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A Review of ECG Signal Processing

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ABSTRACT: The ECG signal, even rest ECG, is often corrupted by artifacts produced by various sources of either artificial or biological nature. Main artificial artifacts are power line interference, Impulse noise, Electrostatic potentials and noise of electronic devices. The main biological artifacts are motion artifacts and muscle artifacts (EMG signal). A ECG signal is added with 50 Hz interference, base line wander noise of 0.15 Hz and high frequency noise of 150 Hz and processed by 4th order Butterworth, Chebyshev 1, Chebyshev 2 and elliptic filters. Performance of filters are analyzed 4th order Butterworth filter gives best performance as compared to others as it introduces minimum distortion to ECG waveform.

KEYWORDS: ECG (electrocardiogram), Butterworth filter, Chebyshev filter, Elliptic filter

I. INTRODUCTION

The ECG signal is processed by Butterworth, Chebyshev 1, Chebyshev 2 and elliptic filters. ECG gets corrupted due to different kinds of the artifacts. The different types of artifacts are Power line interference, motion artifacts, base line drift and instrumental noise. Due to these types of the artifacts ECG gets corrupted and correct information not transfers to the cardiac specialist. The care must be taken to nullify the artifacts to avoid wrong diagnosis. Certain type of the noise may be filter directly by time domain filters using signal processing techniques or digital filters. The advantage of the time domain filtering is that the spectral characterization of the filter may not be required (at least in the direct manner). Different researchers are working on noise reduction in the ECG signal. Wu Y, Yang Y in his article given new method for the ECG noise reduction by using 50 persons ECG based on Levkov method [1]. The Wang H, Dong X has suggested filter method with in filtered QRS wave can be exactly regarded as the mark identifying other physiological Signal. [2]. The method for the removal of the power line interference suggested by ferdJallah M, Barr RE based on iterative division or multiplication of a set of frequencies centered at 60 Hz[3]. The Choy TT, Lenng PM has suggested in his literature the real time microprocessor based notch filter for ECG[4]. The Mc manus CD, Neubert KD has compared the digital filtering methods[5]. The technique for suppressing transient states of ECG the IIR notch filter is investigated by Pie SC and T Seng CC [6]. The work on the ECG beat detection using filter bank is carried out by the Tompkins W J and Luos [7]. Other method like Signal averaging for line interface reduction is also suggested by the scientists [8]. For filtering of electromyogram signal from the ECG signal Christov II, Daskalov IK has given the solution by designing Low pass digital filter of 35 Hz cutoff frequency[9]. Mahesh S. Chavan, R.A. Agarwala, M.D. Uplane has given a comparative study of Butterworth, chebyshev 1, chebyshev 2 and elliptic filter.[10] In this paper a study has been done to investigate the effect of Butterworth, chebyshev 1, chebyshev 2 and elliptic filter on the ECG signal.

1.1. The ECG Leads

Two electrodes placed over different areas of the heart and connected to the galvanometer will pick up the electrical currents resulting from the potential difference between them. For example, if under one electrode a wave of 1 mV and under the second electrode a wave of 0.2 mV occur at the same time, then the two electrodes will record the difference between them, i.e. a wave of 0.8 mV. The resulting tracing of voltage difference at any two sites due to electrical activity of the heart is called a "LEAD" (Figs.1.1 (a) - (d).)

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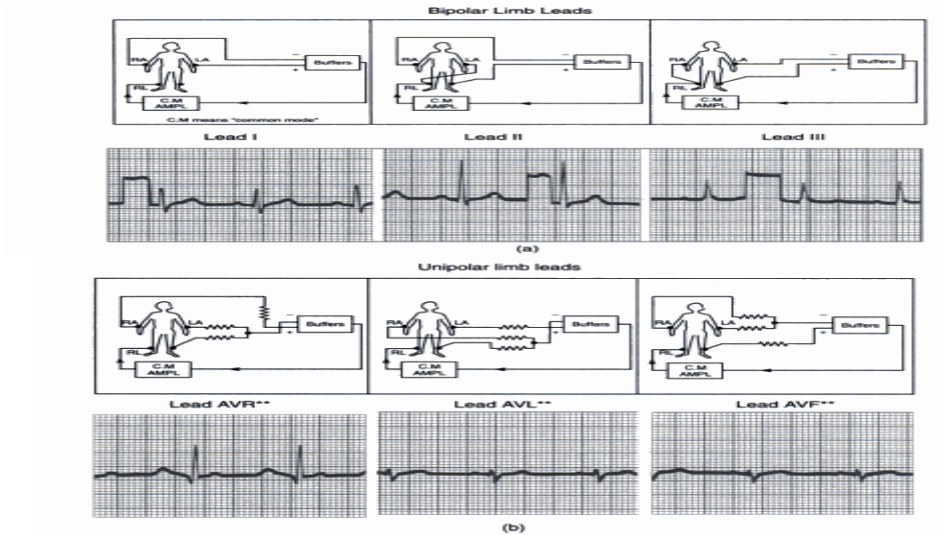


