A Reliable Non-Contact ECG Measurement System with Minimal Power Line Disturbance

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***Abstract*—A noncontact ECG measurement scheme has many advantages over a conventional ECG measurement system. But, one of the main problems of noncontact ECG signal is its susceptibility to power line disturbances, caused by powered electronic equipments or power line wires. In this paper, a scheme for non-contact ECG measurement was first developed and its sensitivity to power line interference got suppressed using a novel signal conditioning method. After designing the suitable capacitive electrodes, the signal from the active electrodes are amplified, filtered and finally displayed in a Virtual Instrument developed in a LabVIEW environment. The simulation of the overall scheme for the suppression of power frequency disturbance has been carried out and the result shows a significant improvement in the SNR.**

***Index Terms*—Capacitive Coupling, Active Shielding, ECG Electrodes, Cancellation of Power Frequency Disturbance, Virtual Instrument**

I. Introduction

The ECG is perhaps the most commonly known, recognized and used biomedical signal. It has been known for a long time for providing very useful and important clues to the status of the cardiovascular system of a patient. In the capacitive coupling method, a capacitive electrode [1] is placed outside the body (used as electrode) and this plate and the electric signal source inside the body forms a condenser and the electric biosignal can be derived through this condenser. Conductive electrode, often made of Ag/AgCl uses a contact gel as a conductive contact to the skin to measure the potential difference. As it shows a resistive behavior, during course of time, the gel undergoes dehydration and hence the quality of the signal get reduced [2]. The potentials can be measured even through several layers of clothing (depending on material and thickness). Each electrode forms a coupling capacitance C with the patient's body, which can be expressed as the following equation:

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \tag{1}$$

where A is the effective surface area of the electrode, d is the thickness, ε_r is the dielectric constant of the clothes, and ε_0 is vacuum permittivity. A small electrode which is at a few mm distant from the body and a large electrode area yields a large coupling capacitance. The capacitive coupling method of bio-signal acquisition has been analyzed and tested even long years back, both for medical and research use. For example, a technique already known since 1967 through Richardson has been focusing in his research area: measuring potentials with isolated electrodes [3]. This method is recently built into a variety of everyday objects like bed [4], bathtubs [5], toilet seats [6], chair [7], incubator [8], and for automotive applications [9]. The underlying principle of right leg driver circuit is given in [10]. Various methods for interference rejection are mentioned in [11]-[13]. Recently adopted methods for signal acquisition using novel electrodes and their signal processing are illustrated in [14]-[19]. An extreme care should be taken while designing of filters. ie., we should be aware of the sources of noises and proper selection of filters and good experimental set up including the various performance enhancement techniques will yield to a meaningful and accurate detection of the ECG signal. In addition to the removal of common mode signals and dc component, a special emphasis is given here for power line interference rejection at the electrode stage itself.

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II. Methodology

A. Noncontact ECG Measurement System

Fig. 1 shows the functional block diagram of the non-contact ECG measurement. The cross-sectional view of the Subject's body and clothes are given, over which the electrodes are placed. The first two electrodes extract the bio-signal from the body by capacitive coupling and then amplified by a high precision instrumentation amplifier (INA) with gain 106. The potential between electrodes is measured with respect to the third electrode called reference electrode. The Subject can sit on a chair and the raw signal obtained from the back of the body is first amplified by an instrumentation amplifier with good CMRR and the amplified signal then properly filtered and given to the data acquisition system and then displayed on a PC.

B. Scheme for Power Line Interference Rejection

Fig. 2 shows the block diagram for power line interference rejection (PLIR). As the interfering signal is random in nature, it can affect the electrodes through body or in other ways in equal manner. More over the

