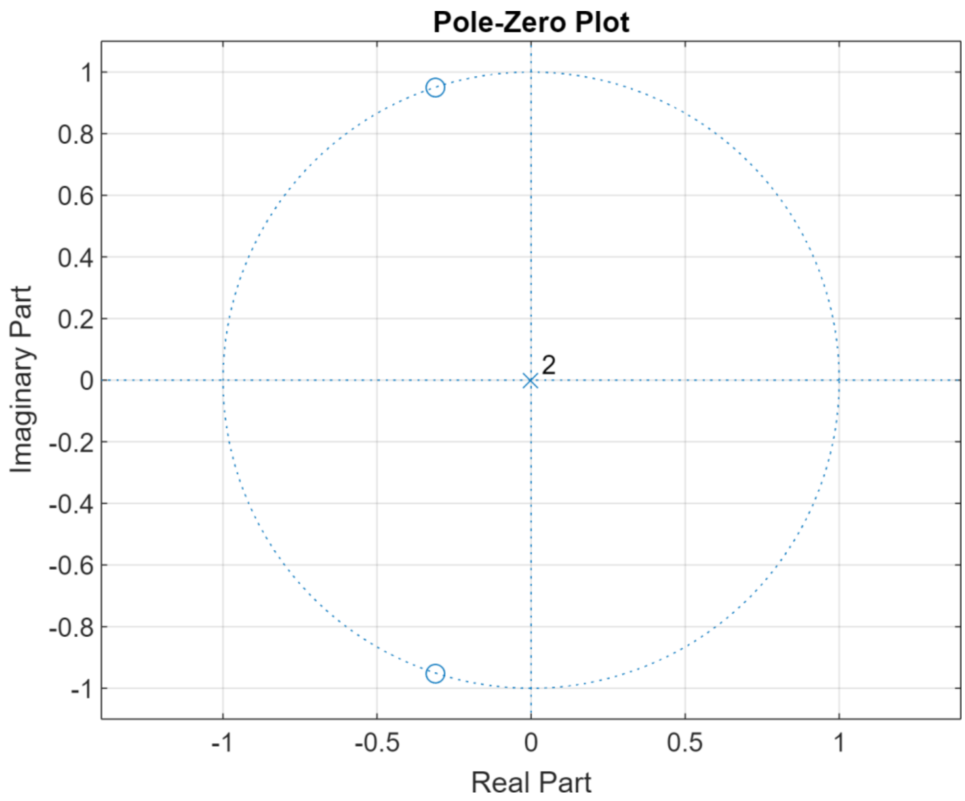

Raw ECG Signal
Amplitude (mV)
time(s)
ECG Signal with 50 Hz Noise
Amplitude (mV)
time(s)
Filtered Signal from 50Hz Noise
Amplitude (mV)
time(s)

