Analysis of Various Filter Configurations on Noise Reduction in ECG Waveform

Prashanth Shetty, and Somashekhara Bhat

Abstract— Electrocardiography (ECG) is the graphical recording of the electrical activity of the heart and plays a vital role in the primary diagnosis and monitoring of the health of heart. The ECG signal being very sensitive and weak in nature, highly prone to even small noise. Hence the design of the entire efficient filter system is the key for the success of the entire ECG processing system.

In this work our main task is to design efficient analog filters to eliminate all the noise sources associated with the ECG signal so as to get a noise free ECG signal as output from the filters. This paper mainly focuses on filtering the noise sources mainly corrupt the retrieved ECG signal such as power line interference, base line wander noise, motion artifact noise instrumentation noise etc.

The main aim of this work is to study the effect of various filtering stages on the noisy ECG signal, to approximately estimate the order of each filter stage required to get the required quality of output signal and to show the proof of concept of the entire filtering process. Several types of analog filters were designed, implemented and tested for their correctness.

Keywords— Analog Filters, Biomedical Signal Processing, Butterworth and Chebyshev filter, Electrocardiogram, Elliptic filter, Signal to Noise Ratio (SNR).

I. Introduction

ELECTROCARDIOGRAPHY (ECG) is a non-invasive method for capturing and processing the electrical signature of the heart via skin electrodes and is in very wide use (an estimated 200 million ECGs taken each year) [1].

ECG applications are broad and varied in their scope, and therefore, so are the requirements for the analog data acquisition and processing system. As with most of the biomedical signals, the ECG signal and its harmonics are low in bandwidth (0.1 to 300 Hz) with typical amplitude of 0.1 to 4 mV as shown in Fig. 1. For this reason, a high dynamic range is required for this system. The increasing demand on portable and wearable personal healthcare devices (e.g. heart rate monitoring watch) requires a new generation of Low Power Low Voltage (LVLP) bio-medical signal processing building blocks. The challenges in ECG signal acquisition revolve primarily around external noise rejection on the analog front-end (AFE) and finally signal processing by the back-end conditioning circuitry.

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For testing purpose, the ECG signals from MIT-BIH Arrhythmia Database are taken as the test data [2]. All the work was done with MATLAB®. The noises were simulated and added to the test data.

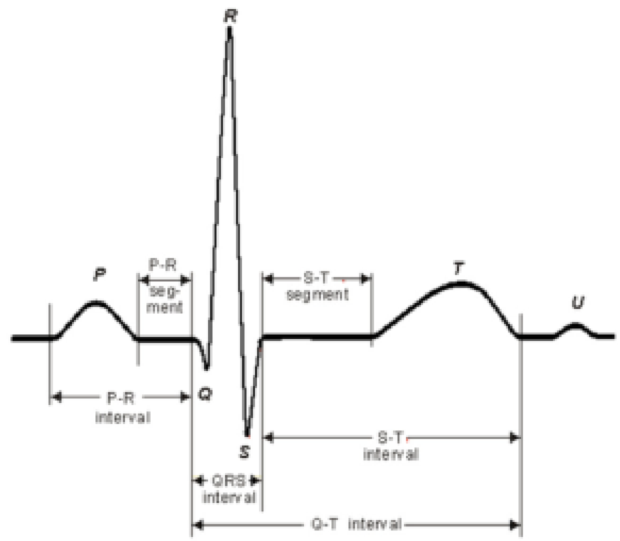

Fig. 1 Typical healthy Electrocardiogram trace [3]

II. Noises And Artifacts In Ecg Waveform

Raw ECG data contain some noise and artifact components that alter the shape of the ECG trace from the ideal structure as shown in Fig. 1 and render the clinical interpretation inaccurate and misleading; consequently, a pre-processing step for improving the signal quality is a necessity. It is therefore important to be familiar with the most common types of noise and artifacts in the ECG and the type of filters required to denoise the ECG.

ECG inevitably affected by various types of noise interference, summed up in the following three types of noise [4]:

A. Baseline Wander

Baseline Wander is extraneous noise in the ECG trace that may be caused from a variety of noise sources including perspiration, respiration, body movements, and poor electrode contact. The magnitude of this wander may exceed the amplitude of the QRS complex by several times, but its spectral content is usually confined to an interval below 1Hz (between 0.15 and 0.3 Hz). Baseline drift can be represented as a sinusoidal component at the frequency of respiration added to the ECG signal. The drift causes problems in the detection of ECG signals, e.g., sometimes the amplitude of T-wave is higher than the peak of R-wave and results in false detection of R-peak.

B. Power Line Interference (50/60 HZ)

Power Line Interference is high frequency noise caused by interferences from nearby devices as a result of improper grounding of the ECG equipment. This noise degrades the signal quality and affects the tiny features which can be critical for clinical diagnosis and monitoring and signal processing. The power line interference is narrow-band noise centered at 50 Hz (or 60 Hz) with a bandwidth of less than 1 Hz.

