1. Introduction:

ECG signal: ECG (electrocardiography) is a method of collecting electrical signals generated by the heart. This allows us to understand the level of physiological arousal that someone is experiencing, but it can also be used to better understand someone's psychological state.

Notch filter: A notch filter (also known as a band stop filter or reject filter) is defined as a device that rejects or blocks the transmission of frequencies within a specific frequency range and allows frequencies outside that range. Notch filters eliminate transmission of a narrow band of frequencies and allow transmission of all the frequencies above and below this band. As it eliminates frequencies hence, it is also called a band elimination filter.

For example, if a Notch Filter has a stop band frequency from 100 MHz to 200 MHz, then it will pass all the signals from DC to frequency of 100 MHz and above 200 MHz, it will only reject frequency between 100 MHz to 200 MHz. Thus, the function of a Notch Filter is to passing all those frequencies from zero (DC) up to lower cut-off frequency(FL) and above higher cut-off frequency and reject all those frequencies that lie in the bandwidth region i.e., BW= Fh - fL.

When there is a need to reject a certain narrow band of frequency, a notch-filter is used. A notch-filter is placed after any source from which the signal needs to be eliminated. In most cases, the filter is set as the very last component of any circuit.

Difference between notch filter and band stop filter

A notch-filter is one type of band stop filter. The only difference between a band stops filter and a notch-filter is that a notch-filter has a narrower bandwidth than a normal band stop filter.

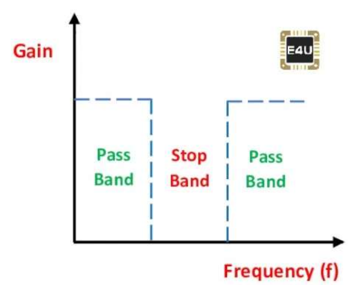


Fig.1: Ideal Characteristics of Band Stop Filter

Power-line Interference:

Electromagnetic fields caused by a power line 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, narrow band noise renders the analysis and interpretation of the ECG more difficult, since the delineation of low-amplitude waveforms becomes unreliable and spurious waveforms may be introduced. 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. 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.

2. Objectives:

- To implement Notch filter to remove 50 Hz power-line interference.
- To learn designing of filter and noise addition to Raw ECG signal.

a) A notch filter (NF) is a band-rejection filter that significantly attenuates specific frequency signals but passes all other frequency components with negligible attenuation. This feature makes the NF attractive in order to cancel the selected desired harmonic components presented in the input signal. The noise of 50 Hz is removed from the Raw ECG signal, by constructing best order band stop filter to remove the interference line of 50Hz frequency. The plotting in Fourier domain gives precise view of addition as well as removal of noise to an ECG signal.

b) Filtering of power line interference is very meaningful in the measurement of biomedical events recording, particularly in the case of recording signals as weak as the ECG. The available filters for power line interference either need a reference channel or regard the frequency as fixed 50/60Hz. Methods of noise reduction have decisive influence on performance of all electro-cardio-graphic (ECG) signal processing systems. This work deals with problems of power line interference reduction.

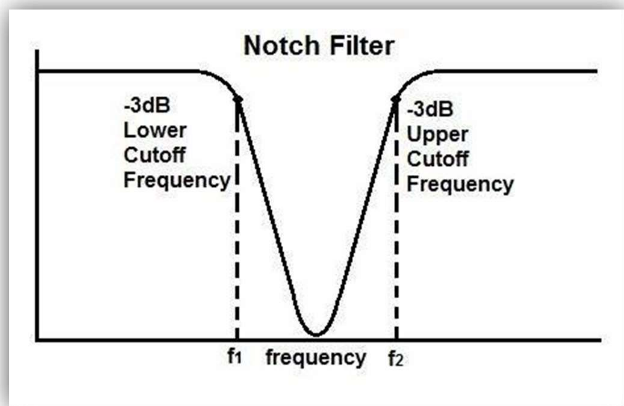


Fig.2: Magnitude Spectrum of Notch Filter

3. Theoretical Background:

Notch filter is used in many applications where specific frequency component is eliminated. For example, instrumentation and recording system signals are interfered by power line frequency 50Hz and these interferences are eliminated by notch filter.

The Notch filter removes the noise by attenuating the entire signal content at 50 Hz. This result in a loss of the frequency components of the desired signal range around 50 Hz

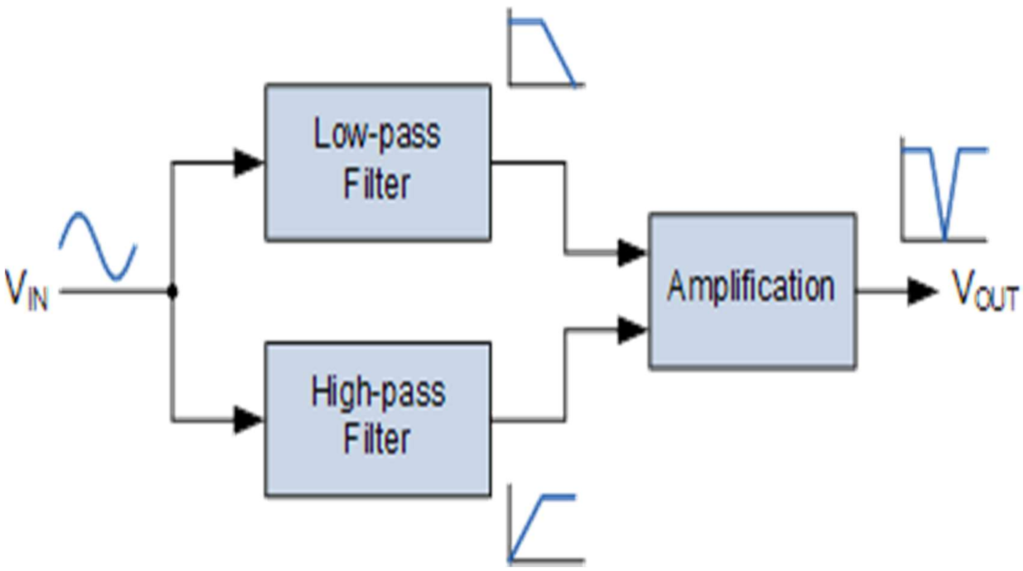


Figure 3

(BLOCK DIAGRAM OF NOTCH FILTER)

The HF cut-off of the LPF: FL = 1 / (2 * RLP * CLP * π)

The LF cut-off of the HPF: fH = 1 / (2 * RHP * CHP * π)

