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# Enhancement of ECG Signal by using Digital FIR Filter

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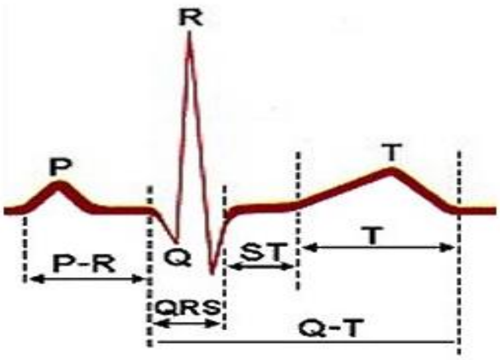
**Abstract:** ***Electrocardiogram (ECG) signal is generally corrupted by various artifacts like baseline wander, power line interference (50/60 Hz) and electromyography noise and these must be removed before diagnosis. The task propounded in this article is removal of low frequency interference i.e. baseline wandering and high frequency noise i.e. electromyography in ECG signal and digital filters are implemented to delete it. The digital filters accomplished are FIR with various windowing methods as of Rectangular, Hann, Blackman, Hamming, and Kaiser. The results received are at order of 300.The signal taken of the MIT-BIH database which contains the normal and abnormal waveforms. The work has been in MATLAB where filters are implemented in FDA Tool. The result received for entire FIR filters with various windows are evaluated the waveforms Signal to Noise Ratio (SNR), Mean Sqaure Error (MSE) of the noisy and filtered ECG signals. The filter which shows the excellent outcomes is the Kaiser Window.***

**Keywords:** ECG, FIR filter, windowing methods, MATLAB

## 1. Introduction

Biomedical signals are produced by the physiological activities in the organism. All living organisms, from gene and protein sequences to neural and cardiac rhythms are capable to produce signals. These signals could be observed or monitored to realize some aspects of a particular physiological system. In medical assistance, the cardiac signal, ECG is the more common signal used by doctors to evaluate heart anomalies. The ECG is a representation of heart electrical activity in time, which is highly used to detect heart disorders. According to the most recent statistics, reported by the World Health organization, cardiovascular diseases remaining the main specific cause of mortality in any region of the world. Several studies demonstrate the importance of reducing the time delay to treatment for improving the clinical outcome of the patients in case of acute coronary syndromes. Some of the most common cardiac problems, or myocardial infarction (heart attack), ventricular tachycardia, ventricular fibrillation or atrial fibrillation, where the early detection of the first symptoms occurrence is crucial, which significantly decreases mortality rate and admission time in a hospital or medical centers. These are sufficient reasons for considering ECG signal as a relevant signal to be monitored by portable systems.

The ECG is a diagnostic tool that measure and records the electrical activity of the heart. The amplitude and duration of the P-QRS-T-U wave contains useful information about the nature of disease related to heart.




The ECG signal is typically in the range of 2 mV and requires a recording bandwidth of 0.5 to 100 Hz. The ECG is acquired by a non-invasive technique, i.e. placing electrodes at standardized locations on the skin of the patient.

## 2. Noise in ECG Signal

Generally the recorded ECG signal is often contaminated by different types of noises and artifacts that can be within the frequency band of ECG signal, which may change the characteristics of ECG signal. Hence it is difficult to extract useful information of the signal. The corruption of ECG signal is due to following major noises:

1. Environmental
2. Biological sources

Environmental noises are 60Hz power interference noise and instrumentation noise generated using hardware.

Biological noise is baseline wander, electromyogram (EMG) and motion artefact.

### 2.1 60-Hz Power Line Interference

Alternating current (AC) is the type of electricity that we get from the wall. It changes direction 60 times per second, hence 60Hz. It is an environmental noise in the ECG that results from poorly grounded ECG recording machine. Because of the alternating current feature, this noise appears

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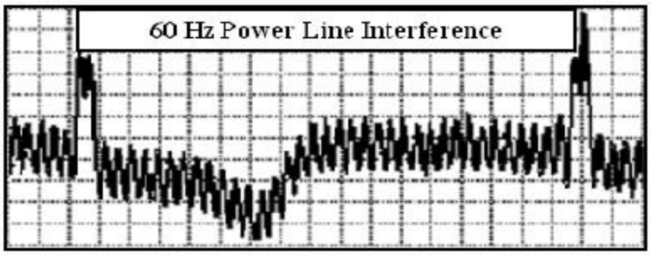
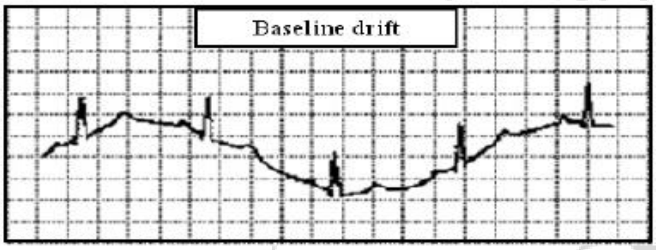
at 60Hz and its harmonics.




