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HARDWARE IMPLEMENTATION OF MODIFIED ECG WITH POWER LINE NOISE CANCELLATION

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ABSTRACT

The electrocardiogram is generally used clinically in diagnosing the heart diseases. Hence, it must be very accurate. Signals recorded are often contaminated with Power Line 50 Hz noise and harmonics originating from power supplies, power mains and lights. The presence of noise corrupts the information content of these signals and can degrade the quality of subsequent data analysis. This electrical interference is notoriously difficult to remove without altering the original signal imbedded within the noise. The power line interference reduction in ECG records is a challenging problem which is still open for research. The power line signal, measured directly from the transmission line may have amplitude, phase and frequency variations. This paper deals with designing 50 Hz Twin-T notch filter for eliminating the power line noise from ECG signal.

يستخدم جهاز رسم القلب إكلينيكيا فى تشخيص أمراض القلب وبالتالى يجب أن يكـون ذو دقـة عاليـة. عـادة الإشارات التى تكون مسجلة بواسطته مليئة بالضوضاء الناتجة من شبكة تغذية التيار المتردد ٥٠ هيرتز وأيـضا التوافقيات المتولدة من التجهيزات الكهربية ، المأخذ الرئيسى والإضاءة الكهربية . وجود هذه الضوضاء قد يفـسد محتوى معلومات هذه الإشارات ويمكن أن يخفض من جودة تحليل البيانات اللاحقة. هذا التداخل الكهربـى مـن الصعب جدا أن يزال بدون تعديل الإشارة الأصلية التى طمرت ضمن الضوضاء. يعد تقليل التداخل مـن شـبكة تغذية التيار المتردد مشكلة تحدى ومازال المجال فيها مفتوح للبحث .الإشارات المسجلة مباشرة من خـط النقـل تحتوى على قيم وزوايا وترددات متغيرة. هذا البحث يتضمن تصميم مرشح شق توأم تى لإلغاء ضوضاء شـبكة تغذية التيار المتردد ٥٠ هيرتز عن إشارات جهازرسم القلب.

Keywords: Electrocardiogram, Power Line noise, 50 Hz Twin-T notch filter.

1. INTRODUCTION

The development of the ECG began with the discovery of the electronic potential of living tissue. This electromotive effect was first investigated by Aloysio Luigi in 1787 [1]. Through his experiments, he demonstrated that living tissues, particularly muscles, are capable of generating electricity. Afterwards, other scientists studied this effect in electronic potential. The variation of the electronic potential of the beating heart was observed as early as 1856 [2], but it was not until Willem Einthoven invented the string galvanometer that a practical, functioning ECG machine could be made.

The string galvanometer was a device composed of a coarse string that was suspended in a magnetic field. When the force of the heart current was applied to this device, the string moved, and these deflections were then recorded on photographic paper. The first ECG machine was introduced by Einthoven in 1903. It proved to be a popular device, and large-scale manufacturing soon began soon in various European countries. Early manufacturers include Edelmann and Sons of Munich and the Cambridge Scientific Instrument Company.The ECG was brought to the United States in 1909 and manufactured by the Hindle Instrument Company.

1.1 Improvements in ECG

Improvements to the original ECG machine design began soon after its introduction. One important innovation was reducing the size of the electromagnet [2]. This allowed the machine to be portable. Another improvement was the development of electrodes that could be attached directly to the skin. The original electrodes required the patient to submerge the arms and legs into glass electrode jars containing large volumes of a sodium chloride solution. Additional improvements included the incorporation of amplifiers, which improved the electronic signal, and direct writing instruments, which made the ECG data immediately available. The modern ECG machine is similar to these early models, but microelectronics and computer interfaces have been incorporated, making them more useful and powerful. While these newer machines are more convenient to use, they are not more accurate than the original ECG built by Einthoven.

More powerful and improved ECG machines are developed. These machines utilize the latest computer technology, making diagnosis quicker and more accurate. They are more powerful and capable of measuring tiny electronic potentials such as fetal heart rates. They also make it possible to construct three-dimensional models of the beating heart, providing doctors with more diagnostic data. New applications for ECG machines may also be found, such as the recent application of an ECG machine to determine the efficacy of drugs [3].