The quality factor of the notch filter: Q = fr / Band Width

Transfer Function of Notch Filter:

$$H(s) = \frac{(S^2 + \omega_z^2)}{S^2 + \frac{\omega_p}{Q} S + \omega_p^2}$$

Characteristics of Notch Filter:

Some of the attributes of a notch-filter –

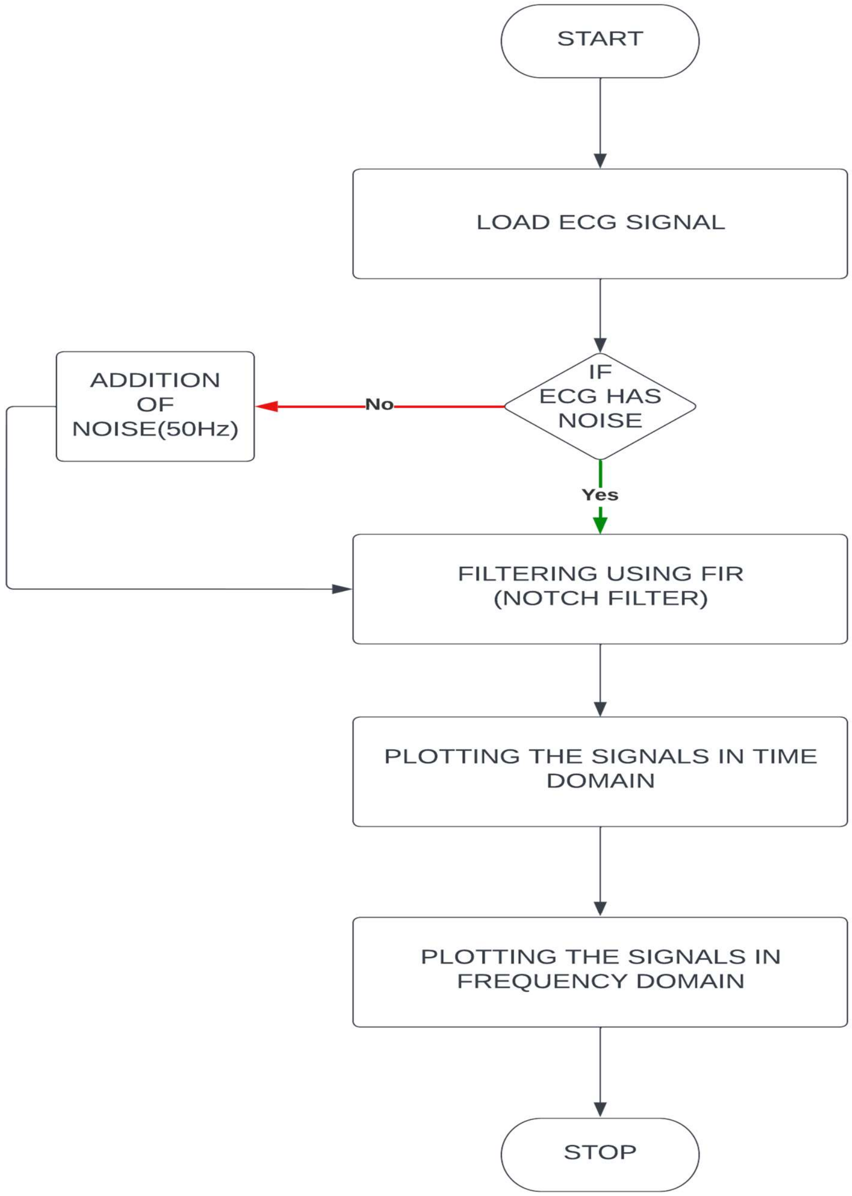
- Narrow bandwidth
- High Q value
- Great depth

points of Discussion	Band pass Filter	Notch-Filter
Principle	Allowing certain band	Rejecting certain band
Bandwidth	Comparatively wider band is passed.	A comparatively narrower band is rejected.

Gain of Notch Filter:

$$V_{out}/V_{in} = 1 - \left(\frac{f}{f_c}\right)^2 \Big/ 1 - \left(\frac{f}{f_c}\right)^2 + \left(\frac{1}{Q}\right) j\left(\frac{f}{f_c}\right)$$

4. FLOWCHART



Load the ECG signal first. Check if 50Hz frequency is already there or not. If 50Hz noise is there then directly jump to the step of filtering otherwise add 50Hz signal as noise to Original ECG signal and apply filtering operation on it. Plot frequency and time response of Original, Noisy and Filtered ECG.

5.Code:

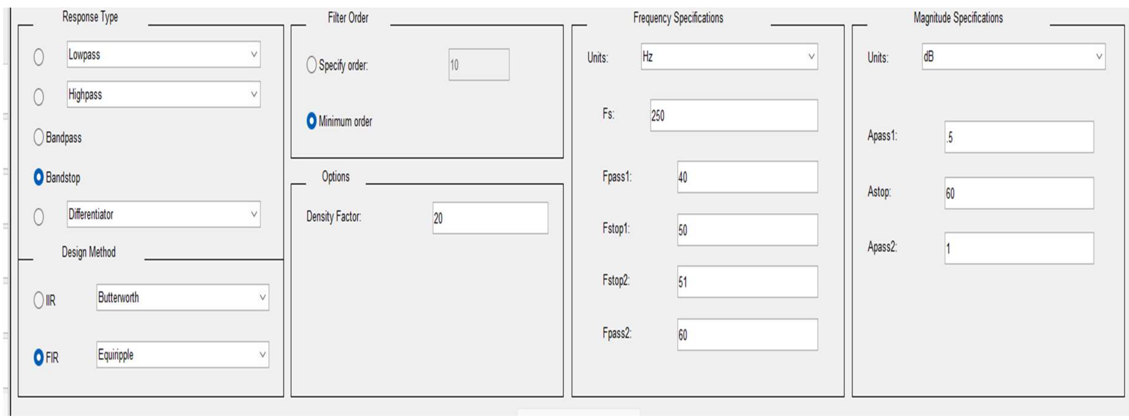
```
clc;
clear all;
close all;

%%
% Load ECG signal
ecg=load('BEAT_2000_samples.txt');
% Sampling frequency of fs
f_s=250;
% Length of ECG signal i.e., number of samples = 2000
N1=length(ecg);
% Signal of 8 second for 2000 samples
t=0:1/f_s:7.999;
% Taking transpose of original ECG so that its dimensions become same as noise signal so
that both signals can be added
ecgnew = transpose(ecg);
disp('Got the ECG signal')
%%
%Noise signal of 50Hz frequency so will get peak at 50Hz
noise=sin(2*pi*50*t);
% Adding noise of 50Hz to original ECG, noise is multiplied with 25 because amplitude of
noise is very small it is not visible in spectrum so to amplify noise, we are multiplying it with
25
xn = ecgnew + noise*25;
disp('Addition of noise to ECG signal')
%%
load('Num.mat')
disp('Filter designed.')
% Applying filter to noisy signal
filtered_ecg = filter(Num,1,xn);
figure
plot(t(1:500),filtered_ecg(1+30:500+30))
disp('Filter applied to noisy ECG')
%%
df=f_s/N1;
frequency_ecg=-f_s/2:df:f_s/2-df;

figure
FFT_ecg_in=fftshift(fft(ecg))/length(fft(ecg));
subplot(3,1,1)
plot(frequency_ecg,abs(FFT_ecg_in));
title('FFT of ECG Input');
xlabel('Frequency(Hz)');
ylabel('Amplitude');

FFT_ecg_in=fftshift(fft(xn))/length(fft(xn));
subplot(3,1,2)
plot(frequency_ecg,abs(FFT_ecg_in));
title('FFT of ECG Noisy');
```