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noise level can be the same or different on each electrodes. Assuming the electrode which is not affected by the interference is a perfect one (PE: either E1 or E2), the noise from the imperfect electrode (IPE) is extracted and processed so that the final processed signal is fed back to the cancelling node either (C_2 or C_1) making an equal imperfection on each input of the instrumentation amplifier. Thus these signals coming to the Instrumentation Amplifier (IA) will be treated as common mode signal and will be nullified significantly depending on the CMRR of the instrumentation amplifier. First of all, a dc signal corresponding to the noise signal error is obtained and is applied to an automatic gain controlled amplifier. For that, a 50Hz BPF, full-wave precision rectifier, LPF and an integrator circuit are used. The output of the integrator controls the gain of the controlled amplifier. Similarly signal from the imperfect electrode is band passed and is suitably phase shifted and given to the input of controlled amplifier. Controlled amplifier automatically makes the amplitude of the signal level equal at the INA inputs by injecting a suitable amount of interfering signal to the less affected electrode. If the assumed electrode is not imperfect (no interference) for a threshold level of the signal that already set within a specified time, electrodes are to be interchanged electrically as per the Fig. 2. This is achieved by combination of switches (S_1 and S_2) and a digital logic which can be implemented using a simple microcontroller.

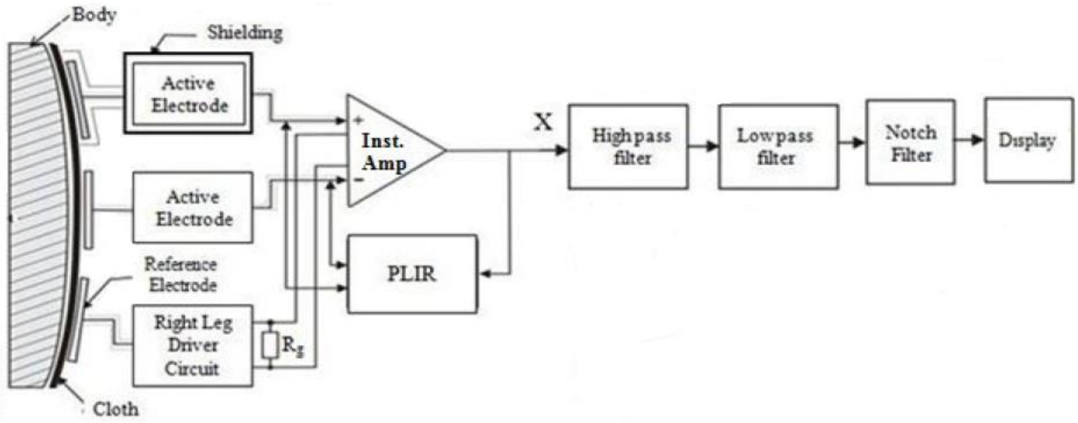

Figure 1. Functional block diagram of non-contact ECG measurement system.

