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ECG Noise Reduction By Different Filters – A Comparative Analysis

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***Abstract* -The electrocardiogram (ECG or EKG) is a diagnostic tool that measures and records the electrical activity of the heart in exquisite detail. The electrocardiogram is commonly used to detect abnormal heart rhythms and to investigate the cause of chest pains, thus it is very important signal in cardiology. While recording noise, sources like the power line interference and other noise sources distorts the original ECG signal. This paper presents a comparative analysis of performances of various filters using approximations like Butterworth and Chebychev, on ECG noise filtration.**

***Keywords*– ECG, Butterworth and Chebychev approximation, FFT**

I INTRODUCTION TO ECG SIGNAL

Electrocardiography is the recording of the electrical activity of the heart over a time period, as detected by electrodes attached to the surface of the skin and displayed by a output device externally. The ECG plot shows the information of heart and cardiovascular condition which can be used for proper treatment and to enhance the patient living quality. The recording produced by this non-invasive method is termed an electrocardiogram (also ECG or EKG).

An ECG is used to measure the heart’s electrical conductivity system. It takes electrical impulses produced by the polarization and depolarization of cardiac tissue and translates into a wave-form. This waveform is then used to measure the rate of heartbeats, and also the size and position of the chambers of the heart, the presence of any kind of damage to the heart, and the various drugs or devices used to control or regulate the heart functioning, like pacemaker. It can also give information regarding the balance of salts (electrolytes) in the blood (e.g. hyperkalaemia) or even reveal problems with sodium channels within the heart muscle cells (Brugada syndrome).It is one of the key tests performed when a heart attack (myocardial infarction or MI) is suspected; the ECG can identify whether the heart muscle has been damaged in specific areas, though not all areas of the heart are covered. The ECG cannot reliably measure the pumping ability of the heart, for which ultrasound-based (echocardiography) or nuclear medicine tests are used. ECG signal taken from a patient was distorted by an external noise, so that we need a proper way to get a noise free ECG signal, a simple ECG wave form shown in Fig.1. An ECG signal is a combination of P, T, U wave, and a QRS complex. The complete wave form is called an electrocardiogram with labels P, Q, R, S, and T indicating its distinctive features.
The P wave arises from the depolarization of the atria and the QRS complex arises from the depolarization of the ventricles. The T wave arises from re-polarization of the ventricle muscle.

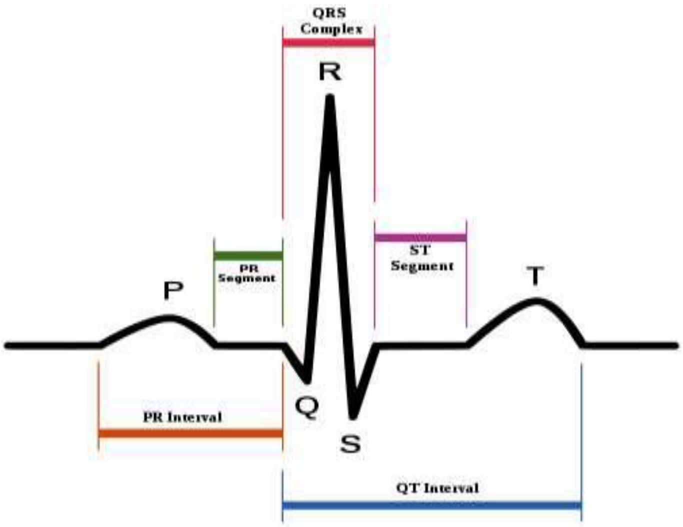

Fig.1. ECG signal

II NOISE AND ARTIFACTS ON ECG WAVEFORM

ECG data consists noise and artifact components that change the waveform of the ECG trace from the ideal structure described earlier and render the clinical observation inaccurate and misleading. Consequently, a pre-processing step to improve the signal quality is recommended. It is therefore important to be aware of most common types of noises and artifacts in the ECG tracing and find a method which can compensate for their presence before proceeding to the future extraction step.

ECG is a typical non-stationary and random signal. ECG signals contain limited information above 100 Hz in which 90% of the ECG spectral energy concentrated in the 0.25 Hz to 20 Hz. ECG inevitably influenced by various kinds of noise interferences, can be summed up in the following three types:

A Baseline Wander:

It is extraneous noise in the ECG trace that may be caused from a variety of noise sources including perspiration or respiration and any kind body movements, or poor electrode contact. The magnitude of this wander may exceed the amplitude of the QRS complex by many times, but spectral content of it is usually confined to an interval below 1Hz

B Power line Interference (50/60 Hz):

It is high frequency noise caused by interferences from nearby devices as a result of improper grounding of the ECG equipment.