Fig1.1- Types of lead Connection with typical ECG waveforms (a) Bipolar limb leads (b) Unipolar Limb Leads

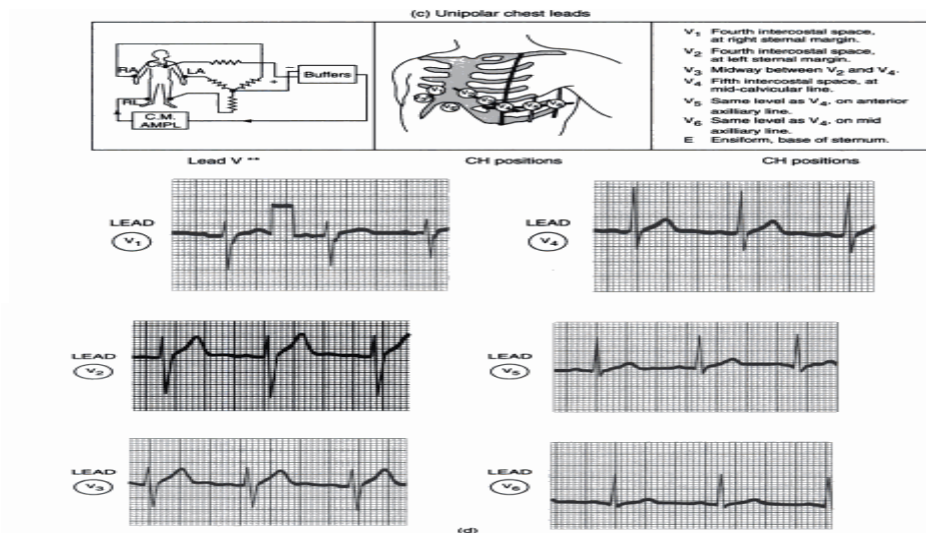


Fig 1.1- Types of lead Connections with typical ECG waveforms (c) Position of chest lead in unipolar pericardial lead recording (d) C Leads

Bipolar Leads: In bipolar leads, ECG is recorded by using two electrodes such that the final trace corresponds to the difference of electrical potentials existing between them. They are called standard leads and have been universally adopted. They are sometimes also referred to as Einthoven leads (Fig1.1 (a)). In standard lead I, the electrodes are placed on the right and the left arm (RA and LA). In lead II, the electrodes are placed on the right arm and the left leg and in lead III, they are placed on the left arm and the left leg. In all lead connections, the difference of potential measured between two electrodes is always with reference to a third point on the body. This reference point is conventionally taken as the "right leg". The records are, therefore, made by using three electrodes at a time, the right leg connection being always present. In defining the bipolar leads, Einthoven postulated that at any given instant of the cardiac cycle, the electrical axis of the heart can be represented as a two dimensional vector. The ECG measured from any of the three basic limb leads is a time-variant

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single-dimensional component of the vector. He proposed that the electric field of the heart could be represented diagrammatically as a triangle, with the heart ideally located at the centre. The triangle, known as the "Einthoven triangle", is shown in the fig 1.2. The sides of the triangle represent the lines along which the three projections of the ECG vector are measured. It was shown that the instantaneous voltage measured from any one of the three limb lead positions is approximately equal to the algebraic sum of the other two or that the vector sum of the projections on all three lines is equal to zero. In all the bipolar lead positions, QRS of a normal heart is such that the R wave is positive and is greatest in lead II.

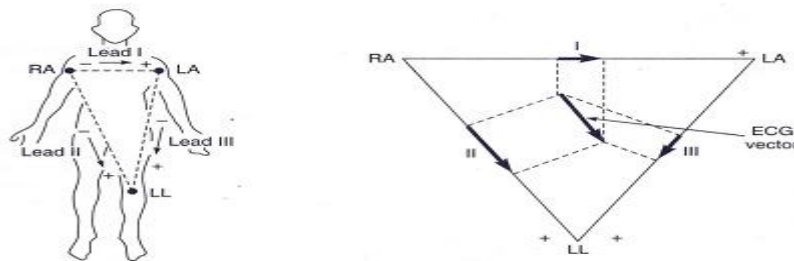


Figure 1.2: The Einthoven triangle for defining ECG lead

Unipolar Leads (V Leads): The standard leads record the difference in electrical potential between two points on the body produced by the heart's action. Quite often, this voltage will show smaller changes than either of the potentials and so better sensitivity can be obtained if the potential of a single electrode is recorded. Moreover, if the electrode is placed on the chest close to the heart, higher potentials can be detected than normally available at the limbs. This led to the development of unipolar leads introduced by Wilson in 1894. In this arrangement, the electrocardiogram is recorded between a single exploratory electrode and the central terminal, which has a potential corresponding to the centre of the body. In practice, the reference electrode or central terminal is obtained by a combination of several electrodes tied together at one point. Two types of unipolar leads are employed which are: (i) limb leads, and (ii) precordial leads.