A recent innovation could mark a new direction in ECG development. One company has developed a portable ECG monitor which collects data that can be transmitted directly over the phone. The patient puts the electrodes under each arm and attaches a transmitter to the phone mouthpiece. The signal is sent to a monitoring center, where computers convert it to ECG readings. This information can then be transferred to a doctor, making it possible to detect heart problems in some patients much earlier.

1.2 Power Line Interference

Electrocardiographic signals (ECG) may be corrupted by various kinds of noise among them, the power line interference which is a serious problem.

Power line interference is easily recognizable since the interfering voltage in the ECG may have frequency 50 Hz. The interference may be due to stray effect of the alternating current fields due to loops in the patient's cables. Other causes are loose contacts on the patient's cable as well as dirty electrodes. When the machine or the patient is not properly grounded, power line interference may even completely obscure the ECG waveform. The most common cause of 50 Hz interference is the disconnected electrode resulting in a very strong disturbing signal, and therefore needs quick action [4]. Electromagnetic interference from the power lines also results in poor quality tracings. Electrical equipments such as air conditioner, elevators and X-ray units draw heavy power line current, which induce 50 Hz signals in the input circuits of the ECG machine. Electrical power systems also induce extremely rapid pulse or the spike on the trace, as a result of switching action. Care should be taken to suppress these transients.

The power-line interference, as obtained from the same electrodes as the ECG, is difficult to remove, due to the frequency of the time-varying power line signal that lies within the frequency range of ECG signal.

Therefore, elimination of 50 Hz interference has been one of the most important problems in biomedical signal measurement and this opened opportunities for researchers to find several solutions to remove the power line interference from ECG signals.

For the meaningful and accurate detection, steps have to be taken to filter out or discard all the noise sources. Analog filters help in dealing with these problems; however, they may introduce nonlinear phase shifts, skewing the signal. Also, the instrumentation depends on resistance, temperature, and design, which also may introduce more error. With more recant technology, Digital filters are now capable of being implemented offering more advantages over the analog one. Digital filters are more precise due to a lack of instrumentation. The work on design and implementation of Digital filter on the ECG signal is in progress in the different part of the world [5].

Many researchers have worked on development of method for reduction of noise in ECG signal. Choy TT, Leung P M. have used 50 Hz notch filters for the real time application on the ECG signal it is found that filter was capable of filtering noise by 40dB.with bandwidth of 4Hz and causes the attenuation in the QRS complex [3]. McManus CD, Neubert KD, Cramer E have surveyed different digital filter method like notch filters, adaptive filters and globally derived filters their performances are compared on artificial signals as well as actual ECGs and found that AC interference in these ECGs is shown to exhibit two qualities especially relevant to filter design: considerable deviations from a nominal 50 Hz frequency and substantial noise at higher harmonics. For this they suggested presented different digital filter methods to eliminate it [6]. Cramers E, McManus CD, Neubert D have introduced Global filtering of AC interference in the digitized ECG as a new concept. Two different filters embodying a global approach are developed. One is based on a least-squares error fit, the other uses a special summation method. Both methods are compared with a local predictive filter by applying each filter to artificial signals and to real ECGs [7]. Some researchers have used analog filters for removal of power line interference. Hejjel L, used the analog digital notch filter for the reduction of power line interference in the ECG signal for the heart rate variability analysis. The investigation addressed the analysis of the effects of AC interference and its filtering on the precision and accuracy of heart rate detection.

Artificial ECG recordings with predefined parameters were simulated by a computer and a data acquisition card, consecutively filtered by an analog notch filter. It is found that the filtering of uncorrupted ECG signals does not result in heart rate period deviations. Power-line interference contamination proportionally alters the accuracy of representative point detection. Literature encouraged using the digital notch filter for the power line contamination removal [8]. Mihov G, Dotsinsky IV, Georgieva TS described the subtraction procedure for the power line interference removal in the ECG signal. In contrast to the well-known hardware and software filters, the procedure does not affect the signal frequency components around the rated power line frequency. Originally, the procedure was developed for multiplicity between the sampling rate and the interference frequency. The implementation of the subtraction procedure can be extended to almost all possible cases of sampling rate and interference frequency variation. The work was initially carried out in a MATLAB environment and latter on programs have been written in C^{++} language for digital signal processors and personal computers [9].