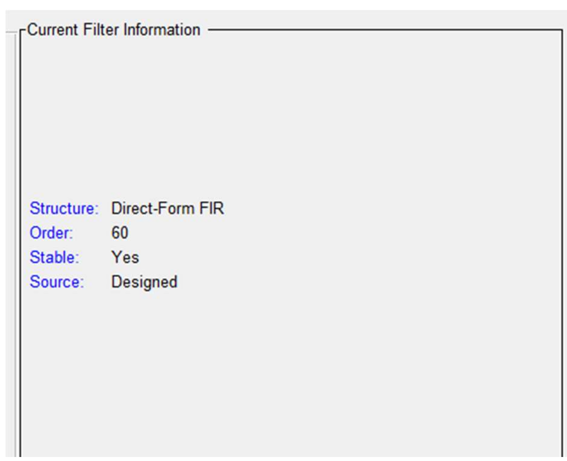
```
xlabel('Frequency(Hz)');
ylabel('Amplitude');

FFT_ecg_in=fftshift(fft(filtered_ecg))/length(fft(filtered_ecg));
subplot(3,1,3)
plot(frequency_ecg,abs(FFT_ecg_in));
title('FFT of Filtered ECG');
xlabel('Frequency(Hz)');
ylabel('Amplitude');

disp('Frequency reponse plotted')
%%
figure

subplot(3,1,1)
plot(t(1:500),ecg(1:500));
title('Original ECG')
xlabel('Time')
ylabel('Amplitude')

subplot(3,1,2)
plot(t(1:500),xn(1:500))
title('Noisy ECG')
xlabel('Time')
ylabel('Amplitude')

subplot(3,1,3)
plot(t(1:500),filtered_ecg(1+30:500+30))
title('Filtered ECG')
xlabel('Time')
ylabel('Amplitude')

disp('Time Domain plot')


figure,plot(ecgnew-filtered_ecg)
disp('Code Complete')
```

6. Results:

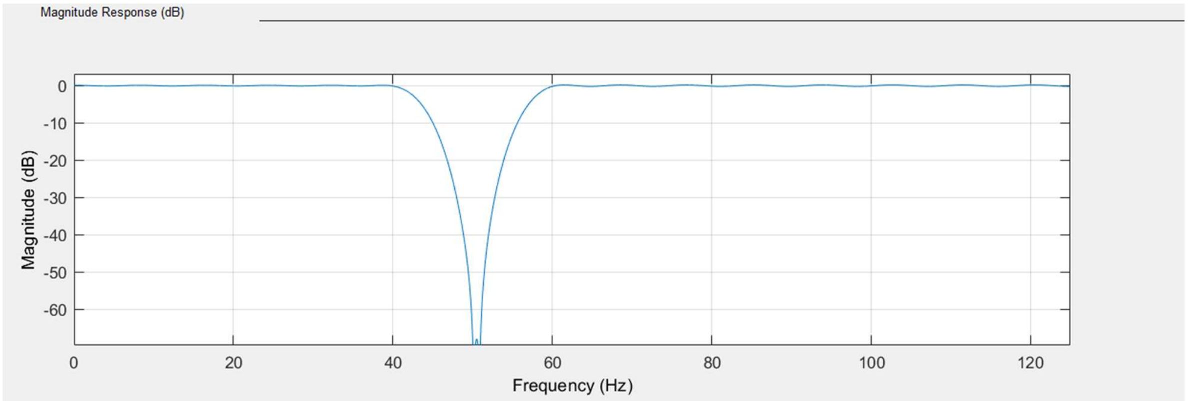
This project focuses on designing a notch filter to filter out power line noise of ECG. We started by using a clean ECG with a length (N) of 2000 and a sampling frequency of 250 Hz. Following that, we added a sine wave of 50 Hertz frequency as noise to clean ECG. Following that, we use the pole-zeros approach to create the particular notch filter. Then we have implemented the filter in MATLAB. A raw ECG signal that has been tainted with power line noise has then been sent into the filter. We were able to successfully eliminate 50 Hz power line interference using the Finite impulse response notch filter, and so the signal quality was enhanced to a greater extent.