(i) **Limb leads** In unipolar limb leads, two of the limb leads are tied together and recorded with respect to the third limb. In the lead identified as AVR, the right arm is recorded with respect to a reference established by joining the left arm and left leg electrodes. In the AVL lead, the left arm is recorded with respect to the common junction of the right arm and left leg. In the AVF lead, the left leg is recorded with respect to the two arm electrodes tied together. They are also called augmented leads or 'averaging leads'. The resistances inserted between the electrodes-machine connections are known as 'averaging resistances'.

(ii) **Precordial leads** the second type of unipolar lead is a precordial lead. It employs an exploring electrode to record the potential of the heart action on the chest at six different positions. These leads are designated by the capital letter 'V' followed by a subscript numeral, which represents the position of the electrode on the pericardium.

1.2 Input ECG:

ECG signal is taken from physionet ECG database with sampling frequency of 500 Hz as shown below in Figure 1.3. A ECG signal (without noise) is added with 50 Hz interference, base line wander noise of .15 Hz and high frequency noise of 150 Hz.

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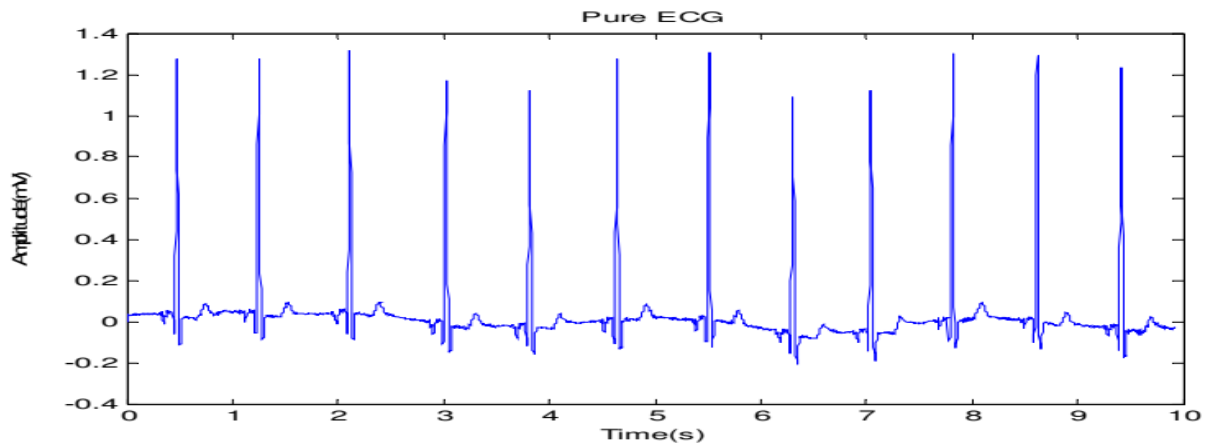


Figure 1.3 input ECG

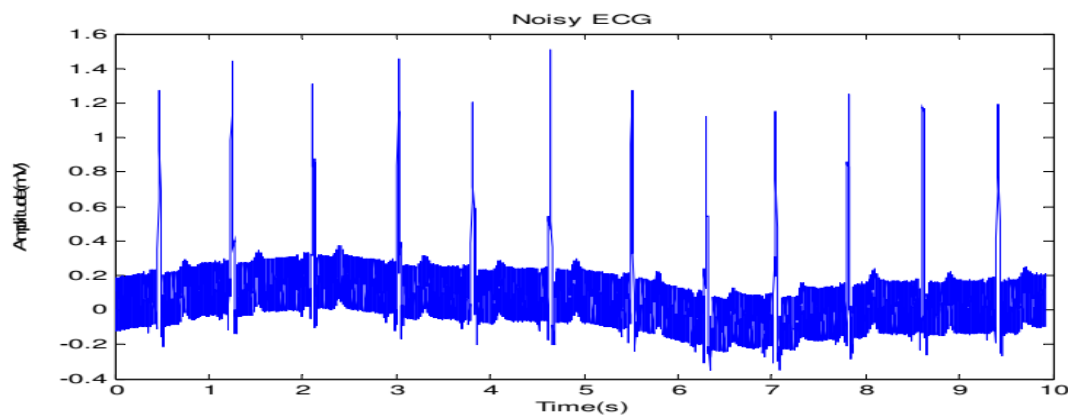


Figure 1.4 A ECG signal is added with 50 Hz interference, base line wander noise of 0.15 Hz and high frequency noise of 150 Hz