A 50 Hz notch filter system was designed to eliminate power line interferences from the high-resolution ECG. This special filter causes only minimal distortions of power spectra and thus permits us to filter high-resolution ECG's without any appreciable changes in the frequency distribution of original signal. Since the filter is based on an integer coefficient filter technique, the calculation time is relatively short and the programming effort comparatively low [10]. Kumaravel N et.al. suggested the power line interference removal technique to enhance the signal characteristics for diagnosis. They suggested the performances of linear FIR filter, Wave digital filter (WDF) and adaptive filter for the power-line frequency variations from 48.5 to 51.5 Hz in steps of 0.5 Hz. The performances of Rule-based FIR filter and Rule-based Wave digital filter are compared with the LMS adaptive filter. They found the adaptive filter more effective than the rule base filtering technique [11]. Wu Y, Yang Y, discussed the advantages and disadvantages of several conventional digital filter methods. Then, based on Levkov method, they proposed a new filter method.Using these methods to remove 50 Hz interference from more than 50 persons' ECG signals. Results show that this new method is the best, and it can satisfy the real time requirement of digital ECG machine [12]. Van Alste JA et.al. suggested the application of an efficient FIR filter with reduced number of taps for the removal of base line wonder and power line interference in the ECG [13]. Mitov IP described a method for reduction of power line interference (PLI) in electrocardiograms with sampling rate integer multiple of nominal power line frequency and tested using simulated signals and records from the databases of the American Heart Association and the Massachusetts Institute of Technology. The method involves parabolic detrending the ECG, estimation of signal components with frequencies corresponding to PLI by discrete Fourier transform, and minimum-squared-error approximation of decimated series of averaged instantaneous values of PLI using appropriately defined weights.

Dotsinsky I, Stoyanov T have assessed the efficiency of notch filters and a subtraction procedure for power-line interference cancellation in electrocardiogram (ECG) signals. In contrast with the subtraction procedure, widely used digital notch filters unacceptably affect QRS complexes [14]. Ider YZ, Saki MC, Gcer HA described a method for line interference reduction to be used in signal-averaged electrocardiography (SAECG) systems and its performance is analyzed. This new method is an adaptation of a different technique for removal of line interference from conventional electrocardiograms. It involves the recording of a line interference signal simultaneous with the lead signals, so that a shifted and scaled version of it can be used to subtract line interference from the leads. It is seen that this line interference subtraction method can reduce line interference effectively and without introducing any additional noise into the ECG signal [15].

Ider YZ, Koymen H. Suggested a theory that power line frequency must be accurately known if line interference is to be accurately subtracted from the output of a bi-potential amplifier [16].

There are different methods like window method and equiripple method also available. The simplest technique is known as "Windowed" filters. This technique is based on designing a filter using well-known frequency domain transition functions called "windows". The use of windows often involves a choice of the lesser of two evils. Some windows, such as the Rectangular, yield fast roll-off in the frequency domain, but have limited attenuation in the stop-band along with poor group delay characteristics. Other windows like the Blackman, have better stop-band attenuation and group delay, but have a wide transition-band (the band-width between the corner frequency and the frequency attenuation floor). Windowed filters are easy to use and scalable.

With this survey of methods used for removal of power line interference from the ECG signal it was seen that no any method based on Twin-T notch filter. Present work deals with design and implementation of Twin-T notch filter for reduction of power line interference in the ECG signal.

2. SYSTEM UNDER CONSIDERATION

2.1 The System Block Diagram

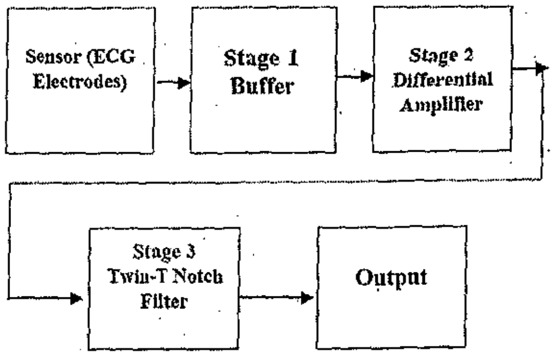

Fig. 1: Block Diagram of ECG

2.1.1 Electrodes

Electrodes are used for sensing bio-electric potentials as caused by muscle and nerve cells. ECG electrodes are generally of the direct-contact type. They work as transducers converting ionic flow from the body through an electron current and consequentially an electric potential able to be measured by the front end of ECG system. These transducers, known as bare-metal or recessed electrodes, generally consist of a metal such as silver or stainless steel, with a jelly electrode that contains chloride and other ions. On the skin side of the electrode interface, conduction results from metal ions dissolving or solidifying to maintain a chemical equilibrium using this or a similar chemical reaction. The result is a voltage drop across the electrode-electrolyte interface that varies depending on the difference in the two half-cell potentials.