C Electromyographic Noise (EMG Noise):

It is mainly caused by the electrical activity of skeletal muscles during periods of contraction or due to a sudden body movement. While the frequency component of EMG considerably overlaps with that of QRS complex and it also extends into higher frequencies. As a result, processing the ECG trace to remove this noise affects naturally results in introducing some distortion to the signal.

The ECG signal mixed with noise, causes distortion of the ECG, affecting the subsequent signal analysis and processing, leading to faulty diagnosis. . Therefore, ECG signal denoising has important significance.

III DIFFERENT FILTERS AND THERE PERFORMANCES

A noisy ECG signal is downloaded from database available on www.physionet.org website. This signal is loaded into Simulink by using workspace in Matlab and used for further processing.

Fig.2 below shows ECG signal contaminated by the various noise sources and it shape is distorted:

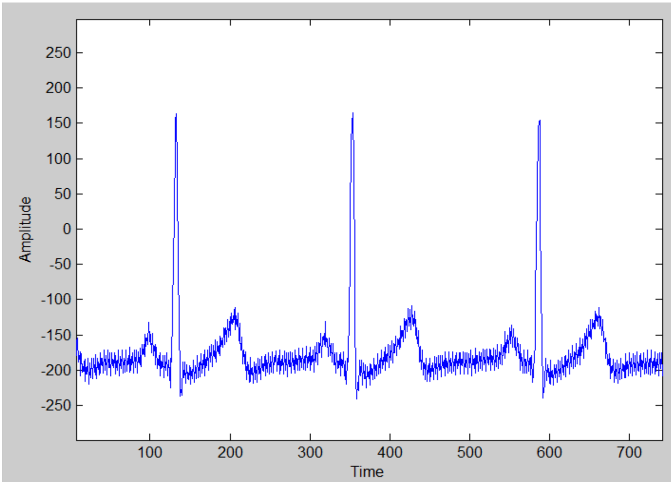

Fig.2. ECG Contaminated by Noise

The FFT (Fast Fourier Transform) of the original recorded noisy signal is as shown in Fig.3:

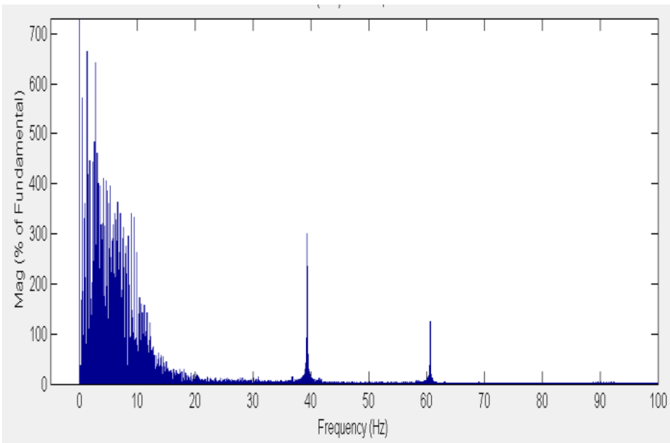

Fig.3. FFT of Noisy ECG signal

In this FFT analysis, it is clearly observed that the signal is mainly distorted by 40 Hz and 60 Hz frequency signals as shown by peaks. So we needed to remove these noises to get the original shape of ECG.
For this, the signal is passed through various filters one by one like 6^{th} order simple low-pass filter, Low-pass filter using Butterworth approximation and Chebyshev approximation, Notch filter and Band-reject filter. All filters and their responses are described below:

A. RC Low-pass filter:

A RC low-pass filter of order 6 having cutoff frequency 150 rad/sec is used. The filtered ECG signal is shown in Fig.4and FFT analysis of filtered signal is shown in Fig.5:

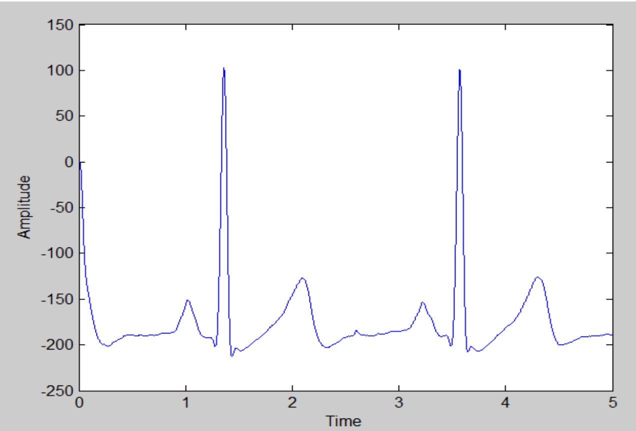

Fig.4. Simple RC Low-pass Filtered ECG

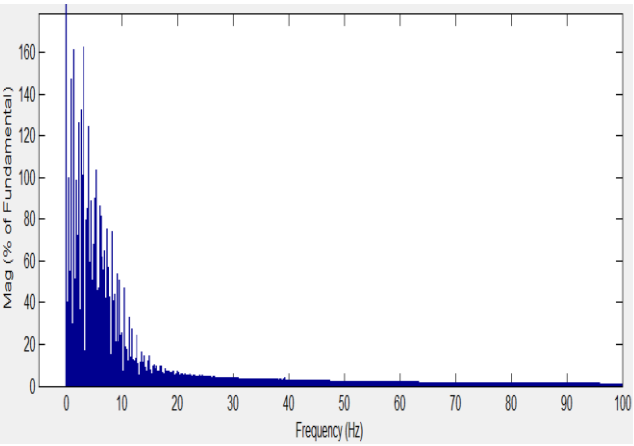

Fig.5. FFT analysis of Simple RC Low-pass Filtered ECG

B. Low-pass filter using Butterworth approximation :

A low-pass filter using Butterworth approximation is designed. Specifications of the filter are:
Pass-band gain is 0.84 dB and stop-band gain is 0.032 dB. Cutoff frequency is 150 rad/sec and stop-band frequency is 300 rad/sec is taken. After calculation it is found that the minimum order of the filter is 6. The filtered ECG signal is shown in Fig.6and FFT analysis of filtered signal is shown in Fig.7**:**

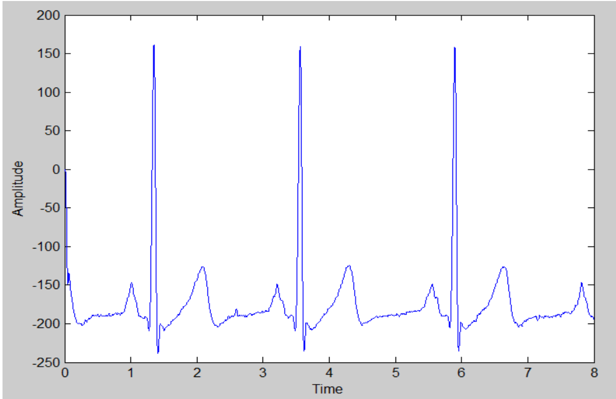

Fig.6. Using Butterworth approximation Filtered ECG

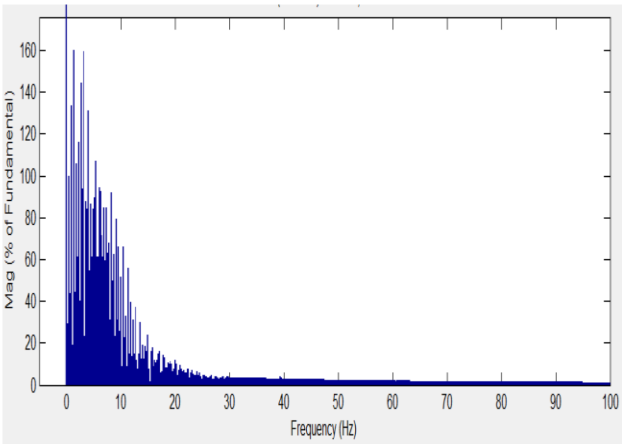

Fig.7. FFT analysis of Butterworth approximation Filtered ECG

C. Low-pass filter using Chebyshev approximation:

Another low-pass filter using Chebyshev approximation is designed. Specifications of the filter are same as Butterworth approximation. After calculation it is found that the minimum order of the filter is 4. The filtered ECG signal is shown in Fig.8and FFT analysis of filtered signal is shown in Fig.9**:**