II. METHODOLOGY

2.1 Design of low pass filter

In the present paper all design is performed using Matlab FDA tool. Figure 2.1 shows basic Matlab model used in the filtration of the noise in ECG. Time scopes are configured to store up to 5000 ECG samples. The 4th order Butterworth low pass filter has cutoff frequency of 50 Hz for monitoring mode. The magnitude response is flat and all poles are inside the unit circle so design filter is stable. The phase response is nonlinear and impulse response decay with time as shown in Figure 2.2.

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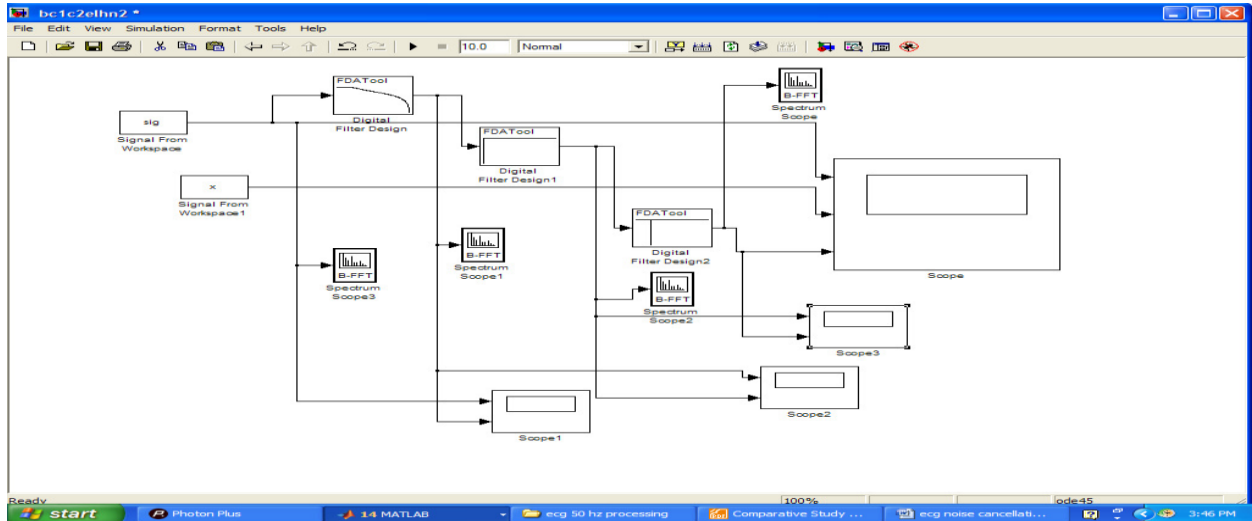


Figure 2.1: basic Matlab model used in the filtration of the power line noise in ECG