C. Electromyographic Noise (EMG Noise)

This 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 the QRS complex, it also extends into higher frequencies. As a result, processing the ECG trace to remove this noise naturally results in introducing some distortion to the signal. It has a frequency range between dc and 10,000 Hz with amplitude of 10% level.

There are other types of noises contaminating the ECG signal such as instrumentation noise, electrosurgical noise and other less significant source of noise. Among these noises, the power line interference and the baseline wandering are the most significant and can strongly affect ECG signal analysis. Except for these two noises, other noises may be wideband and usually a complex stochastic process which also distort the ECG signal.

III. Simulation And Filtering Of Noise In ECG

Since the goal of this paper is to design and implement analog filters for the filtering of noises and to evaluate the performance of these filters, each noise signal is first modeled and simulated. The characteristics of each noise described in section 2 play a vital role in modeling the noise signal.

A. Simulation of Power Line Interference [5]

Power line interference consists of 50/60 Hz and its harmonics which can be modeled as sinusoids and a combination of sinusoids with amplitude up to 50 % of the peak- to-peak of ECG amplitude. The model of power line interference is provided as in (1). Fifty Hertz power line noise is simulated using the MATLAB® [6]. The noise level corresponds to the peak-to-peak amplitude of 0.15 mV. The frequency of power line is 50 Hz.

$$N(t) = A \times \sin(2 \times \pi \times f \times t) \quad (1)$$

Where N(t) is the power line noise, A is the amplitude and f is the frequency of power line.

Analog notch filter or band stop filter is mostly the first choice for rejecting the specific frequency of the signal. The notch filters were designed to suppress the 50 Hz power line noise. The performance of the filter was evaluated by comparing their power spectra along with the mean square error (MSE).

B. Simulation of Baseline Wander

Baseline wander is one of the most significant noise sources during the ECG measurement. This noise is simulated as a low frequency sinusoid. The frequency is 0.3 Hz and the amplitude is 1 mV for the simulation. It is modeled similar to the power line interference in (1).

The frequency content of baseline wander is usually in a range well below 0.5 Hz (between 0.15 and 0.3 Hz). These low frequency components can severely affect the visual interpretation of an ECG. In order to discard baseline drift, a high pass filter designed with 0.5 Hz of cutoff frequency is required.

C. Simulation of Electromyographic Noise (EMG Noise)

The frequency content of EMG signal is usually in a range from dc to 10 KHz. The high frequency components may be discarded using a low pass filter designed with 100 Hz of cutoff frequency. The Table I gives the filter type required for removing the various sources of noise components.

TABLE I
CONSOLIDATED FILTER TYPE FOR DIFFERENT NOISE REMOVAL

S. No	Noise Type	Filter Used	Frequency Range
1	Baseline Wander	High Pass Filter	Below 1 Hz
2	Power Line Interference	Band Stop Filter	50/60 Hz
3	EMG Noise	Low Pass Filter	Above 100 Hz

A time domain plot of noise free ECG signal from database and the ECG contaminated by power line interference and baseline wander is described in Fig. 2, 3.

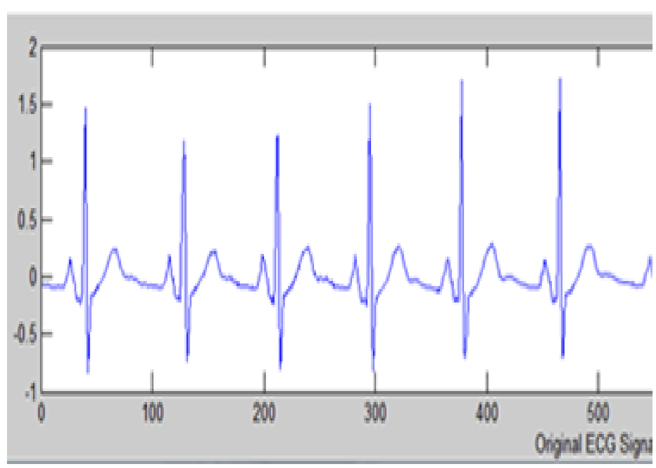

Fig. 2 Noise free ECG signal

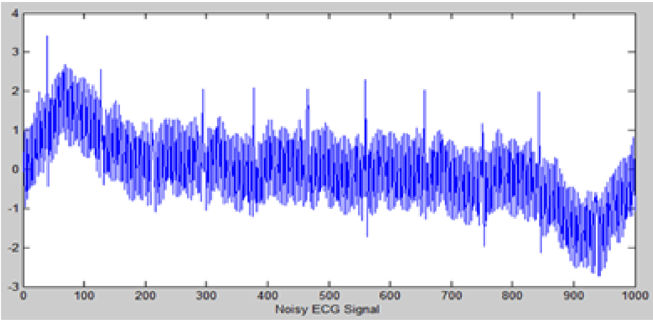

Fig. 3 ECG signal corrupted with noise sources

IV. Results And Discussions

Five standard filter configurations have been tested for high pass and notch filter implementations to suppress both Baseline wandering noise and power line interference noise. Their performances are compared by computing the Signal-to-Noise ratio (SNR) for each of them. The results of this comparison are summarized in the Table II.