Removing Power Line Interference of 60Hz Using FIR Notch Filter

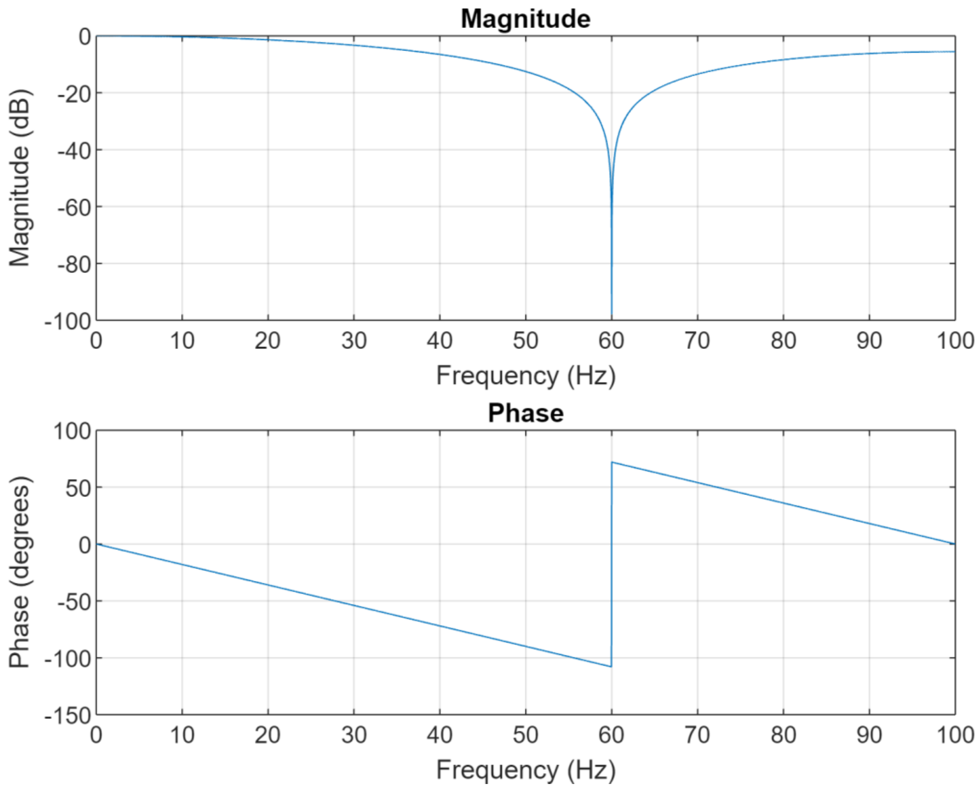
```
clc;
clear all;
close all;

%Loaded ECG Signal
load('100m.mat')

%Removing Gain and Base
ECGsignal_original = (val -1024)/100;
Fs = 200;
f1 = 50;

t = (0:length(ECGsignal_original)-1)/Fs;

%Generating Noise for f1 = 50 Hz
N= 0.1*cos (2*pi*f1*t);

%Adding Noise to ECG signal
ECG_Noise = ECGsignal_original + N;


%FIR Notch Filter Designing
b = [1 0.618 1];
a = 1;

%Making the Gain = 1
b = b/sum(b);

%Transfer Function of the filter
t1 = tf(b,a,(1/Fs))
```

```
t1 =

  0.382 z^2 + 0.2361 z + 0.382

Sample time: 0.005 seconds
Discrete-time transfer function.
Model Properties
```

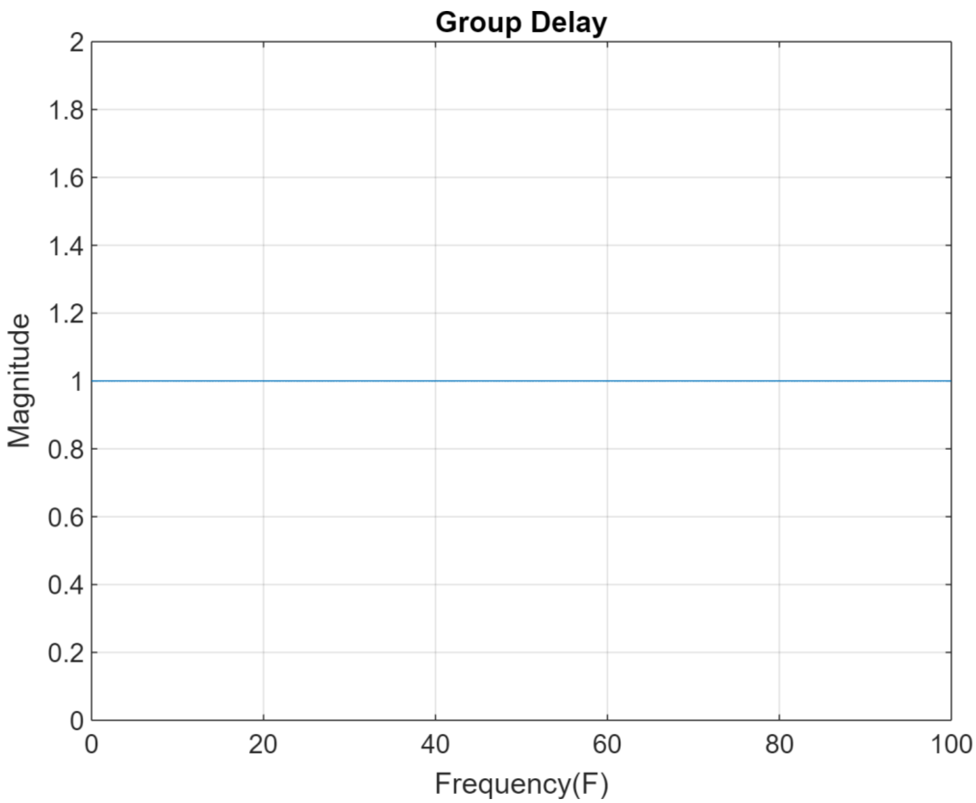
```
[z,p,k] = tf2zpk(b,a);

%pole zero plot
zplane(z,p)
grid on
```