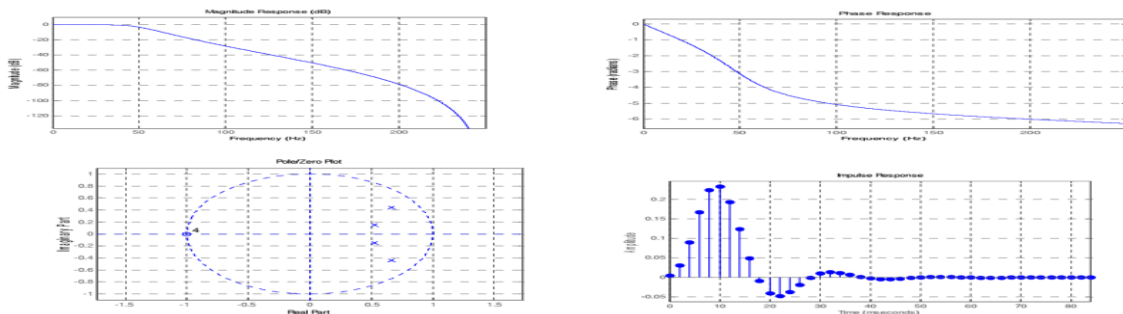
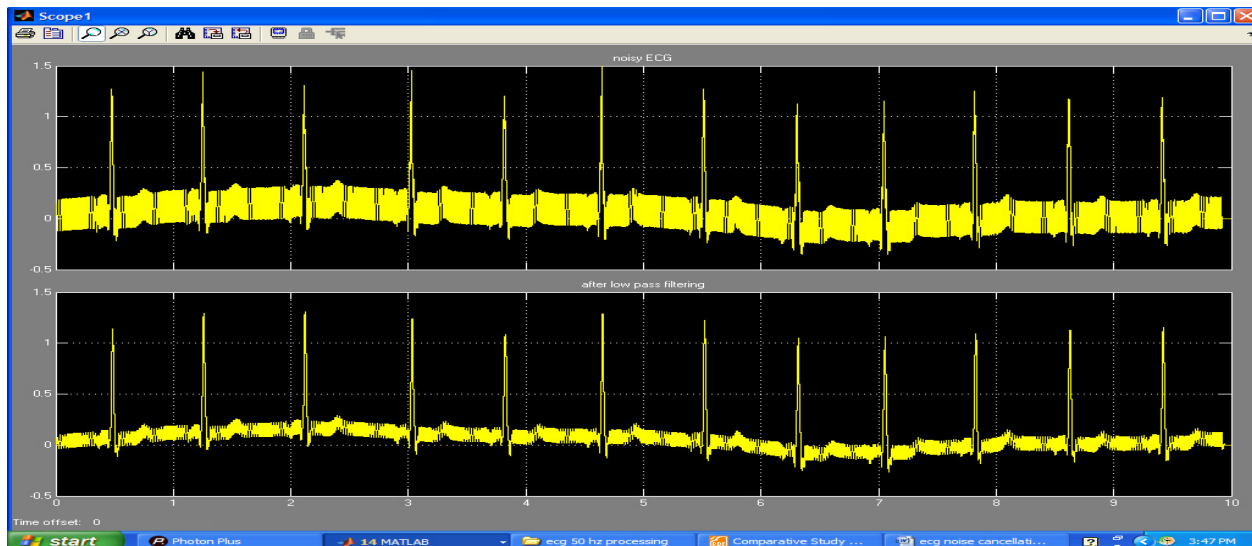


Figure 2.2: magnitude response, phase response, pole-zero diagram, impulse response, step response of the Butterworth low pass filter with cutoff frequency of 50 Hz



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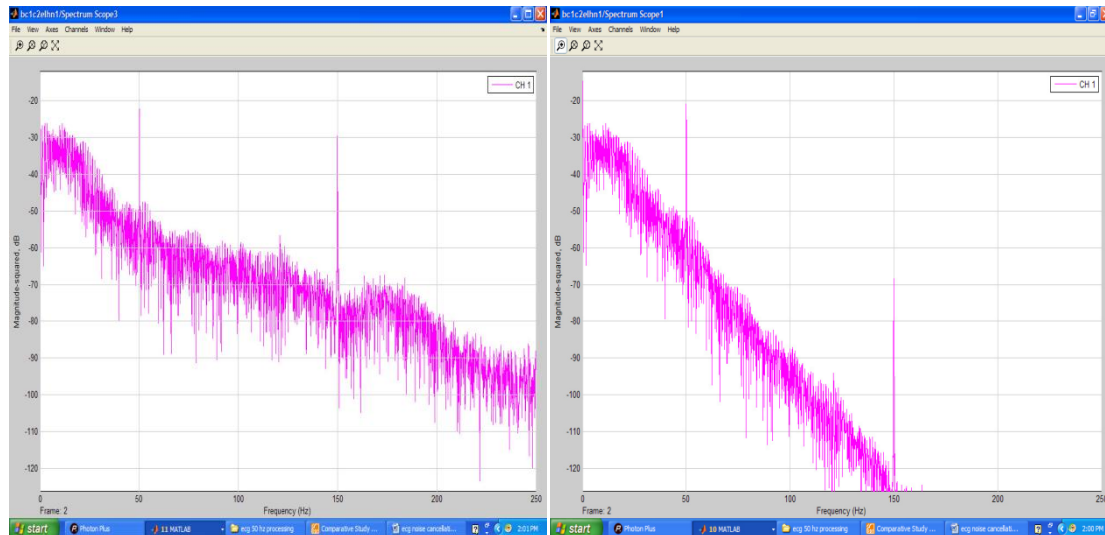


Figure 2.3: time and frequency domain response of before and after filtration of low pass Butterworth filter with cutoff frequency of 50 Hz

2.2 Design of High pass filter

The 4th order Butterworth high pass filter has cutoff frequency of 0.5 Hz for monitoring mode. The phase response is linear. Impulse response is 1 at $t=0$ and is 0 for rest of time. Poles lies on unit circle of the z plane. Designed filter is stable.