2.1.2 Stage 1 & 2 Instrumentation Amplifier

An instrumentation amplifier is a differential voltage – gain device that amplifies the difference between the voltages existing at the two input terminals. The main purpose of an instrumentation amplifier is to amplify small signals that are riding on large common – mode voltages. The key characteristics are high input impedance, high common – mode rejection, low output offset, and low output impedance. A basic instrumentation amplifier is made up of three operational amplifiers and several resistors.

2.1.3 Stage 3 Twin-T Notch filter

A notch filter is a circuit that rejects a very narrow band of frequency. A common application of a notch filter is the removal of 50-Hz hum from an AC line. The Twin-T filter, one of the most commonly used notch filters, is a passive filter composed of two T-networks. One of these T networks has one resistor and two capacitors, while the other has two resistors and one capacitor. For the twin-T notch filter in Fig. 2, maximum attenuation occurs at

$$F_o = \frac{1}{2\times\pi\times R_{12}\times C_5} = 50Hz$$

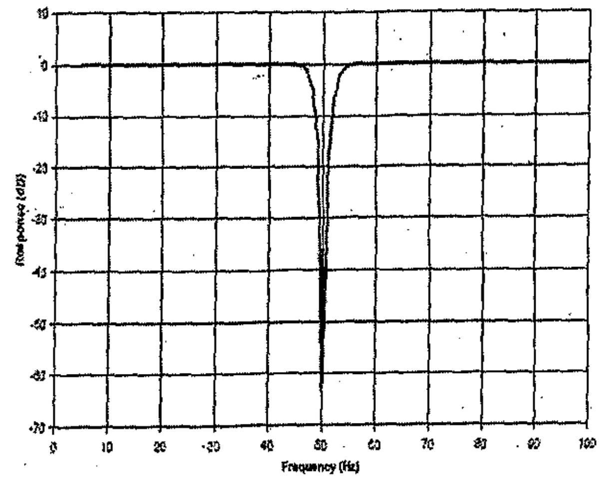

Fig. 2: 50 Hz Notch Filter

3. THE OVERALL CIRCUIT DIAGRAM OF ECG

The over all circuit diagram of ECG is shown in Fig3.

3.1 The Buffer Stage of ECG Circuit

The patient would be connected to RA (Right Arm) and LA (Left Arm). RL (Right Leg) is connected directly to the ground. R_2 and R_3 add extra input impedance.

The op amps provide high input impedance as to not load the patient and draw a lot of current that would distort the ECG signal.

Gain of this stage $= \frac{R_1}{R_2} = \frac{20\times10^6}{10\times10^3} = 2000$.

3.2 The Differential Amplification Stage

The potentiometer located at R_9 can be adjusted to match R_7 so that the common mode gain is minimal. This will improve the common mode rejection ratio (CMRR). Gain of this stage $= \frac{R_7}{R_9} = \frac{47\times10^3}{10\times10^3} = 4.7$

4. SYSTEM ANALYSIS

A differential amplifier is a type of electronic amplifier that multiplied the difference between two inputs by some constant factor, know as gain

$$V_{out} = \frac{R_5}{R_2}(V_{R3} - V_{R2})$$ "Amplifies a Difference".

Common noise sources add symmetrically to an opamp. Thus there is a differential $(V_{R3} - V_{R2})$ and a common mode $(V_{R3} + V_{R2})$ component to the input. Thus,

$$V_{out} = A_C(V_{R3} + V_{R2}) + A_D(V_{R3} - V_{R2})$$

Where, A_C: Common mode (noise) gain, A_D: Differential (signal) gain.