2.1 60 Hz Power line interference

**2.2 Baseline Wander Noise**

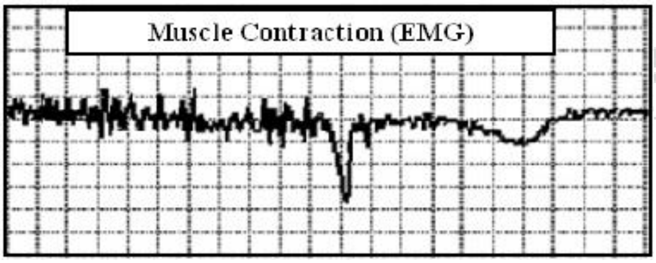
Baseline drift is a biological noise that appears in ECG signal. It is caused by variations in the position of the heart with respect to the electrodes and changes in the propagation medium between the heart and the electrodes. This causes sudden changes in the amplitude of the ECG signal, as well as low frequency baseline shifts.




In addition, poor conductivity between the electrodes and the skin reduces the amplitude of the ECG signal and increases the probability of disturbances (by reducing SNR).

**2.3 Electromyography Noise**

Electromyography noise is caused by the contraction of other muscles besides the heart. When other muscles in the vicinity of the electrodes contract, they generate depolarization and repolarization waves that can also be picked up by the ECG.




The extent of the crosstalk depends on the amount of muscular contraction (subject movement), and the quality of the probes. The frequency of this EMG noise is in between 100-500 Hz.

## 3. ECG Database

I have collected ECG data from the laboratories at Boston's Beth Israel Hospital (BIH) and at Massachusetts Institute of Technology (MIT) have supported the research in arrhythmia analysis and related subjects by creating a database. The ECG samples database consists 48 half hours excerpts of two channel ambulatory ECG recordings are utilized to verify the results of digital filter designed as described above in methodology.

## 4. Digital filter

A digital filter is a system that performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. FIR filters are digital filters with finite impulse response. They are also known as non-recursive digital filters as they do not have the feedback, even though recursive algorithms can be used for FIR filter realization. The design of FIR filters is preferred due to the following advantages:

1) Exact linear phase
2) Always stable
3) Design methods are linear
4) Can be realized efficiently in hardware

## 5. Window Method

In this method, we start with the desired frequency response specification $Hd(\omega)$ and the corresponding unit sample response $hd(n)$ is determined using inverse Fourier transform. The relation between $Hd(\omega)$ and $hd(n)$ is as follows :

$$h(n) = hd\,(n)\,w(n)$$

Now, the multiplication of the window function $w(n)$ with $hd(n)$ is equivalent to convolution of $Hd(\omega)$ with $W(\omega)$, where $W(\omega)$ is the frequency domain representation (Fourier transform) of the window function. By using appropriate window functions method which is time function we can reduce Gibbs oscillations.

## 6. Window functions

Using appropriate window functions which are time domain function, we can reduce Gibb's oscillations and to precondition the impulse response. The following window functions are most commonly used:

1)Rectangular window
2)Harr window and hamming window
3)Blackman window
4)Kaiser window

The FIR filter design procedure with window functions method can be classified to different stage:

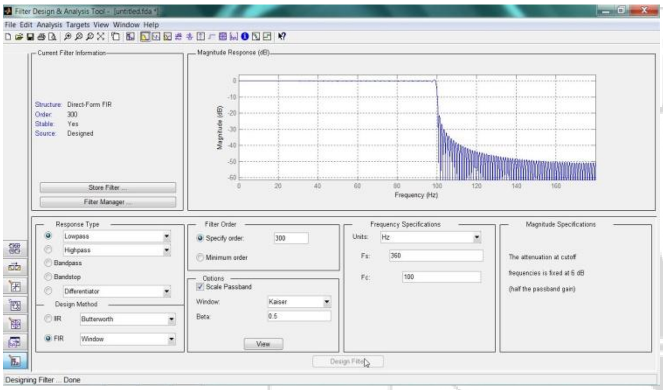
- Defining filter characteristic
- Determining a window function according to the filter characteristics
- Calculating the filter order required for a given set of characteristics
- Computing the window function coefficients
- Calculating the ideal filter coefficients according to the filter order
- Computing FIR filter coefficients according to the gain window function and ideal filter coefficients
- If the resulting filter has too wide or too narrow transition area, it is required to change the filter order by increasing

or decreasing it according to denoising of ECG signal.