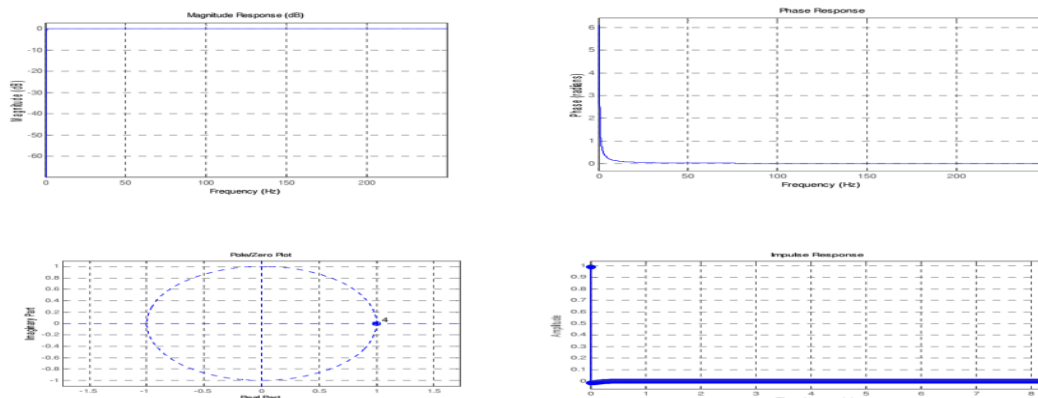


Figure 2.4: the magnitude response, phase response, pole-zero diagram, impulse response of the Butterworth high pass filter with cutoff frequency of 0.5 H