- The ratio A_D/A_C (Common Mode Rejection Ratio – CMRR) is a very important parameter.
- Ideally CMRR $\rightarrow \infty$

- For the Twin-T notch filter, Q factor is controlled by the ratio of R_{15} and R_{16}.
- Q factor is constant; $Q = \frac{R_{15}}{R_{16}} = 0.05$

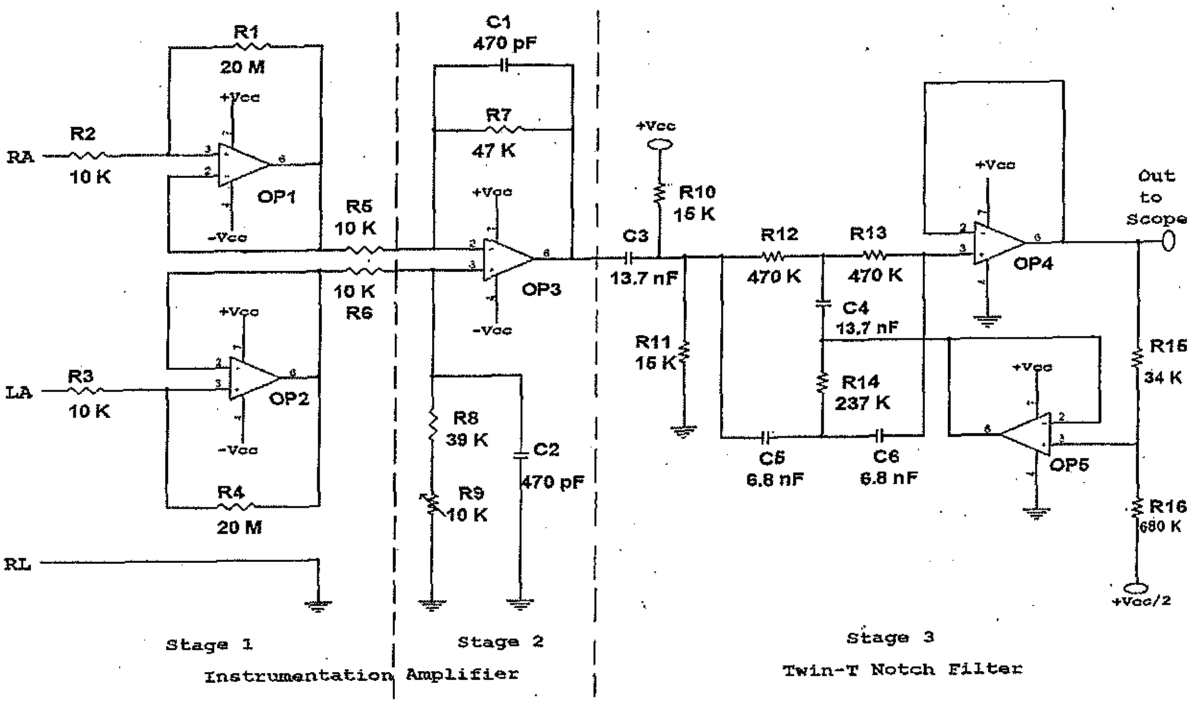

Fig. 3: Circuit Diagram of ECG

5. ANALYSIS OF POWER LINE ELIMINATION FROM ECG

The subtraction procedure is applied originally with sampling frequency f_s and hardware synchronized with the PL frequency f_{PL} [17].

A linear criterion C_r usually corresponds to the second difference of the signal. The first C_r is defined in the following manner. Six consecutive first differences FD_i are calculated using signal samples, X_i spaced at one T_{PL}:

$$FD_i = X_{i+n} - X_i \quad \text{for} \quad i = 1.....6 \qquad (1)$$

The PL interference in the first differences is suppressed if $n = f_s/f_{PL}$. In this case $n = 5$, since the procedure was developed initially for rated $f_{PL} = 50Hz$ and $f_s = 250Hz$. Furthermore, the maximum FD_{max} and minimum FD_{min} values are taken to determine C_r:

$$C_r = |FD_{max} - FD_{min}|(M \qquad (2)$$

Where M is the threshold value.

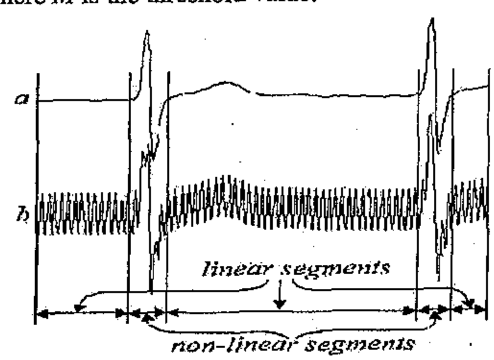

Fig. 4: Linear and non linear segments in real ECG signal

Typical linear and non-linear segments are shown in Fig. 4. Real ECG signal (trace a) is superimposed by interference (trace b). This criterion works accurately, but can hardly be applied in real time because it's relatively slow implementation. This drawback is overcome by Christov and Dotsinsky [18] who use a modified criterion of just two subsequent differences.