➢ Specifications Used

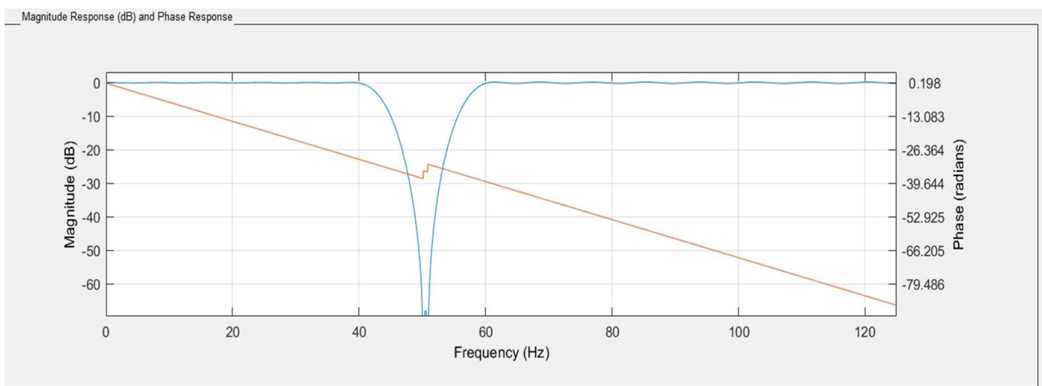




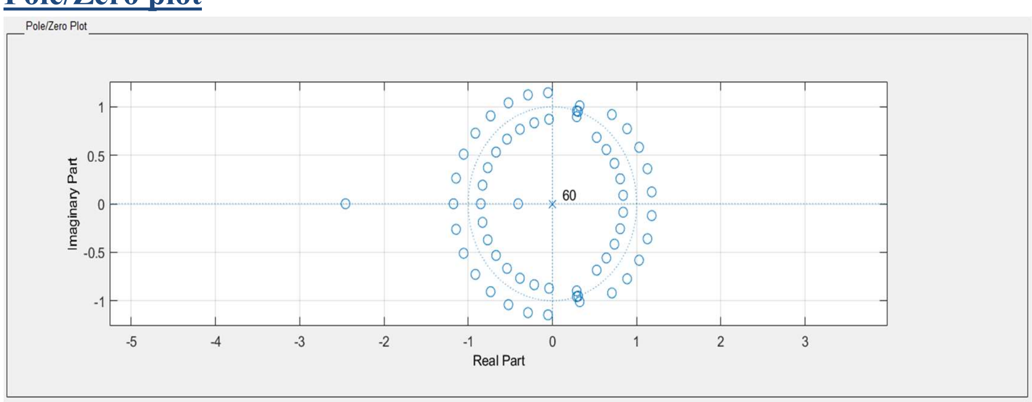
➢ Magnitude Response: -



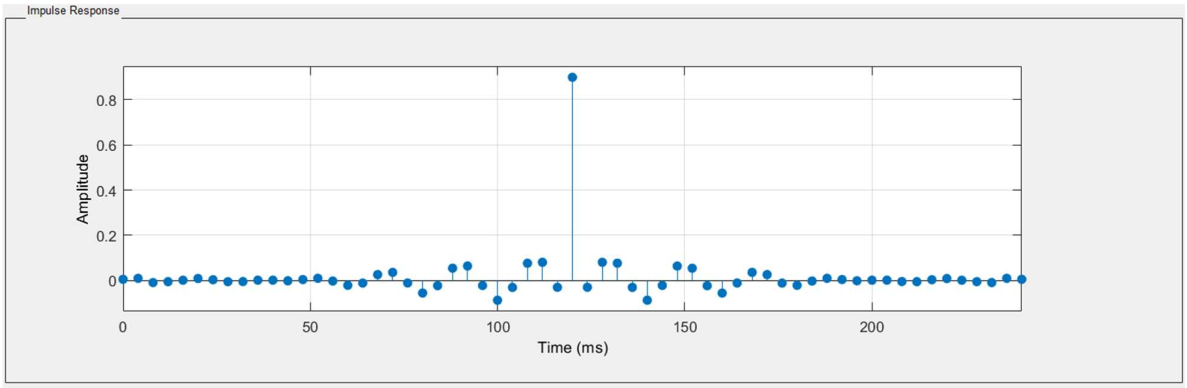
➢ Magnitude and Phase Response



➢ Pole/Zero plot

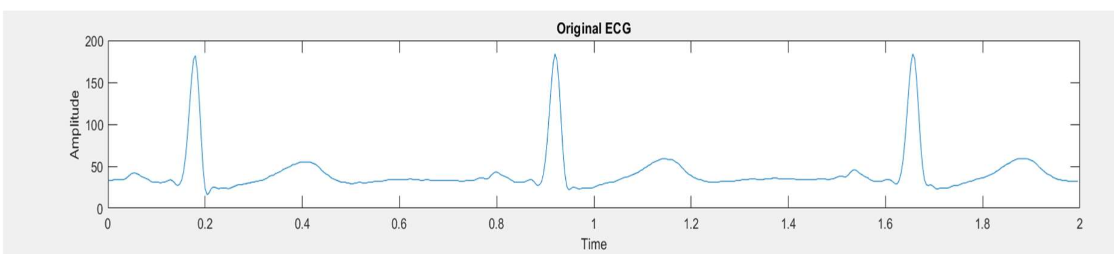


➢ Impulse Response

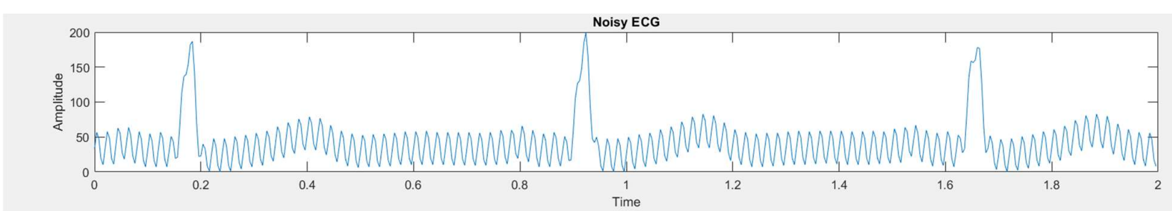


Final Outputs After Plotting

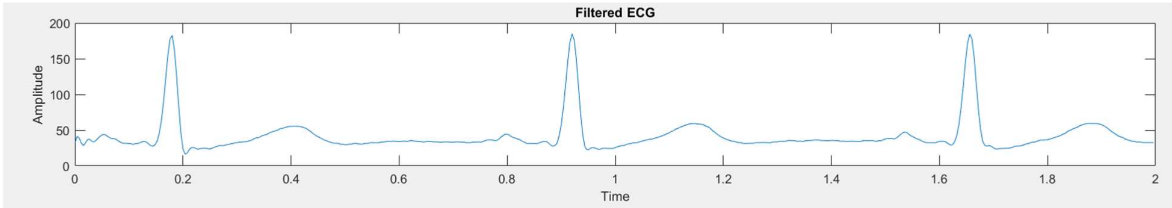
➢ In Time Domain



Original ECG signal

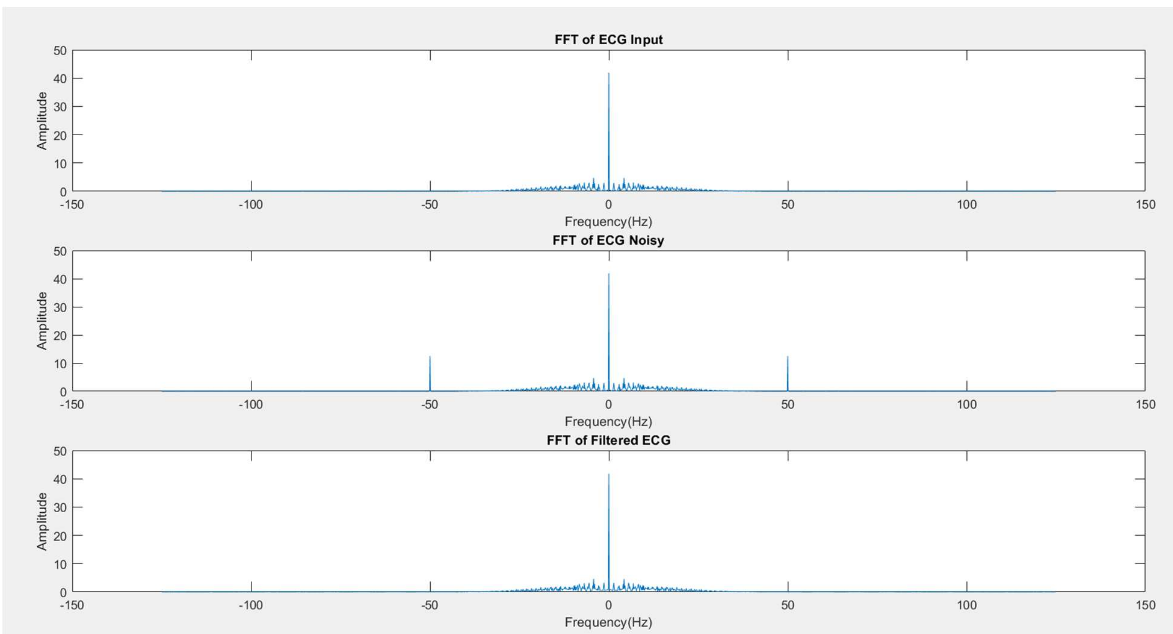


NOISY ECG signal

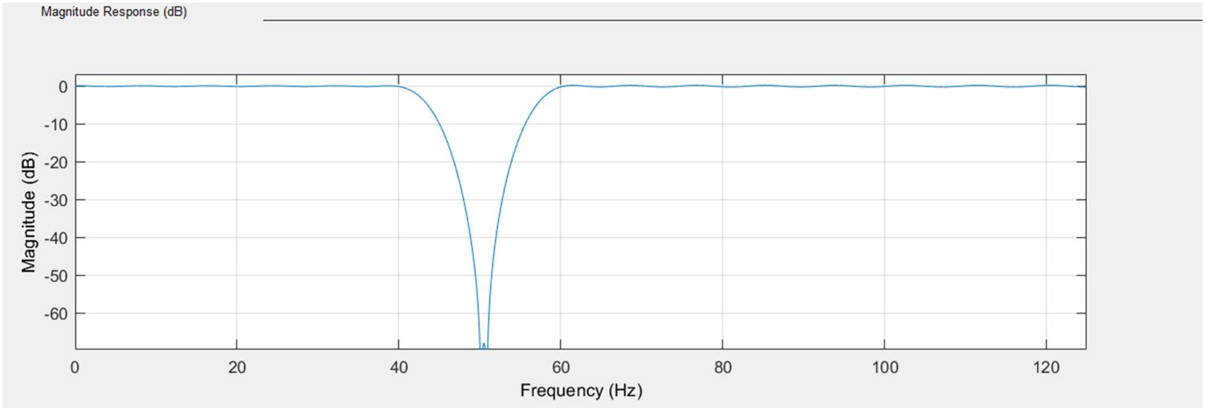


Filtered ECG signal

(II) In Frequency Domain: -



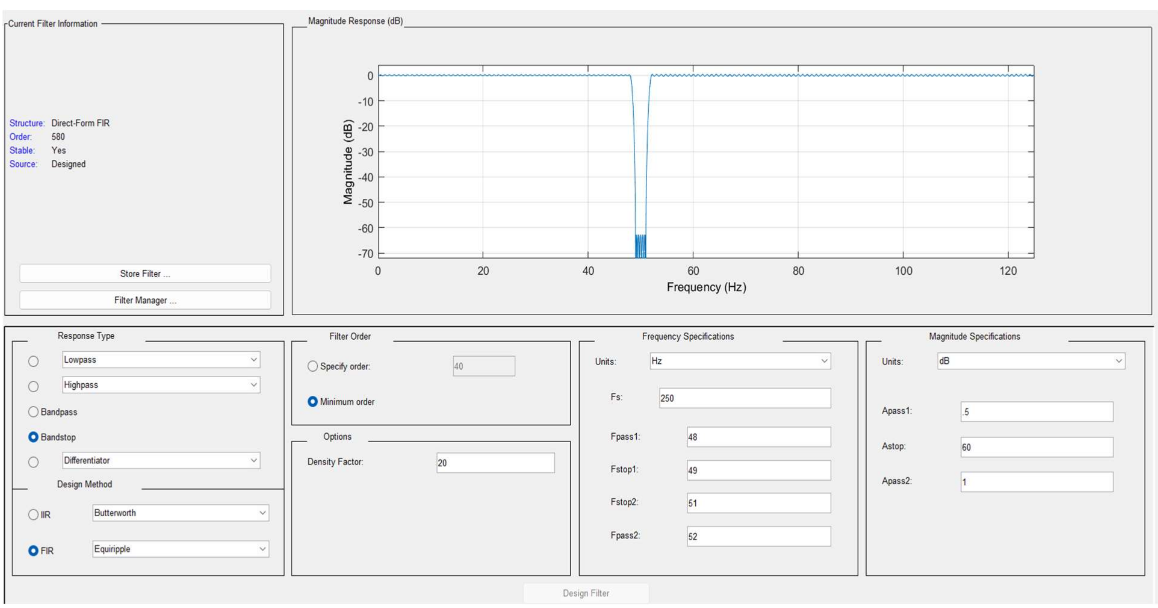
We have Designed FIR Equiripple Notch Filter with specification sampling frequency of 250Hz and lower pass band frequency fpass1=40Hz, higher pass band frequency fpass2=60Hz, lower stop band frequency fstop1=50Hz, higher stop band frequency fstop2=51Hz. With these specifications the magnitude spectrum of Notch filter is appearing as-



As we have chosen pass band frequencies 40Hz and 60Hz, from 0Hz to 40Hz and 60Hz onwards all frequency components are passing through filter without attenuation. As stop band frequencies are 50Hz and 51Hz, frequency components from 40 to 49Hz and 51 to 60Hz gets attenuated after passing through filter and the frequency components of 50Hz is completely suppressed.