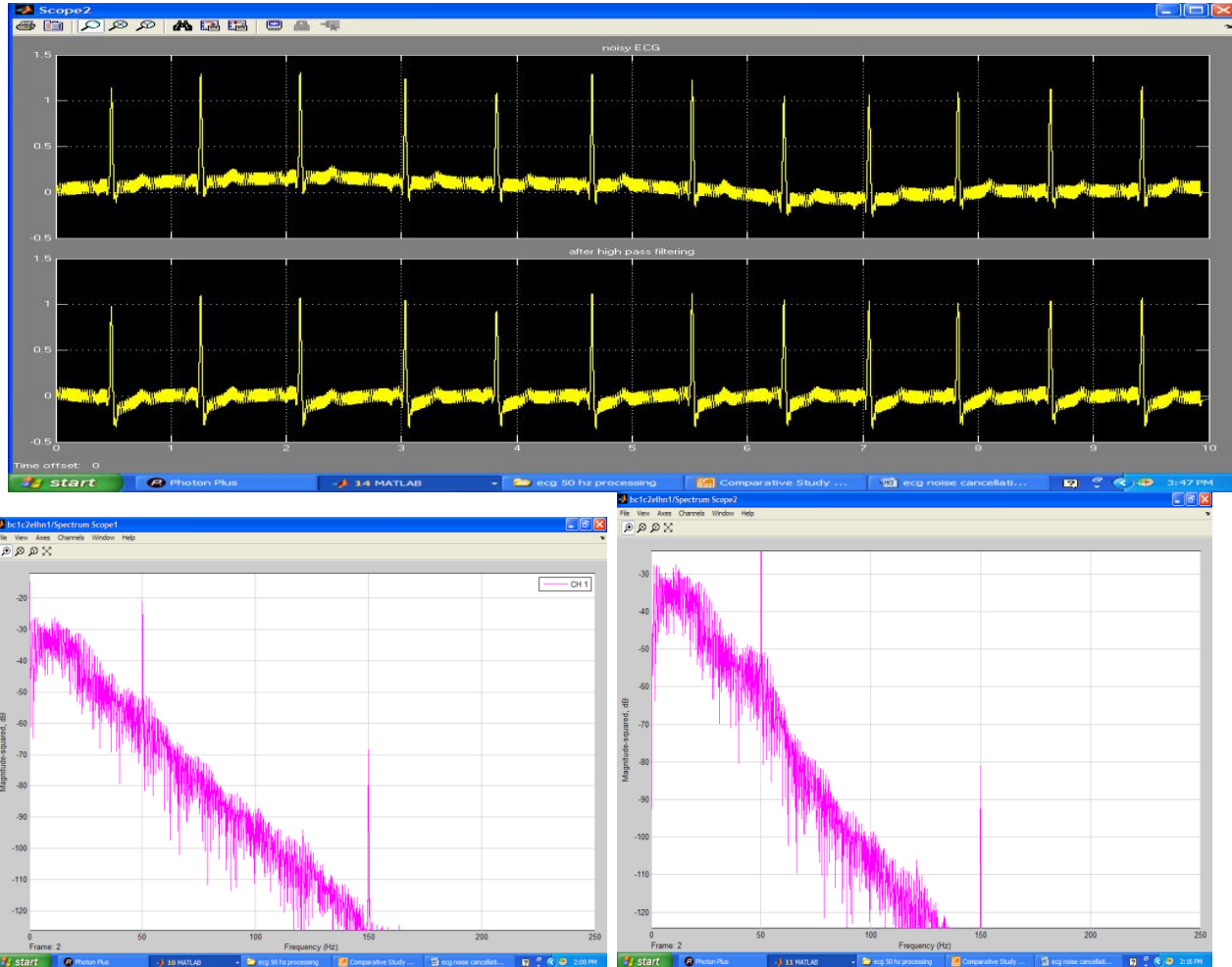


Figure 2.5: time and frequency domain response of before and after filtration of high pass Butterworth filter with cutoff frequency of 0.5 Hz

2.3 Design of Notch filter

3- dB stop band bandwidth and the order of the filter were defined to design the Butterworth notch filter. In the present case, order of the filter is 4 and the 3- dB stop band bandwidth of 0.2(49.9–50.1)Hz were considered. Figure 10 shows the magnitude , phase response pole-zero diagram, impulse response, step response of the Butterworth notch filter with the 3- dB stop band bandwidth of .2(49.9–50.1). The magnitude response shows sharp cutoff at 50 Hz. The phase response is nonlinear. All zeros lies on the unit circle. The zeros are located at ± 0.6 radians.

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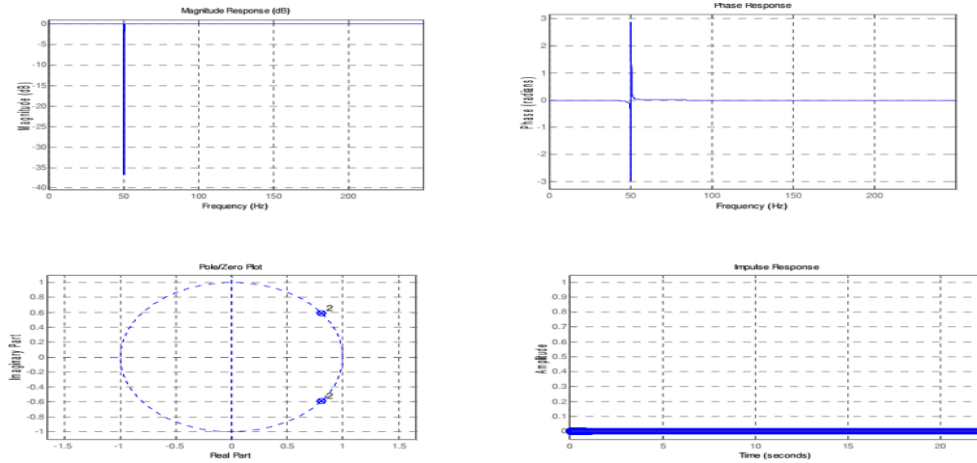


Figure 2.6: the magnitude response , phase response, pole-zero diagram, impulse response of the Butterworth notch filter with the 3- dB stop band bandwidth of .2(49.9–50.1)

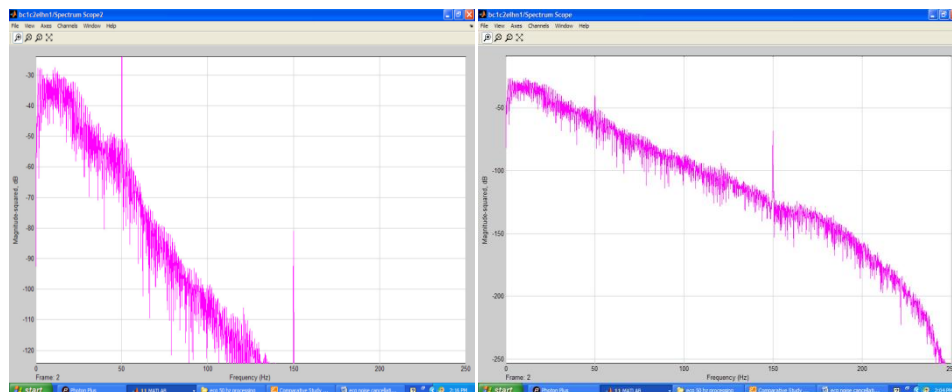


Figure 2.7: time and frequency domain response of before and after filtration of Butterworth notch filter with 3- dB stop band bandwidth of .2(49.9–50.1) Hz

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III. SIMULATION RESULT

Butterworth Low pass filter

The time domain response shows that high frequency noise is considerably reduced and amplitude of R wave is also reduced slightly.

Butterworth High pass filter

The time domain response shows that low frequency noise i.e. baseline wander noise is reduced to minimum.