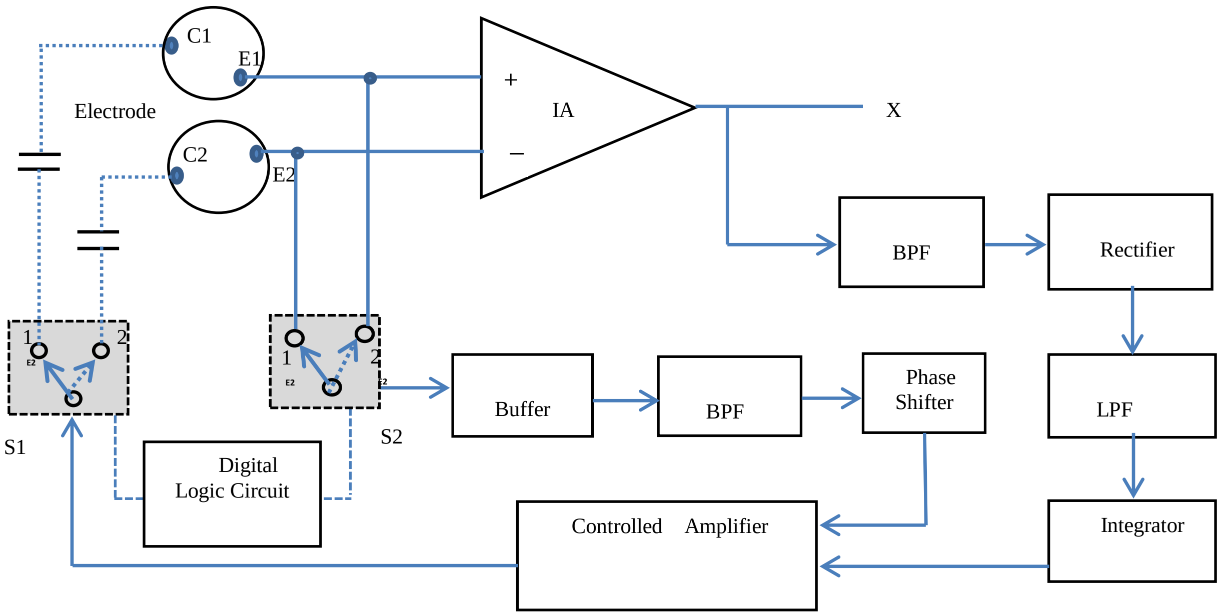

Figure 2. Block diagram of the proposed 50/60 Hz interference rejection system.

The electrode condition and the switching action of the proposed methodology are shown in Table I. When both electrodes are either perfect (PE) or equally imperfect (IPE), there is no need of the controlled feedback arrangement.

The Bandpass filter extracts the required signal frequency and the phase shifter adjusts the extra phase shift introduced in the path so that the noise can be nullified by the virtue of Instrumentation amplifier. Here the gain of a non-inverting amplifier is varied using the action of a MOSFET. For this purpose, MOSFET is used as the voltage variable resistor. Normally there are three regions of operation for a MOSFET, out of which in triode region only, it will act a voltage variable resistor. The MOSFET should be properly biased and voltage at the input should also be in the specified range for getting the required action. A digital logic unit should be used for generating control signals and for switching the electrodes effectively on the basis of a threshold value. The digital logic unit can be implemented using an 8 bit micro-controller.

TABLE I. ELECTRODE NOISE AMPLITUDE AND SWITCHING POSITIONS

Electrode1 Status	Electrode 2 Status	Remarks
PE	PE	Both are having same amplitude and phase
IPE	IPE	INA output will be ideally noiseless
PE	IPE	Switch position: (2,2)
IPE	PE	Switch position: (1,1)
IPE_1	IPE_2, $IPE_2 > IPE_1$	Switch position: (2,2)
IPE_2	IPE_1, $IPE_1 > IPE_2$	Switch position: (1,1)

III. RESULTS

A. Experimental Result

The electrodes designed are in circular shape and are firmly placed on a chair over which, Subjects can sit and observe their ECG. On observing the output continuously, the acquired signal may interfere with power line signals and the output may not be that much intelligible. Though the QRS peak may be identified, the P and T wave may not be clearly visible. From QRS peaks, Heart rate variability can be calculated. Once it is free from the disturbance, the signal would show all the ECG components as shown in Fig. 3(a). Hence as a matter of performance enhancement, a new signal conditioning method is proposed and simulated.

The power line signal is actually interfered to the ECG measurement system through capacitive coupling effect. Hence for simulation purpose, some capacitances of the order of pico- Farads can be introduced to the electrodes E_1 and E_2 as shown in the block diagram. Noise cancelling leads C_1 and C_2 can also connected to the same electrodes which are specifically fabricated, without causing any short circuit so that interference cancellation can be achieved by the same capacitive coupling principle.