## 7. The Window Based FIR Filter Design

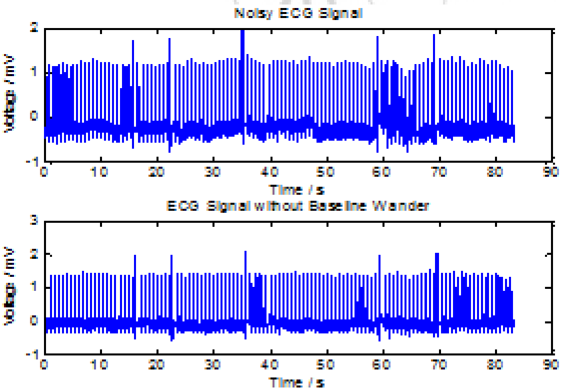
We designed the filter for corrupted ECG signal in four steps:

1. In first step with the help of FDA Tool in MATLAB software design FIR with high pass filter cut off frequency 0.5 Hz based on window to removing baseline wander noise from noisy ECG signal.
2. In second step removing power line interference (50/60 Hz) by band stop with cut off frequency (59.5Hz-60.5 Hz).
3. In third step we deleting EMG noise by applying low pass filter with cut off frequency 100Hz.
4. Finally moving average filter to smooth the ECG waveform. The task was accomplished in various orders.