A 4th order Elliptic filter and a 7th order Chebyshev Type II configurations are found to be better choice for the implementation of high pass and Notch filters respectively.

TABLE II
Comparison Of Parameters Of Various Filtering Approaches

	Highpass Filter Filter Order: 4 Input SNR= -11.6132	Notch Filter Filter Order: 7 Input SNR= -8.2286
Filter Type	SNR (dB)	SNR (dB)
Butterworth	2.4946	8.9274
Chebyshev-I	3.3689	8.7764
Chebyshev-II	2.5501	8.9676
Elliptic	3.3846	8.9669

A. Baseline Wander Removal by Elliptic High Pass Filter

Baseline wandering is eliminated by using an Elliptical high pass filter [7]. After we remove baseline wandering, the resulting ECG signal is more stationary and explicit than the original signal.

The high pass elliptic filter is designed with order of 4 with the attenuation in pass band is 1 dB, the attenuation in the stop band is 60dB and cut-off frequency 0.5Hz. Fig. 2-4 shows the responses of the elliptic high pass filter.

From responses of the filter following observations are made:

– This filter provides equiripple behavior in the pass as well as stop band.
– Pole-zero diagrams clearly shows that poles and zeros are within the circle so that the designed filter is stable.

Fig. 4 shows the magnitude response of the elliptic high pass filter of the order 4 and cutoff frequency 0.5Hz. The ECG signal after passing through the high pass filter is shown in the Fig. 5. It can be seen that the signal now is free from baseline wander noise.

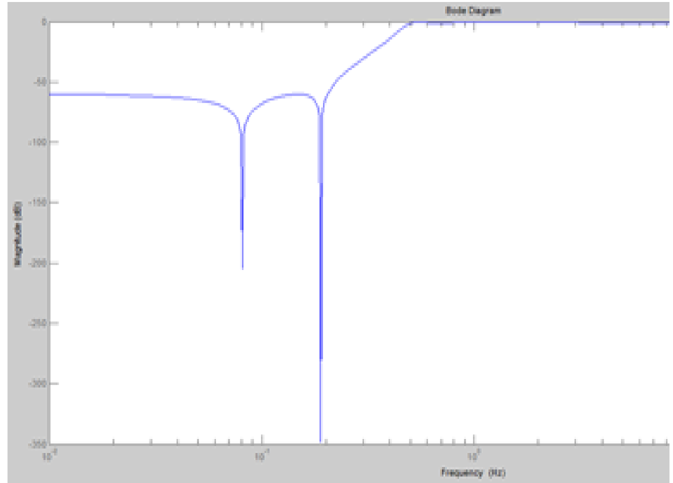

Fig. 4 Magnitude response of the Elliptical High pass filter

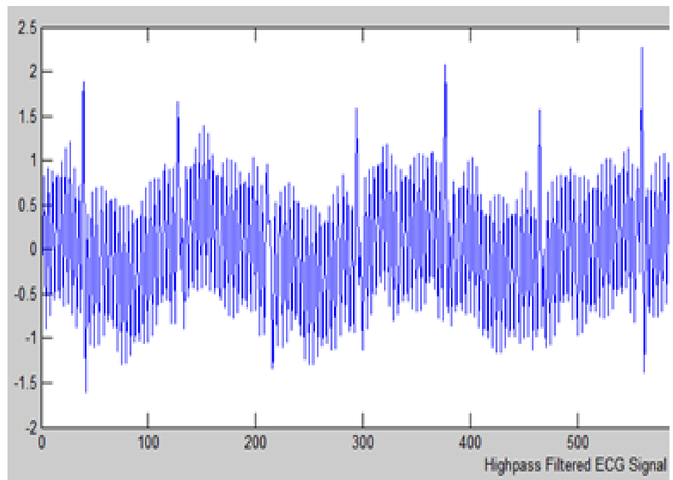

Fig. 5 ECG signal after high pass filtration

B. Power Line Interference Removal by Chebyshev II Notch Filter

The frequency component at 50 Hz can be removed by using a notch filter, in which a zero is placed on the unit circle at the location corresponding to 50Hz.