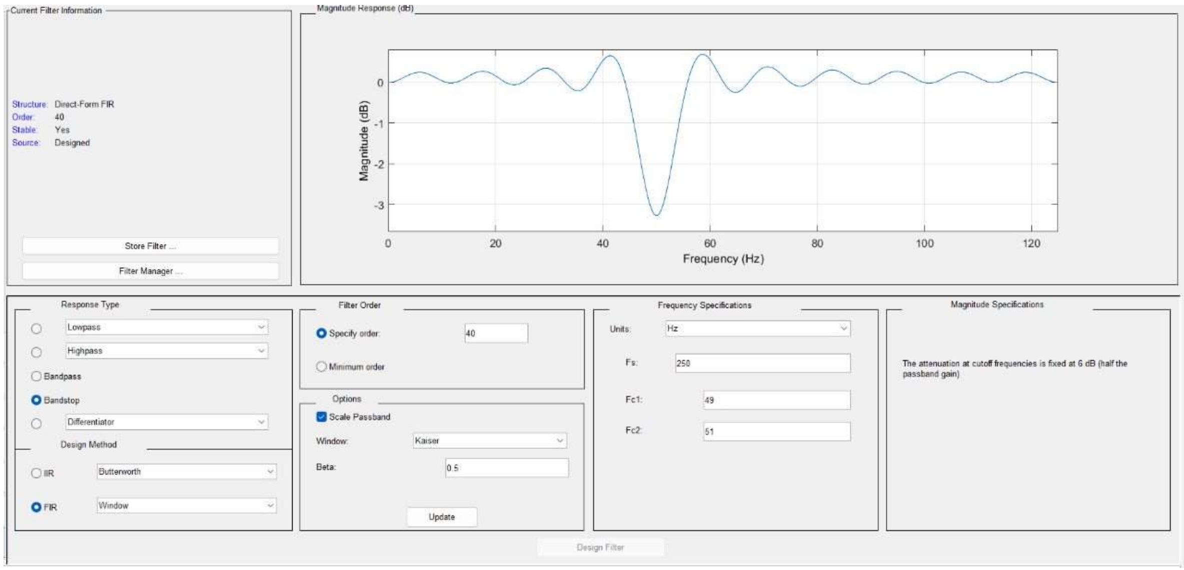
So, with this Notch filter we are meeting our expectation as 50Hz powerline interference is suppressed completely but the disadvantage is that the neighborhood frequencies of 50Hz is getting attenuated which is not wanted.

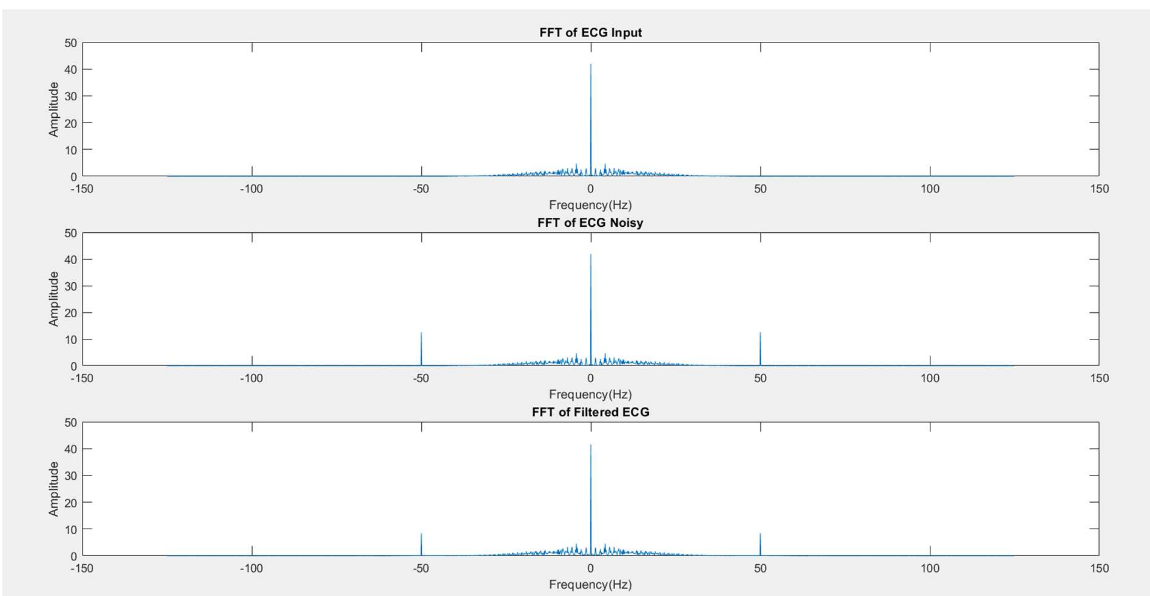
So, to overcome this we have chosen fpass1=48Hz, fpass2=52Hz, fstop1=49Hz, fstop2=51Hz. So, the magnitude spectrum is appearing as

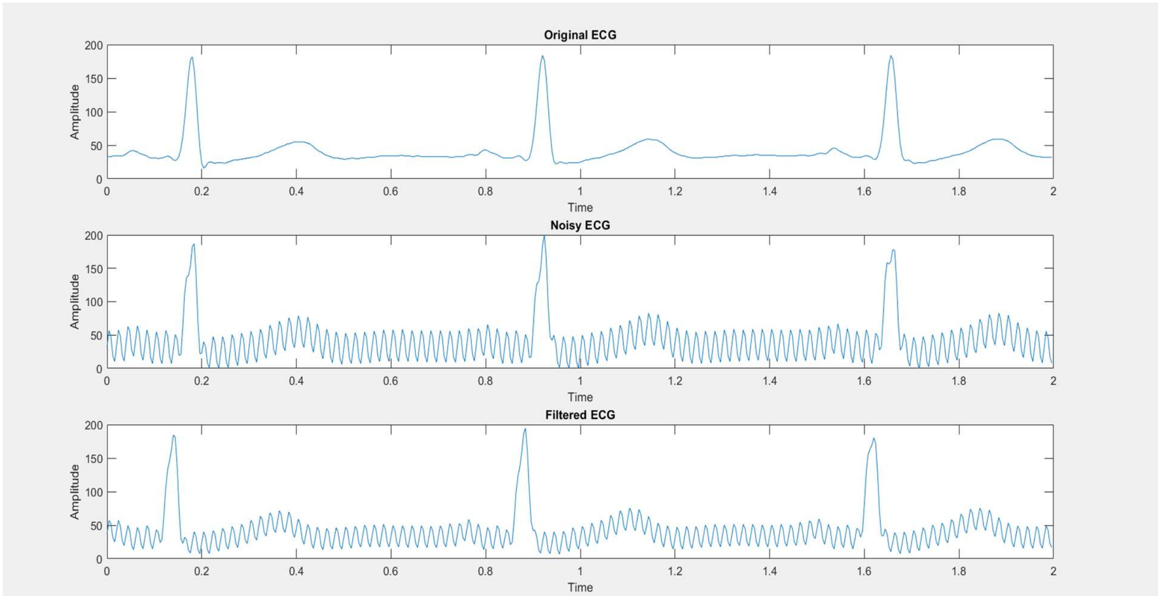


So, we can observe that transition band now has become narrow. Magnitude spectrum is now sharper than the previous case but the order of filter is increased which results in increase in hardware.