$$C_r = |FD_{i+1} - FD_i| \langle M| \qquad (3)$$

The first sample, which does not fulfill equation (3), is associated with the beginning of a non-liner segment. In the non-linear to linear transition, equation (3) should be satisfied consecutively n times in order to avoid premature detection of the linear segment. The criterion is implemented in real time for $f_S = 400$ Hz and $n = 8$.

Later, Dotsinsky and Daskalov [19] defined the criterion as two non-subsequent differences:

$$C_r = |FD_{i+k} - FD_i| \langle M \quad \text{for} \quad k \rangle 1 \qquad (4)$$

This approach makes the transition from linear to non-linear segment more precise.

For odd sample number $n = 2m + 1$ in one period of PL interference, the filtered value:

$$Y_i = \frac{1}{n} \sum_{j=-\frac{n-1}{2}}^{\frac{n-1}{2}} X_{i+j} \qquad (5)$$

is phase-coincident with the non-filtered one.

In case of even number $n = 2m$, the two values are phase-shifted by a half of the sample period:

$$\frac{t_s}{2} = \frac{1}{2f_s} = \frac{T_{PL}}{2n}$$

but become in-phase coincidence using the formula

$$Y_i = \frac{1}{n}\left[\sum_{j=-(n/2-1)}^{n/2-1} X_{i+j} + \frac{X_{i-n/2} + X_{i+n/2}}{2}\right] \qquad (6)$$

It is possible to take for averaging every second, third or q^{th} sample if n/q is integer. Depending on whether n/q is odd or even, Eqn (7) or (8) is used, respectively.

$$Y_i = \frac{q}{n} \sum_{j=-\frac{n/q-1}{2}}^{\frac{n/q-1}{2}} X_{i+jq} \qquad (7)$$

$$Y_i = \frac{q}{n}\left[\sum_{j=-(n/2q-1)}^{n/2q-1} X_{i+jq} + \frac{X_{i-n/2} + X_{i+n/2}}{2}\right] \qquad (8)$$

A special case of maximum sample reducing arises with $q = n/2$. The corresponding formula:

$$Y_i = \frac{X_{i-n/2} + 2X_i + X_{i+n/2}}{4} \qquad (9)$$

is called 'three-points' filter. In addition to Eqn (8), the following formula

$$Y_i = \frac{q}{n} \sum_{j=-n/2q}^{n/2q-1} X_{i+\frac{2j+1}{2}q} \qquad (10)$$

can also be applied if q is even. In case of $q = n/2$, the filter becomes 'two-points' and is represented by:

$$Y_i = \frac{X_{i-n/4} + X_{i+n/4}}{2} \qquad (11)$$

Reduced sample number in a period of the interference will lead to enhanced steep slope of the comb filter lobes and will shorten the computation time. However, these 'advantages' must be assessed carefully in order not to violate the Nyquist rule with a large amount of the third harmonic present. The other harmonics are not taken into consideration since the highest odd harmonics are usually suppressed by low-pass filters with cut-off in the range of 100–150 Hz, while the even ones are practically absent because of the precise pole manufacturing of electric power station generators.

Frequency variations lead to a special case of non-multiple sampling with real n, instead of integer one. This complication can be bypassed if the deviations are detected by continuous hardware measurement of f_{PL} and corrected by small adjustments of the sample interval t_s around its rated (R) value, $t_{RS} = T_{RPL}/n$ (here, $T_{PL} = 20$ ms is the rated T_{PL} for $f_{RPL} = 50Hz$). For f_{PL}, deviation between 49.5 and 50.1 Hz, the t_s variations are in the range of 1%, and consequently they do not introduce errors beyond the accepted measuring accuracy of parameters that are usually used for automatic ECG classification.