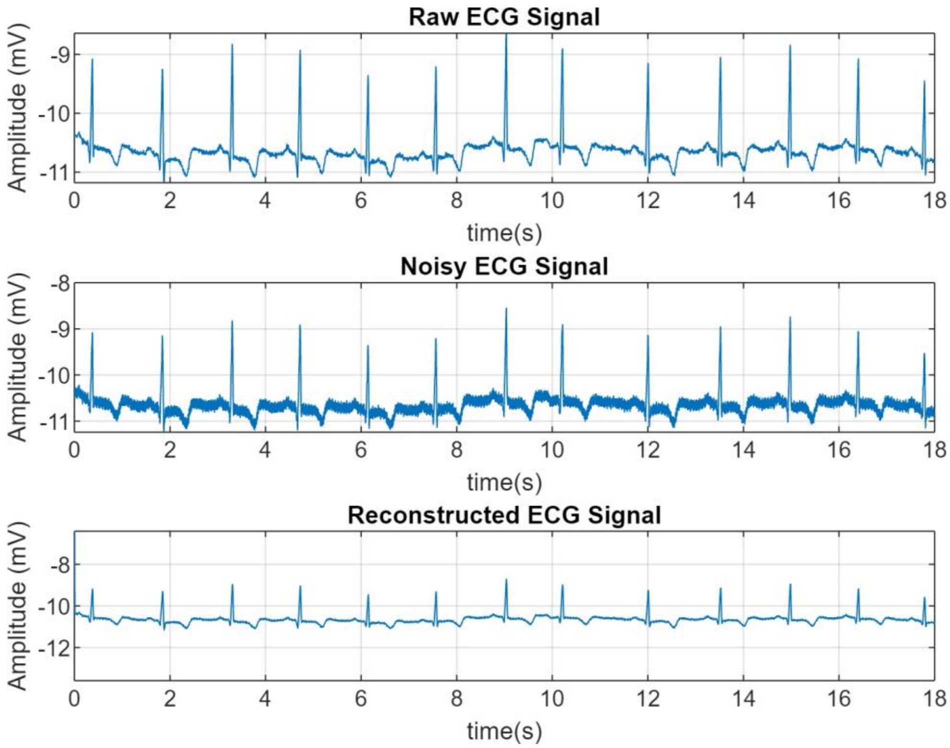

```
%Plotting the frequency response and group delay for the filter
L = length(ECGsignal_original);
freqz(b,a,L,Fs);
```




```
[Gd,f] = grpdelay(b,a,L,Fs);
plot(f,abs(Gd))
title('Group Delay')
xlabel('Frequency(F)')
ylabel('Magnitude')
grid on
```




```
%Plotting the signals
figure(2)
ECG_Filtered = filter(b,a,ECG_Noise);
subplot(311);
plot(t,ECGsignal_original)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('Raw ECG Signal')
grid on
subplot(312)
plot(t,ECG_Noise)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('Noisy ECG Signal')
grid on
subplot(313)
plot(t,ECG_Filtered)
xlabel('time(s)')
ylabel('Amplitude (mV)')
title('Reconstructed ECG Signal')
subplot(3,1,3)
xlim([0.0 18.0])
ylim([-13.6 -6.4])
grid on
```



Raw ECG Signal
Amplitude (mV)
-9
-10
-11
0
2
4
6
8
10
12
14
16
18
time(s)
Noisy ECG Signal
Amplitude (mV)
-8
-9
-10
-11
0
2
4
6
8
10
12
14
16
18
time(s)
Reconstructed ECG Signal
Amplitude (mV)
-8
-10
-12
0
2
4
6
8
10
12
14
16
18
time(s)