Instead of using equiripple FIR filter, if we use window technique and choose kaiser window with order 40 and specifying fc1=49Hz and fc2=51Hz then the magnitude response is looking like



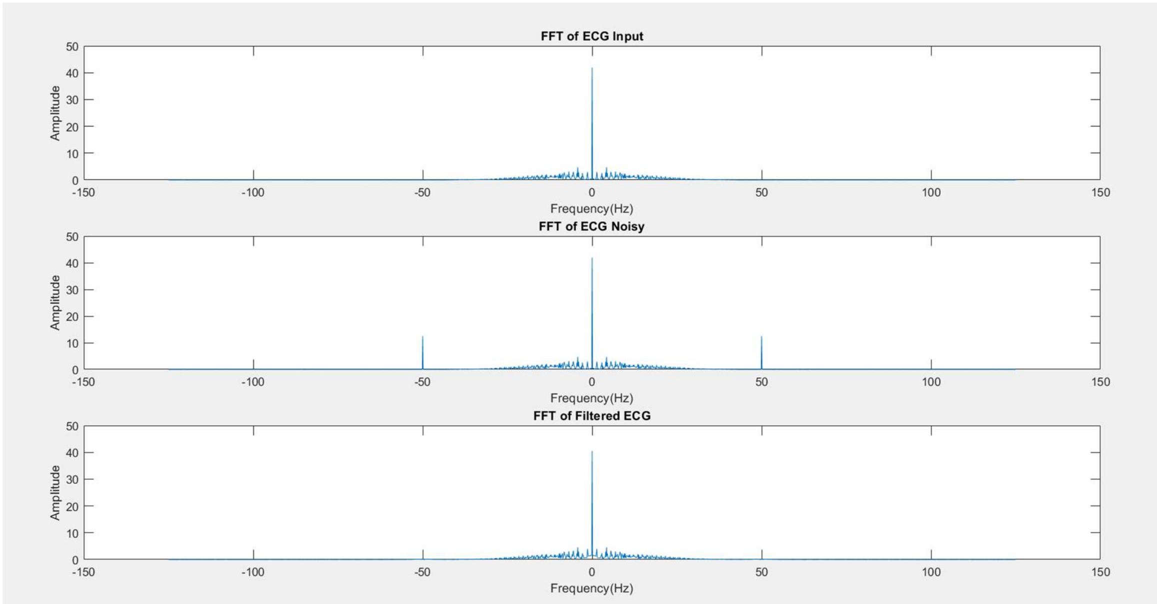


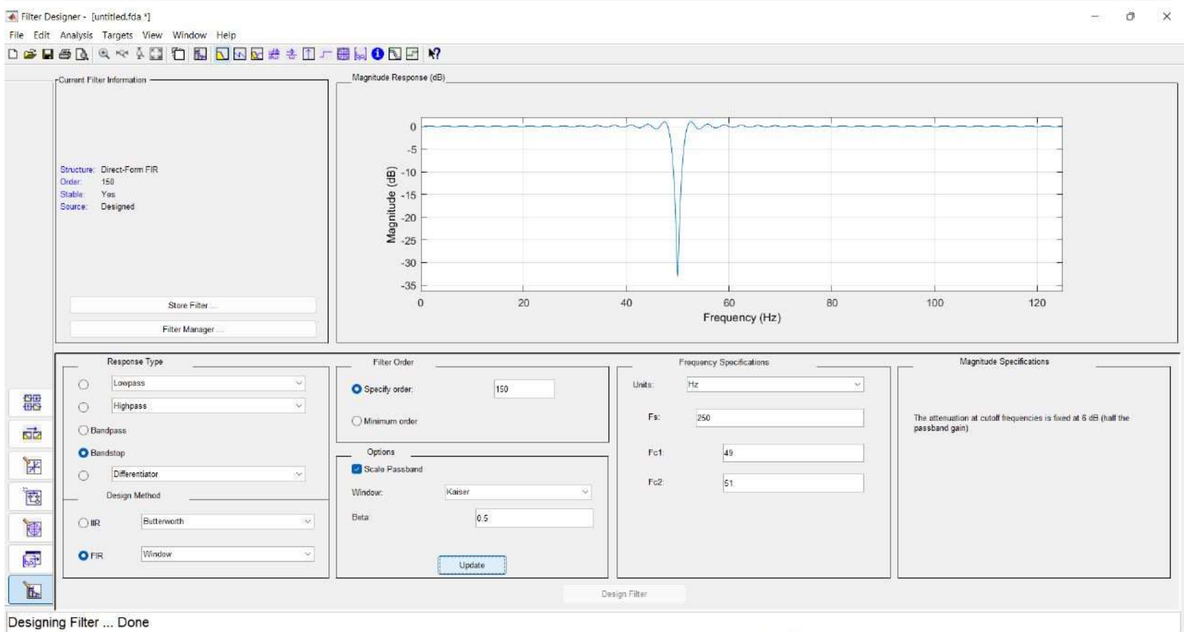


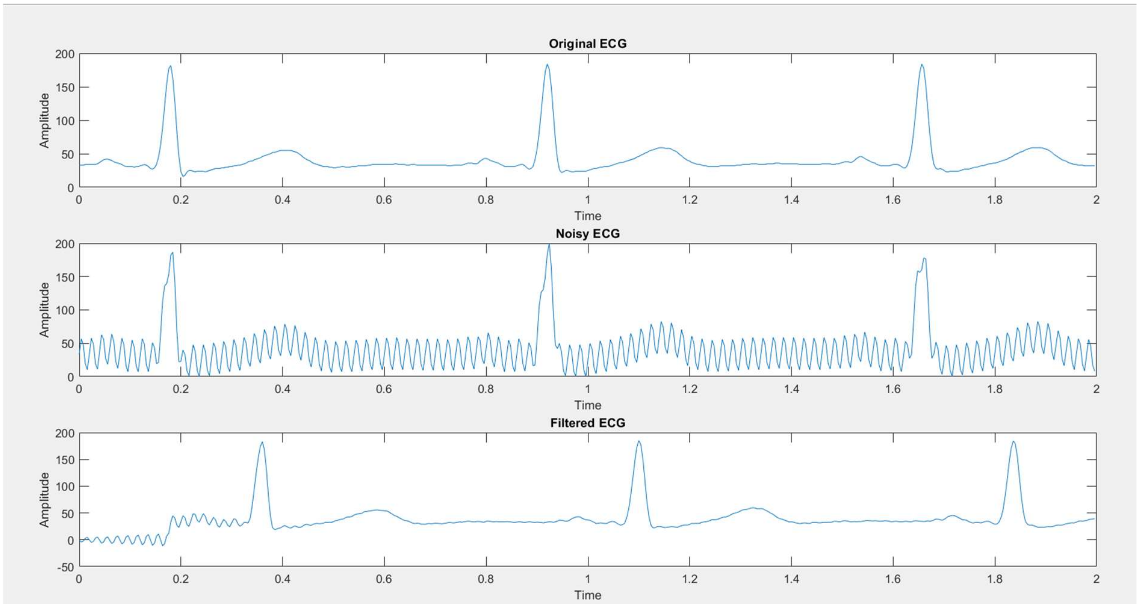
As we can see in above response, there are ripples in pass band as we are converting infinite system into finite by truncating some samples. Here we can observe that the response in not sharp and transition band is wide.

From time and frequency plots, it is clear that 40^{th} order filter is removing noise but it is not able to remove noise completely.

If we increase the order to 150, the magnitude response looks like


FFT of ECG Input
Amplitude
Frequency(Hz)
FFT of ECG Noisy
Amplitude
Frequency(Hz)
FFT of Filtered ECG
Amplitude
Frequency(Hz)


Filter Designer - [untitled.fda *]
File Edit Analysis Targets View Window Help
Current Filter Information
Structure: Direct-Form FIR
Order: 150
Stable: Yes
Source: Designed
Store Filter ...
Filter Manager ...
Magnitude Response (dB)
Magnitude (dB)
Frequency (Hz)
Response Type
Lowpass
Highpass
Bandpass
Bandstop
Differentiator
Design Method
IIR
Butterworth
FIR
Window
Filter Order
Specify order:
150
Minimum order
Options
Scale Passband
Window:
Kaiser
Beta:
0.5
Update
Frequency Specifications
Units:
Hz
Fs:
250
Fc1:
49
Fc2:
51
Magnitude Specifications
The attenuation at cutoff frequencies is fixed at 6 dB (half the passband gain)
Design Filter
Designing Filter ... Done



Here we can observe that the response is sharper and amplitude of ripples is decreased in pass band.

From frequency and time response it is visible that the noise is removed to greater extent.

From above discussion we can conclude that for lower order of filter, response is not sharper but as we increase the order of notch filter, we are getting response closer to ideal characteristics. Increasing order will increase the hardware, space occupation and cost as well. As we are using FIR filter increasing order will increase the delay elements in filter which results in delayed output.

6.Applications:

- The notch filters are widely used in electric guitar amplifiers. Actually, the electric guitar produces a ‘hum’ at 60 Hz frequency. Then this filter is used to reduce that ‘hum’ by rejecting 60 Hz in order to amplify the signal produced by the guitar amplifier and make it the best equipment. These are also used in acoustic applications like Mandolin, Bass instrument amplifiers, etc.

- In communication electronics, the signal is distorted due to some harmonics (Noise) which makes the original signal to interfere with noise signal which leads to error in the output. Thus, notch filters are used to eliminate these unwanted frequencies of harmonics.