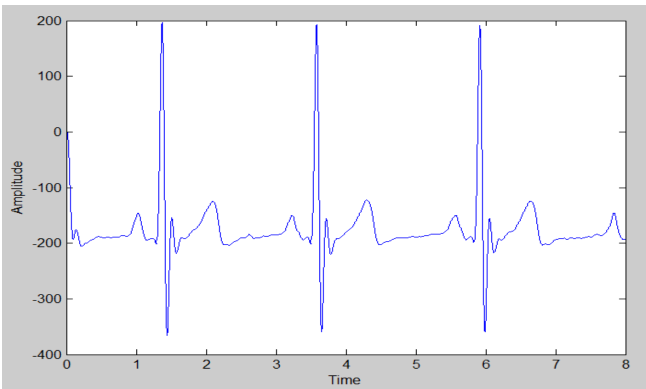

Fig.8.Using Chebyshev approximation Filtered ECG

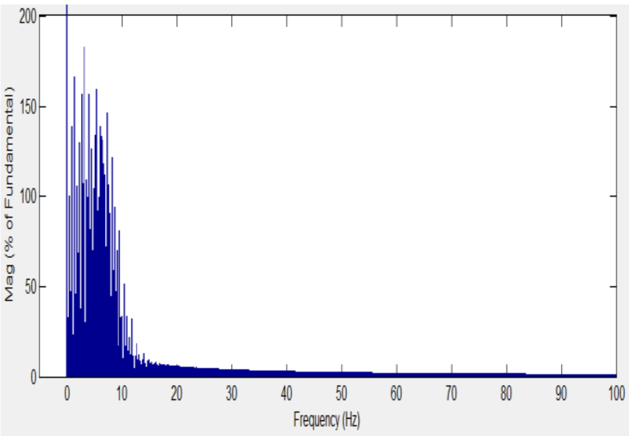

Fig.9. FFT analysis of Chebyshev approximation Filtered ECG

D. RLC Notch filter:

As it is noticed in FFT analysis of noisy ECG signal, there are two spikes at 39.6 Hz and 60.6 Hz. So a Notch filters are designed. The filtered ECG signal is shown in Fig.10and FFT analysis of filtered signal is shown in Fig.11**:**

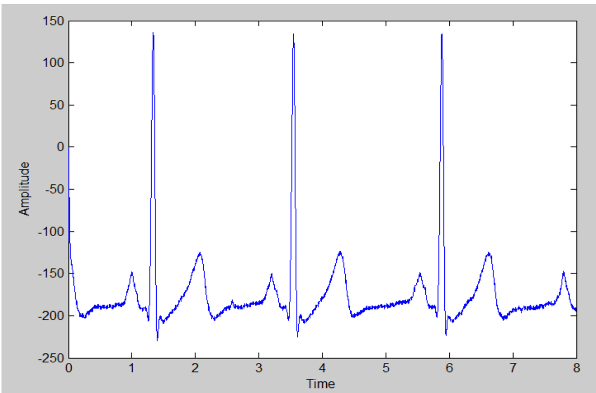

Fig.10. RLC Notch Filtered ECG

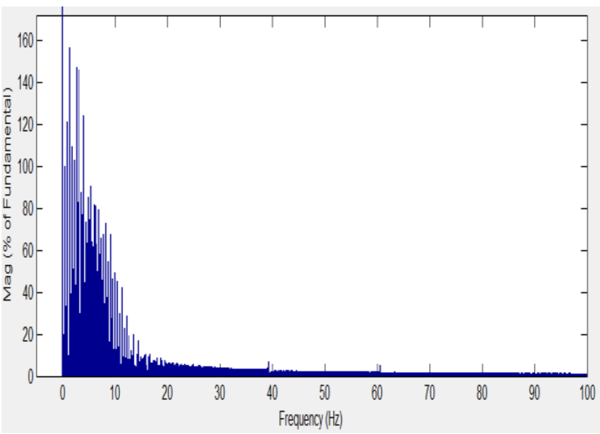

Fig.11. FFT analysis of Notch Filtered ECG

E. Butterworth Band-reject filter:

After careful observation of FFT analysis of Noisy ECG signal, it is found that there is a band of frequency around 39 Hz and 60 Hz. So a band-stop or band-reject filters are used to filter this signal. The filtered ECG signal is shown in Fig.12and FFT analysis of filtered signal is shown in Fig.13:

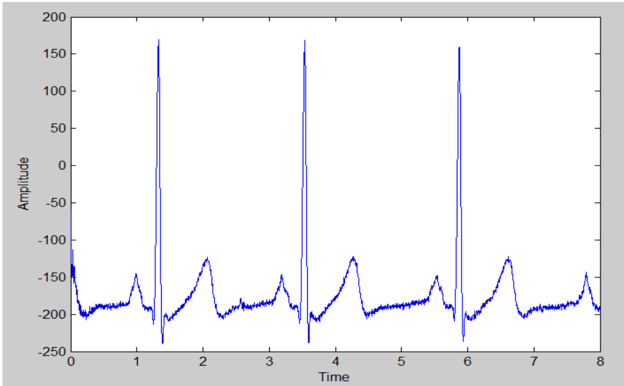

Fig.12.Butterworth Band-reject Filtered ECG

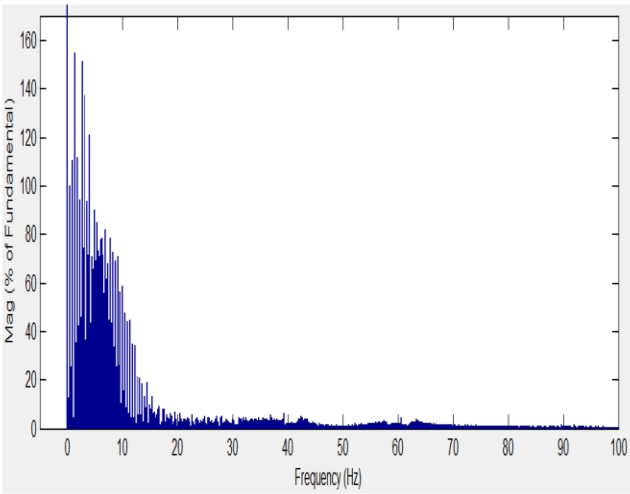

Fig.13.FFT analysis of Butterworth Band-reject Filtered ECG

IV TESTING THE PERFORMANCE OF FILTERS

Different filters are used and the output responses are almost similar. As pure ECG signal is not present to compare with so it is difficult to discriminate that which filter is better. So here is need to test the performance of the filters on a different known signal.

For testing the performance of various filters used in ECG noise filtration, a signal approximately similar to Noisy ECG signal is generated using 20 sine wave functions having different amplitude and frequency range between 0.75 Hz to 15 Hz. The generated signal is as shown in Fig.14:

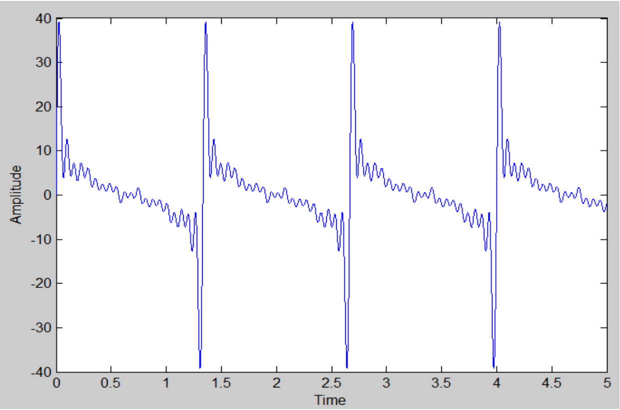

Fig.14. Generated signal

Now two sinusoidal signal having frequencies 39.4025 Hz and 60.5865 Hz are added to create noisy signal. The noisy signal and FFT analysis of this signal are shown below in Fig.15 and Fig.16.