Removing Electrode Motion Artifacts Using Butterworth Highpass filter

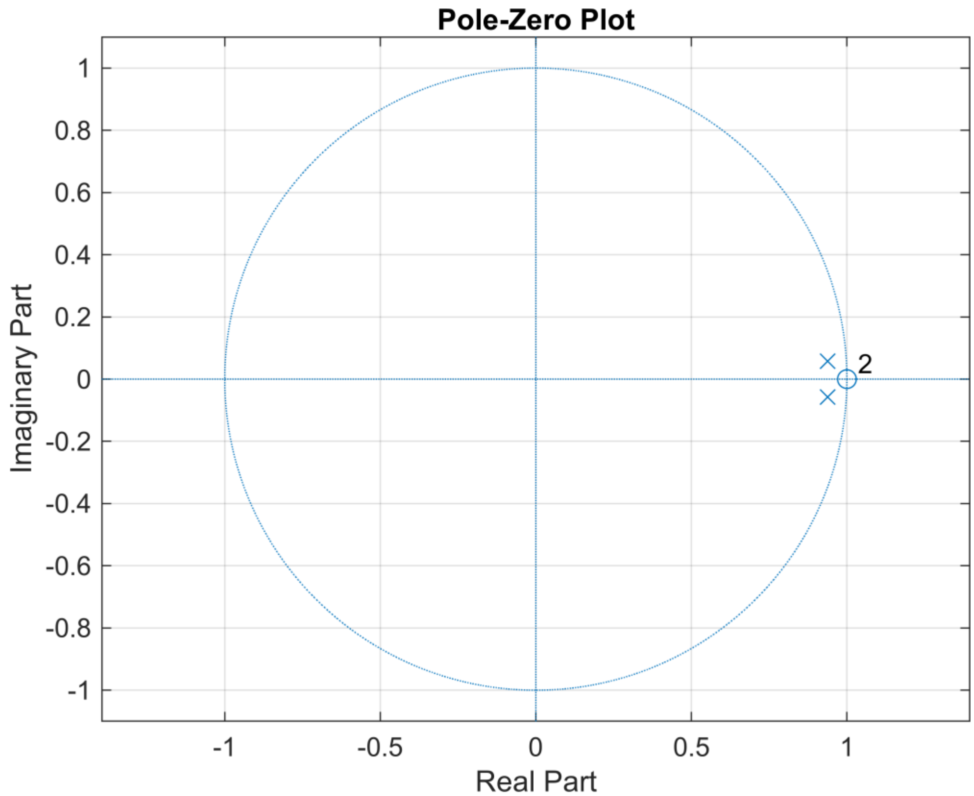
```
clc;
clear all;
close all;

%Loaded ECG Signal
load('100m.mat')

%Removing the Base and Gain from ECG Signal
ECGsignal_original = (val -1024)/100;
Fs = 360;

%Frequency of PowerLine Interference
L = length(ECGsignal_original);
t = (1:L)/Fs;

%Defining Cutoff Frequency and order
fc = 5;
n = 2;
[b,a] = butter(n,fc/(Fs/2),'high');
t1 = tf(b,a,1/Fs)
```

```
t1 =

  0.9402 z^2 - 1.88 z + 0.9402
  ----------------------------
     z^2 - 1.877 z + 0.8839

Sample time: 0.0027778 seconds
Discrete-time transfer function.
Model Properties
```

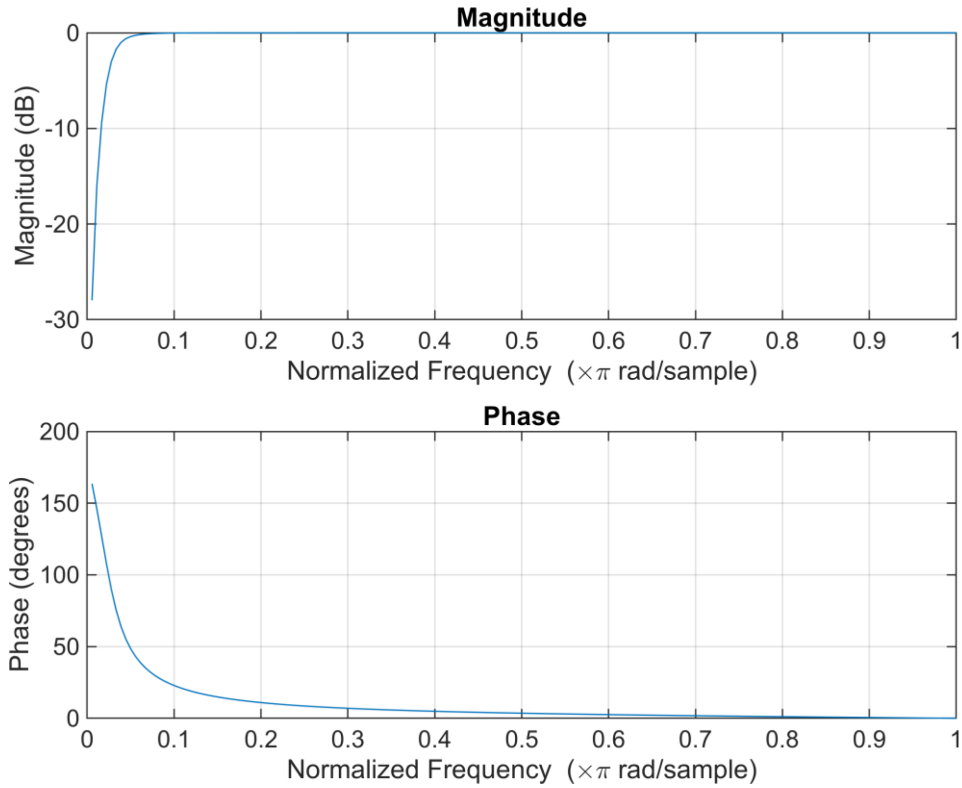
```
[z,p,k] = tf2zp(b,a)
```

```
z = 2×1
     1
     1
p = 2×1 complex
   0.9384 + 0.0581i
   0.9384 - 0.0581i
k = 0.9402
```