  These filters are used by musicians in high-quality audio applications such as graphic equalizers, synthesizers, and PA systems.

- In image and signal processing, these filters are highly preferred to eliminate noise.

- It is also used to reduce the static on the radio, which is commonly used in our daily life.

- These filters are also used in medical field applications, i.e., in biomedical instruments like ECG for removing lines.

7.(a) Limitations

Fixed filters are well suited for stationary environment and can be used for eliminating the power line interference60/50 Hz noise. When we know which frequency is to be eliminated, fixed filters are the best choice. In case of non-stationary signals such as ECG, filters designed using advanced learning algorithms are the optimum choice. After reviewing the literature carefully, we have chosen adaptive filters as potential candidate for the processing of ECG signal because

Of its flexibility to adapt to the changes in the signal. As Egos a non-linear signal, adaptive filters are well suited for its processing.

7. (B) Future Scope

Making the bandwidth narrower can reduce this violation of the frequency components of the desired signal. But narrowing the bandwidth of the notch filter requires a higher order of the filter that will result in many coefficients and more processing time. Another problem encountered when using a narrow band notch filter is that the filter loses its effectiveness in removing the AC noise when the interference frequency shifts or deviates from 50 Hz. In this work, only the Notch Filter is studied other noise filters can be studied and their suitability for application can be compared. Other algorithms that can be used include Recursive Least Squares and Least Mean Square. Moreover, this project does not consider the real time processing of finite-length filters and the causal approximation and also improvement of the thesis can be further implemented with different algorithms such as RLS algorithm and wiener filter to achieve the desired result.

8. References:

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[3] Malinda, P., “Cancelling power line interference in electrophysiological signals”. ECT Research Journal, Vol.2, 2002
[4] Windrow B. and Hoff M.E. (1960), “Adaptive switching circuits”, In IREWESCON Convention Record, pp. 96-104, New York.
[5] Zhang Joshua, Tai Hang-Ming, “Adaptive Noise Cancellation Algorithm for Speech Processing”, IEEE Transactions, pp. 2489- 2492, 2007.
[6] Jig ram H. Shah, Jay M. Joshi, “Digital signal processing”, University science press lama publication company Limited New Delhi.
[7] Suzanna M. M. Martens, Massimo Mischief, S. Guide Obey, “An Improved Adaptive Power Line Interference Canceller for Electrocardiography” IEEE transactions on biomedical engineering, vol. 53, no. 11, November 2006.
[8] https://fb.watch/ggA5xdr8jB/
[9] https://youtu.be/ke4i9NsTOyQ