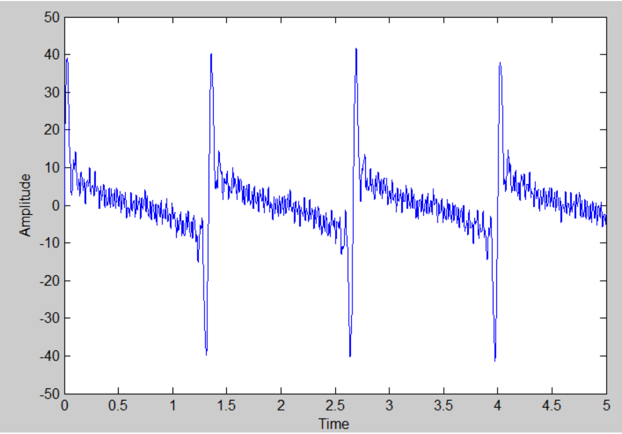

Fig.15. Generated Noisy signal

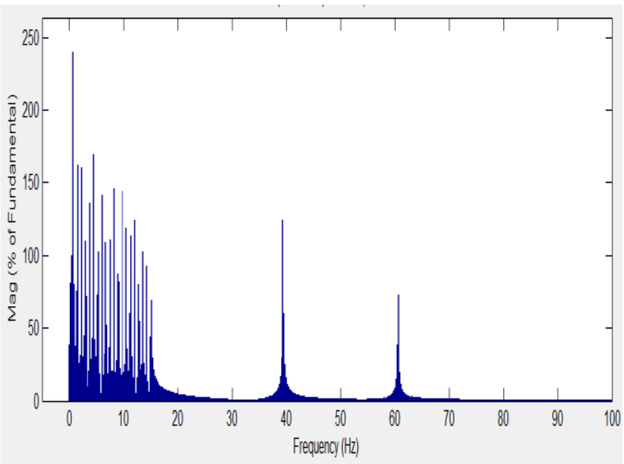

Fig.16. FFT of Generated Noisy signal

As shown in above Figures that the signal is approximately having the same characteristics. Now same filters are used to filter this signal in order to get the original generated signal. Various responses and their FFT analysis of all filters are shown in following Figures:

A. Response of 6th order RC low-pass filter:

After filtering the signal, the output is not matched with the input original signal. As shown in Fig. 17 and Fig.18.

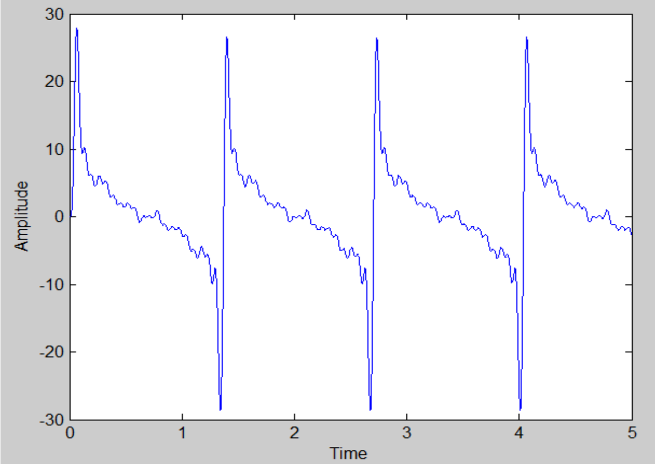

Fig.17. Response of 6th order RC low-pass filter

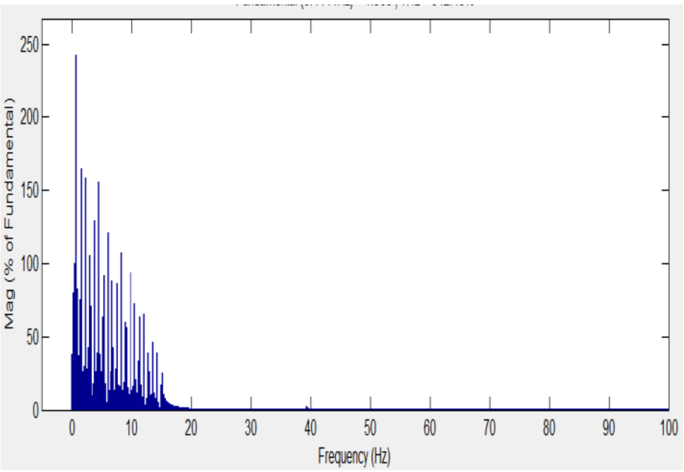

Fig.18. FFT analysis of 6th order RC low-pass filter

B. Response of Low-pass filter using Butterworth approximation:

This filter gives the exact signal as original is. As shown in Fig.19 and Fig.20.