6. PRACTICAL MEASUREMENTS

6.1 Electrode and Electrode Placement

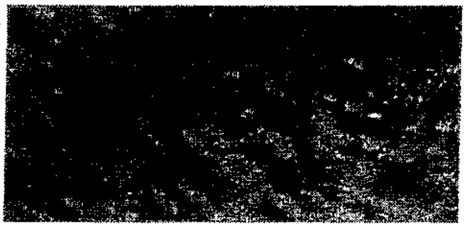

Fig. 5: The ECG Ag – AgCL Electrodes

As a general principle, the closer the electrodes are to the heart, the stronger the signal that will be obtained. The electrodes were placed on the right arm (RA) and left arm (LA) with right leg (RL) acting as the ground for the body.

Fig. 6: The ECG Circuit Connection

6.2 Signal Display

Figure 7 shows the noisy ECG waveform due to the Power line interference which corrupts the ECG signal.

Figure 8 shows the resultant ECG waveform on the oscilloscope after filtration. However, noise particularly the power – line interference and baseline wander, were reduced after using Twin-T notch filter.

For better hardware sensitivity and results, three things must always be considered: electrode placement, electrode selection, and skin preparation.

Electrodes must be placed in smooth even surfaces with minimal hair growth, skin creases and lesser muscle. The skin must be treated so that interference is minimized and signal transmission is maximized.

Few tips are: (1) Clean the skin – using soap and water or alcohol wipes. Skin must be free of all oils, lotions, perspiration, and gross dirt; (2) Clip excess hair if necessary; (3) Allow the skin to dry; (4) Use a dry rub – using a clean, dry gauze pad to remove any skin slough thus further enhancing the ECG trace.

7. DIGITAL SIMULATION

The harmonics of power line will appear if the interference is a periodic waveform that is not a sinusoid such as rectangular pulses. The power spectrum of the signal should provide a clear indication of the presence of power-line interference as an impulse or spike at 50 Hz; harmonics, if present, will appear as additional spikes at integral multiples of the fundamental frequency.

Figure 9 shows frequency spectrum of the ECG signal before filtration and the effect of power line interference is clear on the signal.

Software solution before and after using Twin-T notch filter method was proposed for 50 Hz interference suppression as shown in Figs. 10&11.

As shown both practical and simulation results are close before and after using Twin-T notch filter, the 50 Hz power line interference noise was eliminated and this filter is effective.