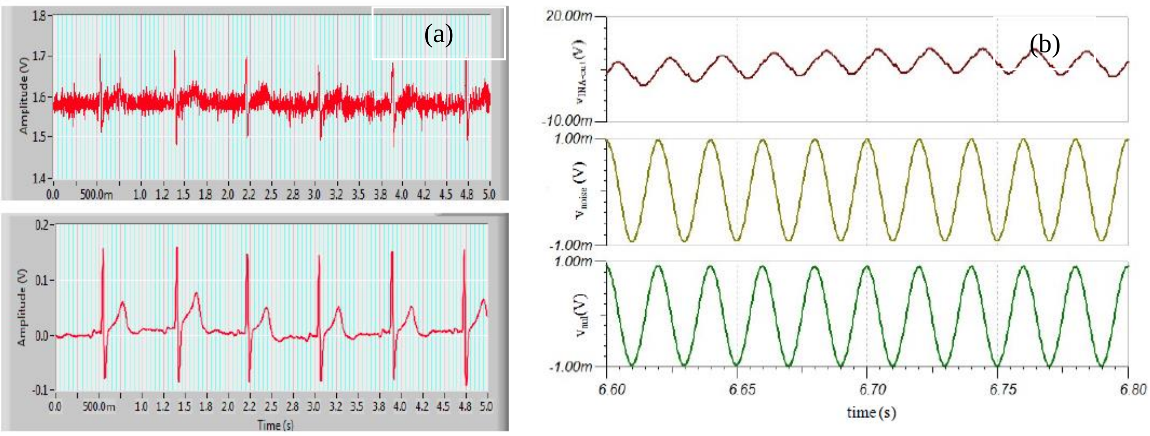

Figure 3. (a) ECG result with and without Interferences; (b) Simulation result of 50Hz power line noise suppression.

B. Simulation Results

The overall circuit for the power line interference rejection is simulated using SPICE based TINA-TI simulation software and the result is shown in Fig. 3(b). The running time was up to 10s and the signal amplitude is expressed in mV. Ideally, the last two signals shown in Fig. 3(b) should have equal amplitude and phase, so that the amplitude of the IA output (VINA-OUT) would be zero. This means, noise will get suppressed fully. But, this is practically impossible, considering the minute value of the phase difference and a very small simulation error etc. yielding an output noise of 7mV from the 200mV noise. Effectively the simulation result shows an increase in SNR by around 30dB. In other words, the amount of noise get suppressed is around 97%.

The signal amplitude of the ECG at the IA output,

$$V_{ina} = 150\text{mV}$$

The noise amplitude before using the control system,

$$V_{noise} = 200\text{mV}$$

The noise amplitude with the use of control system,

$$V_{noise'} = 7\text{mV}$$

$$\text{The change in SNR} = 20\log\left(\frac{V_{ina}}{V_{noise}}\right) - 20\log\left(\frac{V_{ina}}{V_{noise'}}\right)$$

$$= 20\log\left(\frac{V_{noise'}}{V_{noise}}\right)$$

$$= 20\log\left(\frac{7}{200}\right)$$

$$= -30\text{ dB}$$

The above calculation shows that the SNR is improved by 30dB. This study is repeated with different values of coupling capacitances and the result is found to be consistent for the designed circuit as shown in Table II. The complete circuit set up can also be tested using LabVIEW after wiring the essential hardware part. The filters, controlled amplifier and the switching circuits etc. as shown in the Fig. 2 get wired up on NI ELVIS board.

TABLE II. SIMULATION ANALYSIS FOR DIFFERENT COUPLING CAPACITANCES

Coupling Capacitance (pF)	V_{noise} amplified by INA (mV)	V_{ina}-out (mV)	Improvement in SNR (dB)
0.5	49.98	1.66	29.57
1	100.12	3.31	29.62
2	200.34	6.6	29.64

IV. CONCLUSION AND FUTURE SCOPE

In this article, a noncontact ECG measurement has been carried out and a scheme for suppressing power line interference is also proposed and simulated. A prototype had been built; tested and non-contact ECG signals had been obtained from the body of many volunteers. The developed non-contact scheme provided reliable and very good signal quality without losing any important morphological information compared to a conventional ECG. The proposed scheme is very applicable if the noncontact ECG measurement system lies adjacent to powered electronic equipments. A variety of analog cum digital circuits for power line interference rejection can be designed and tested. But, the task of getting continuous, accurate and stable non-contact ECG measurement is a challenging one. The proposed noncontact scheme that tested on a chair can also be applied on bed for long term cardiovascular monitoring. In this case some array of electrodes can be implemented and multiplexed to avoid distortion of the ECG signal from the body when the Subject is changing his/her position to right or left on the bed. Moreover, the signal obtained can be sent to the doctor using telemetry principle.

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