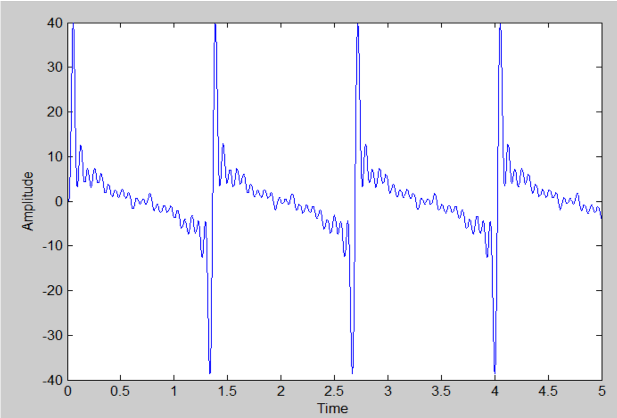

Fig.19. Response of Low-pass filter using Butterworth approximation

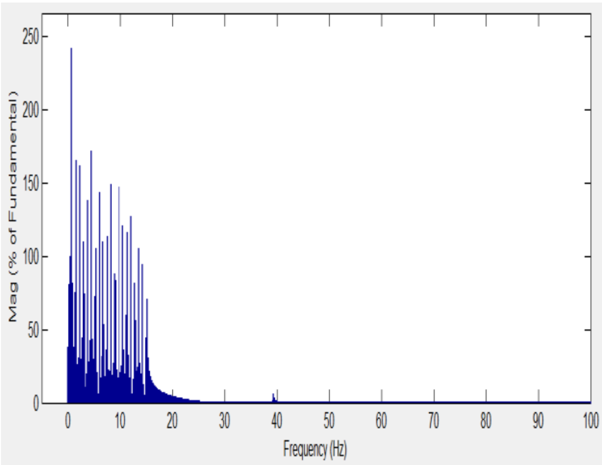

Fig.20. FFT analysis of Low-pass filter using Butterworth approximation

C. Response of Low-pass filter using Chebyshev approximation:

This filter gives the distorted signal, although it removes the noise frequency but distorts the shape of the signal as shown in Fig. 21 and Fig.22.

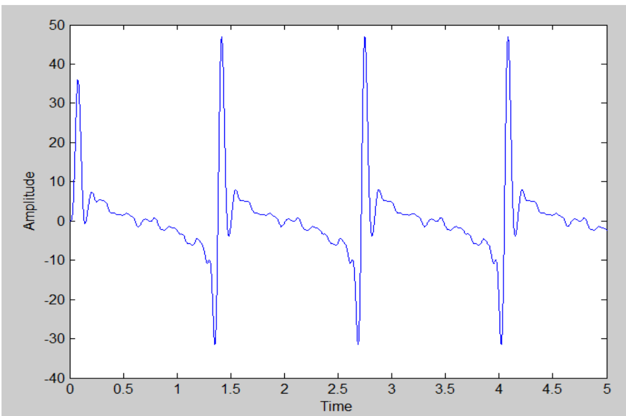

Fig.21. Response of Low-pass filter using Chebyshev approximation

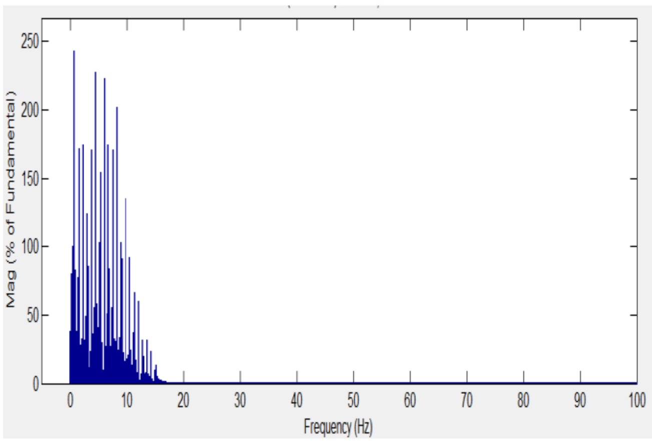

Fig.22. FFT analysis of Low-pass filter using Chebyshev approximation

D. Response of RLC Notch filter:

Notch filter somehow shows results better than chebyshev filter as shown in Fig.23 and Fig.24.