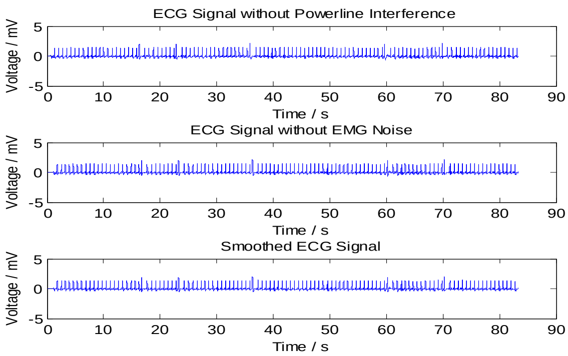


7.1 Filter analysis tool

## 8. FIR High Pass Filtered Signal

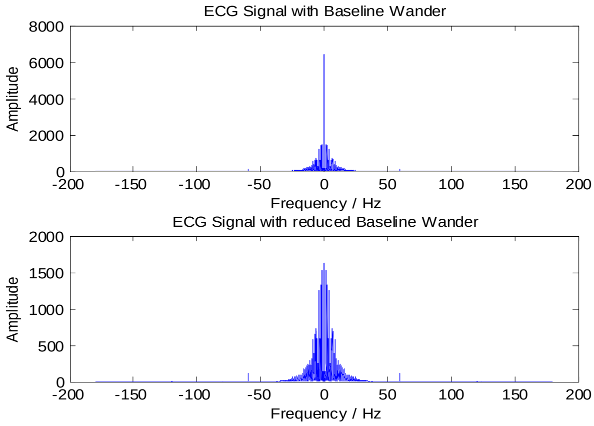


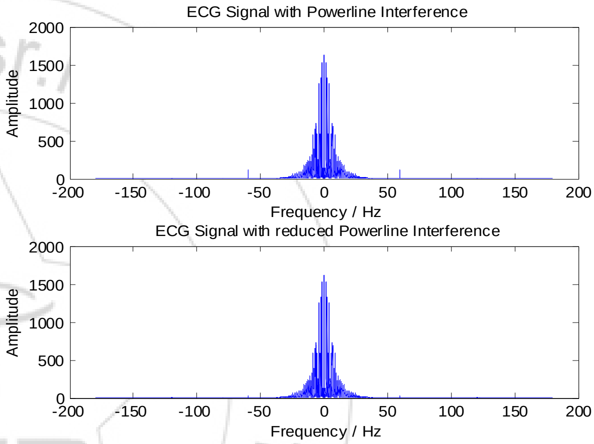

8.1 ECG before & after filtering of Baseline Wander

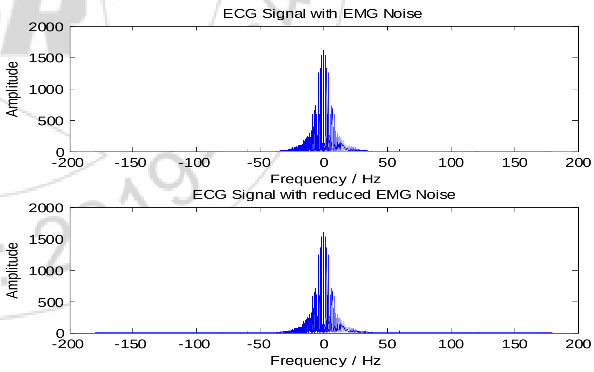



8.2 ECG shows signal after denoising and smoothing

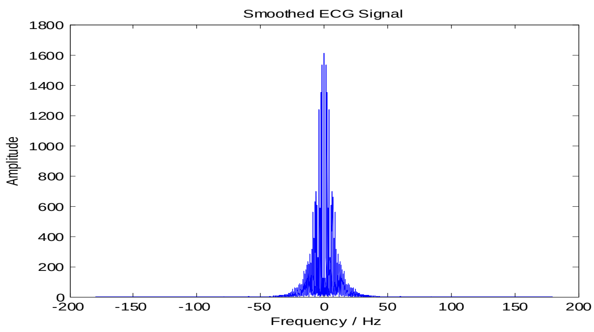
### 8.1 FFT of noisy and filtered ECG



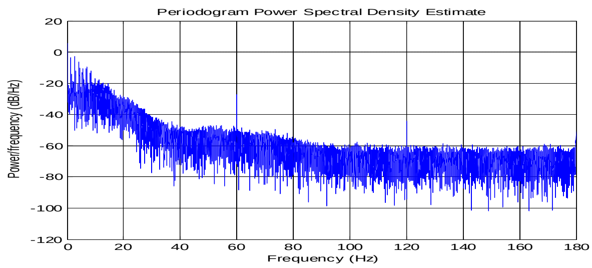



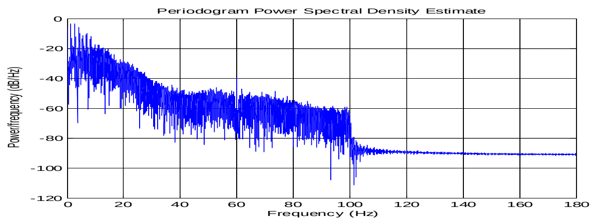




### 8.2 Smoothed ECG signal

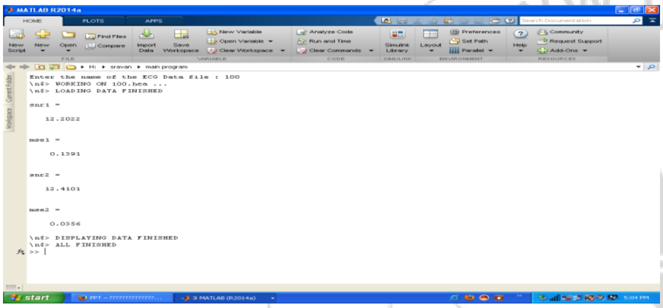


### 8.3 Power spectral density of noisy and filtered ECG




### 8.4 Result in command window



### 8.5 SNR (Signal to noise ratio) comparison of window based FIR filters

| Real ECG data | SNR | Signal to noise ratio of FIR (windowing) filtered ECG signal | | | | |
|---|---|---|---|---|---|---|
| | | Rectangular | Hann | Hamming | Blackman | Kaiser |
| 100m | 12.2 | 12.331 | 14.14 | 13.977 | 14.144 | 12.42 |
| 104m | 8.09 | 7.8216 | 7.520 | 7.581 | 7.7855 | 7.793 |
| 105m | 8.30 | 9.2670 | 8.396 | 8.4674 | 8.5737 | 9.333 |
| 106m | 10.1 | 10.963 | 12.44 | 12.478 | 12.504 | 13.01 |
| 108m | 4.71 | 3.4711 | 5.155 | 4.9928 | 5.4241 | 5.516 |
| 109m | 6.33 | 7.2382 | 6.258 | 6.3297 | 6.3841 | 7.184 |

### 8.6 MSE (Mean square error) comparison of window based FIR filters

| Real ECG data | MSE | Mean square error of the FIR (windowing) filtered ECG signal | | | | |
|---|---|---|---|---|---|---|
| | | Rectangular | Hann | Hamming | Blackman | Kaiser |
| 100m | 0.1391 | 0.0349 | 0.0667 | 0.0631 | 0.0751 | 0.036 |
| 104m | 0.1303 | 0.0637 | 0.0811 | 0.0792 | 0.0852 | 0.066 |
| 105m | 0.1423 | 0.0968 | 0.1067 | 0.1054 | 0.1095 | 0.097 |
| 106m | 0.1288 | 0.0920 | 0.1008 | 0.0997 | 0.1031 | 0.092 |
| 108m | 0.0892 | 0.0262 | 0.0434 | 0.0414 | 0.0481 | 0.027 |
| 109m | 0.2500 | 0.1725 | 0.1915 | 0.1891 | 0.1956 | 0.173 |

## 9. Conclusion

The results for various filters are considered and evaluated by waveforms, power spectrums density (PSD), signal to noise ratio (SNR), Mean square error (MSE) where Kaiser Window show the best outcome.The order 300 of filters designed showing the best results comparison to order 450 and 600. Hence it can be finalized that Kaiser Windowing shows best outcomes at order 300.

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