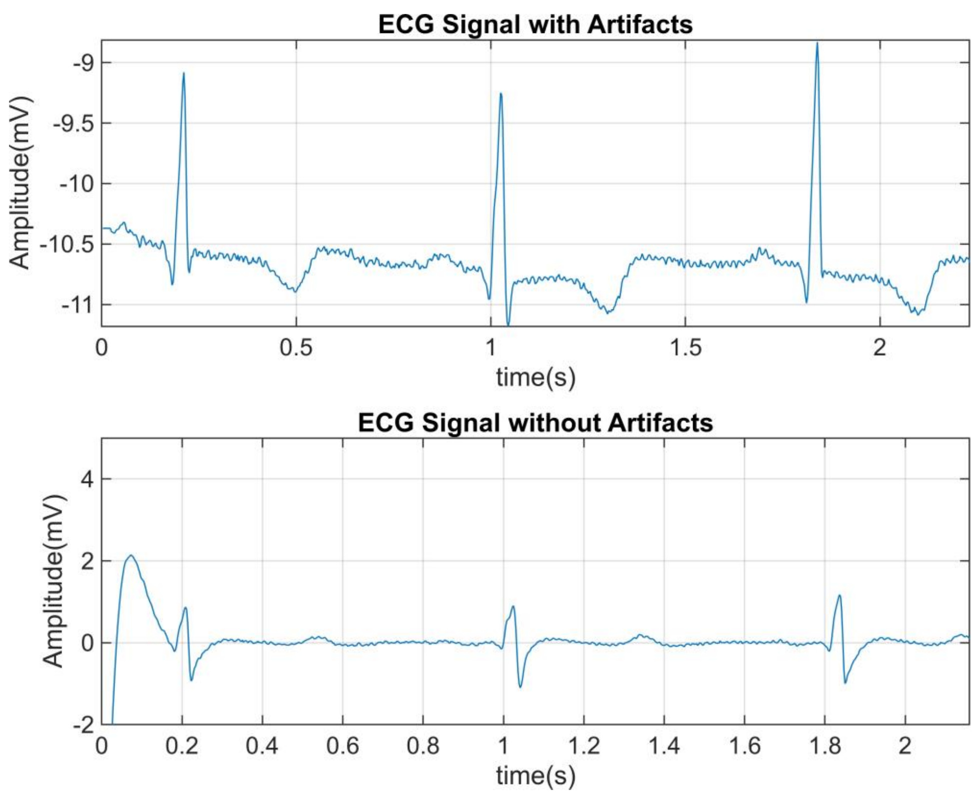
```
zplane(z,p,k)
grid on
```




```
w = 0:2*pi/Fs:pi;
freqz(b,a,w)
```



```
%Reconstructing the signal
ECG_filtered = filter(b,a,ECGsignal_original);
subplot(211)
plot(t,ECGsignal_original)
title('ECG Signal with Artifacts')
xlabel('time(s)')
ylabel('Amplitude(mV)')
xlim([0.00 2.23])
ylim([-11.18 -8.81])
grid on
subplot(212)
plot(t,ECG_filtered)
title('ECG Signal without Artifacts')
xlabel('time(s)')
ylabel('Amplitude(mV)')
xlim([0.00 2.16])
ylim([-2.0 5.0])
grid on
```



References:

1. R. Mark and G. Moody (1997), “MIT-BIH arrhythmia database,” [online]. Available: http://www.physionet.org/physiobank/mitdb.
2. Power Line Interference Cancellation for ECG. Aung Soe Khaing, Zaw Min Naing, Hla Myo Htun
3. Rahul Kher (2019) Signal Processing Techniques for Removing Noise from ECG Signals. J Biomed Eng 1: 1-9
4. A. Jayant, T. Singh and M. Kaur (2013): Different Techniques to Remove Baseline Wander from ECG Signal, Int. J. of Emerging Research in Management & Technology, 2