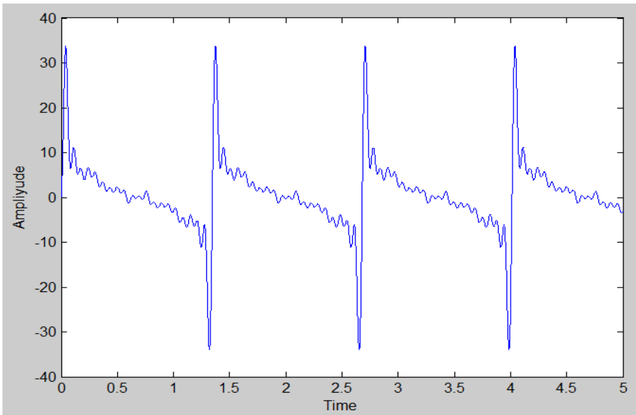

Fig.23. Response of RLC Notch filter

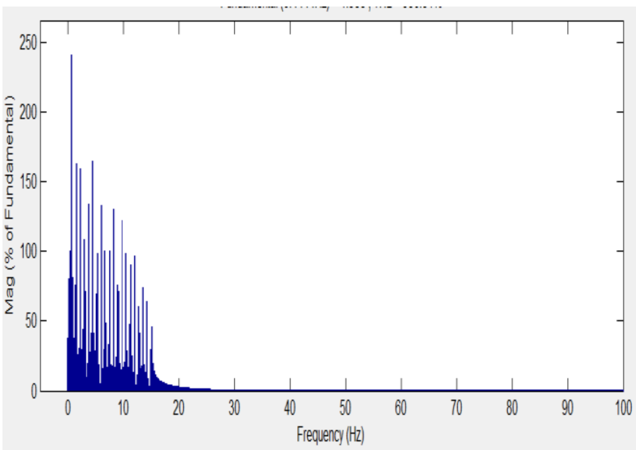

Fig.24. FFT analysis of RLC Notch filter

E. Response of Butterworth band-reject filter:

This filter also shows the better response than Notch filter as shown in Fig.25 and Fig.26.

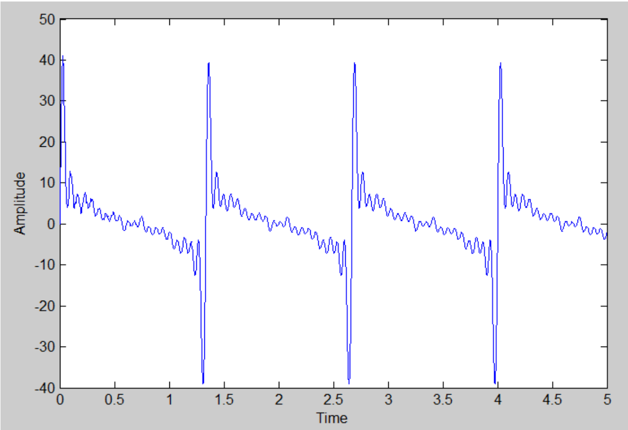

Fig.25. Response of Butterworth band-reject filter

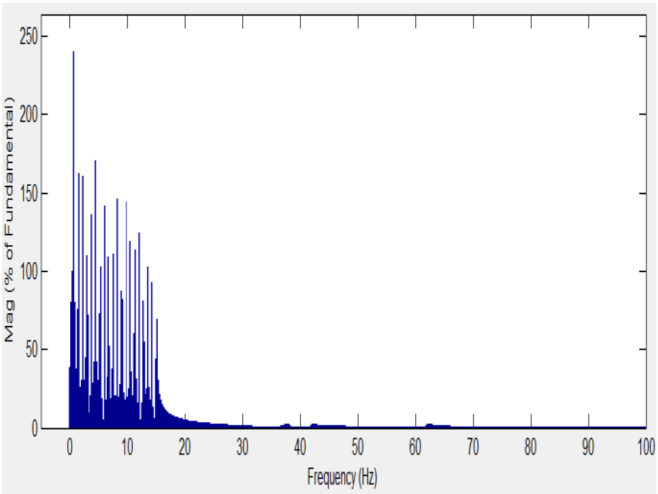

Fig.26. FFT analysis of Butterworth band-reject filter

V CONCLUSION

After designing the various filters and observing the performances of filters by testing, it is found that Butterworth filtering technique is better among all filters whereas Chebyshev filtering technique shows a comparatively poor response among all filters. As order of the Butterworth filter is high so this technique might be costly (as more reactive elements to be used) among all but in performance, it is very reliable. For a given set of specifications, the order of the desired Chebyshev filter will be lower than that of the desired Butterworth filter but the response of Chebyshev is not that desirable.

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