V. Conclusion

Results of this investigation have shown that both Elliptic high pass filter and Chebyshev Type II notch filter methods are better choice for the successful removal of major components of noise from the ECG signal. As the order of filtering system is increased, so the signal to noise ratio improves. On the other hand, increasing the order of the filter increases the number of components and hence more power dissipation. The proposed filter structure is based on satisfying both an acceptable signal to noise ratio and real time analysis of the ECG signal.

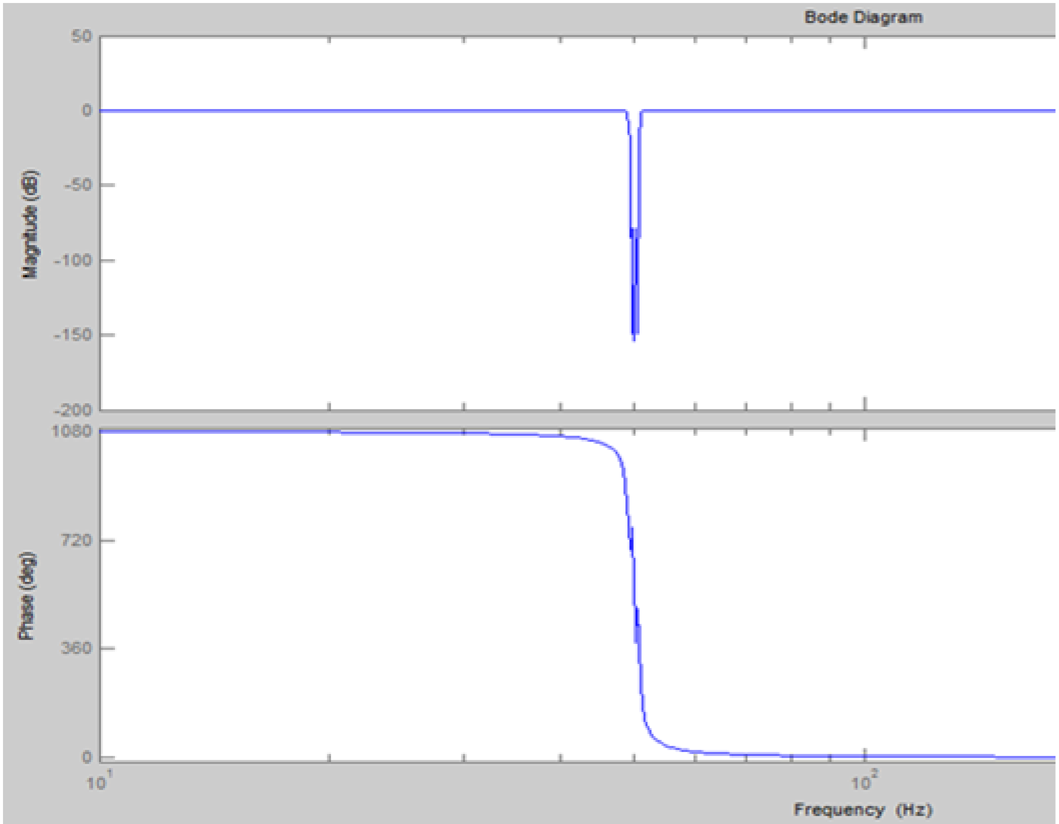

Fig. 6 Magnitude and Phase response of the Chebyshev-II notch filter

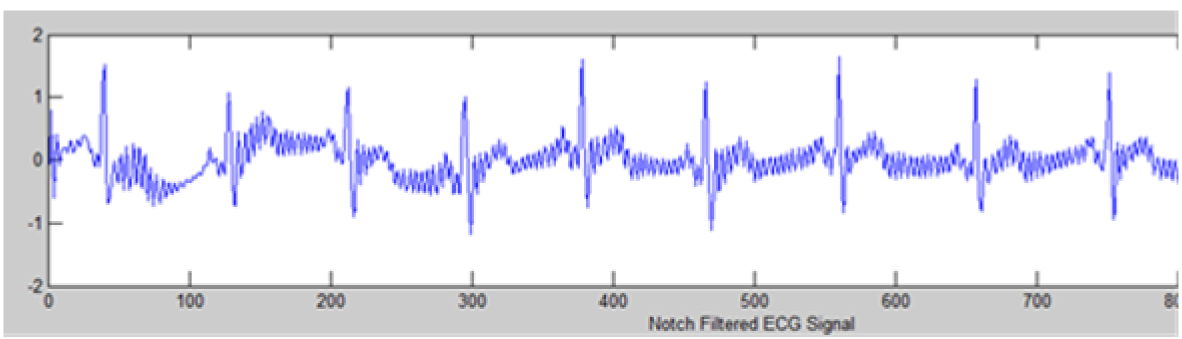

Fig. 7 ECG signal after power line artifact filtration

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