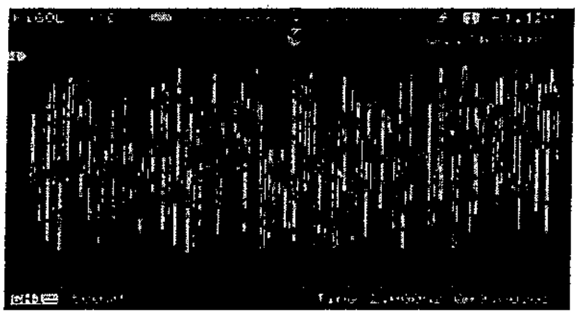

Fig. 7: Power Line Interference displayed on Oscilloscope

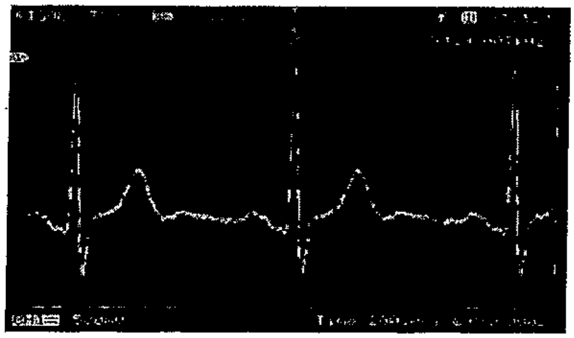

Fig. 8: Waveform of ECG on Oscilloscope after filtration

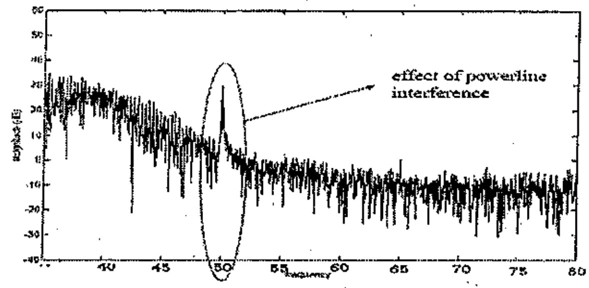

Fig. 9: Frequency spectrum of the ECG signal

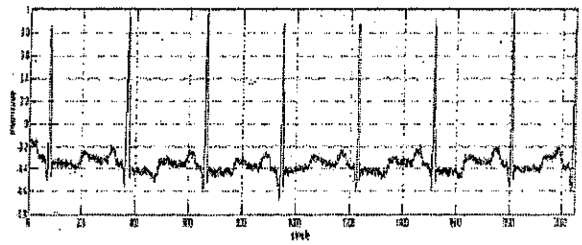

Fig. 10: Power Line Interference on ECG waveform before filtration

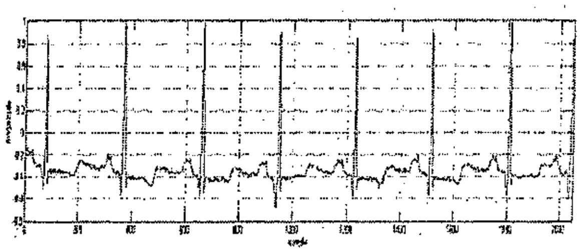

Fig. 11: Resultant ECG Waveform after filtration

8. CONCLUSIONS

Power line is a major interference of bio-potential measurement. There are many studies devoted to the elimination of power line in ECG signal processing; however, it is still a challenging problem due to its time varying characteristics.

The elimination of sinusoidal interference in an observed signal is an important issue in many areas. Power line may be one kind of such interference that appears most popularly and in practical case may consist of the fundamental component and its harmonics. This study focuses on the elimination of the fundamental component.

Arbitrary removal of power line frequency signals may not pose a problem for standard ECG signals since the main frequency components of P, R and T waves are far below 50 Hz. However, when ECGs are examined for small variations that are indicative of scar tissue due to previous myocardial infraction, removal of power line interference has to be done with almost care not to eliminate or distort the ventricular late potentials, microvolt level (1 to 20μV) waveforms that are continuous with the QRS complex and occupy a relatively wide frequency band (40 to 200 Hz) that peaks exactly within the range 50 to 60 Hz.

The selection of any other types of notch filters will not only remove the power line interference but will also take away parts of the signal of interest. In addition, they may introduce nonlinear phase shifts in frequency components within the filter's pass band.

In this paper, the Twin-T notch filter was used for eliminating the 50 Hz power line interference.

In the future, more powerful and improved ECG machines will be developed. These machines will utilize the latest computer technology, making diagnosis quicker and more accurate. They will be more powerful and capable of measuring tiny electronic potentials such as fetal heart rates. They will also make it possible to construct three-dimensional models of the beating heart, providing doctors with more diagnostic data. New applications for ECG machines may also be found, such as the recent application of an ECG machine to determine the efficacy of drugs.

A recent innovation could mark a new direction in ECG development.

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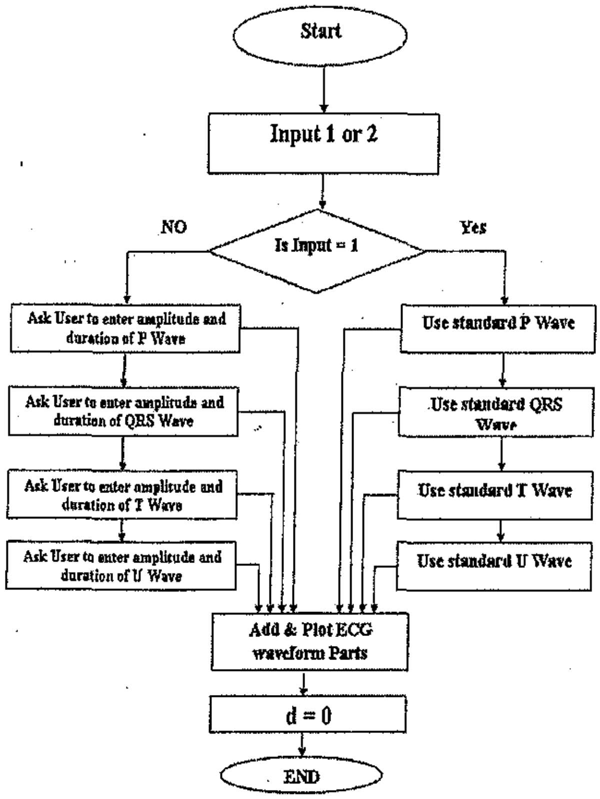
10. APPENDIX

Flow Chart of ECG Waveform



1&2 are inputs on matlab command window that calls for M-files written for ECG waveform.