Butterworth Notch filter

The time domain response shows that ECG noise at 50 Hz is effectively reduced.

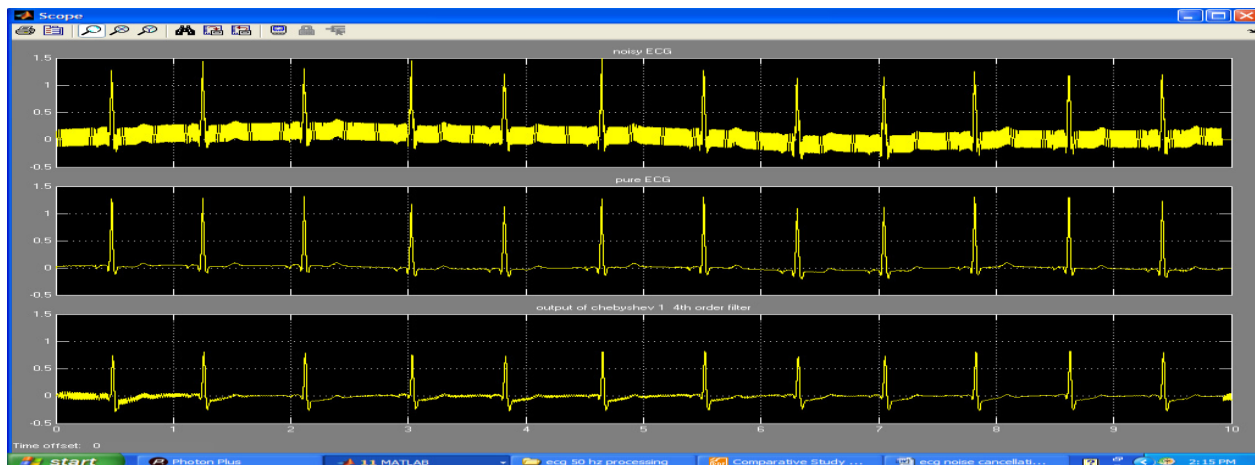


Figure 3.1: shows noisy ECG, pure ECG, output of 4th order Chebyshev 1 filter

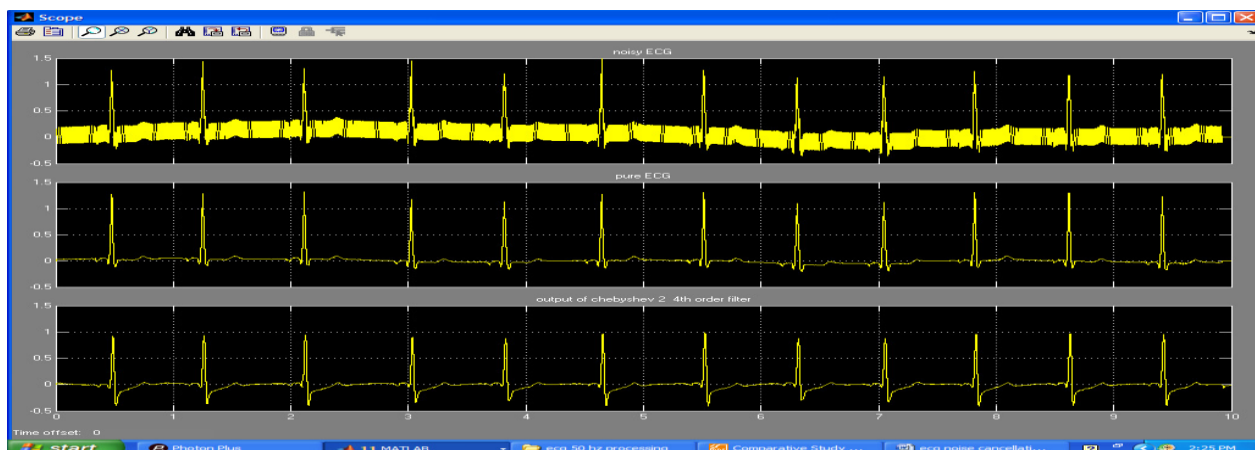


Figure 3.2: shows noisy ECG, pure ECG, output of 4th order Chebyshev 2 filter

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Figure 3.3: shows noisy ECG, pure ECG, output of 4th order elliptic filter

IV. CONCLUSION

4th order Butterworth, Chebyshev 1, Chebyshev 2 and elliptic filters were designed for sampling frequency of 500Hz. It is observed from time domain analysis of Figure 2.7, Figure 3.1, Figure 3.2, Figure 3.3 that PQRST distortion in ECG waveform is lowest in Butterworth filter as compared to other filters. Low pass filter reduces high frequency noise, high pass filter reduces base line wander and notch filter reduces power line noise.

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