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Comparative Considerations of Eliminating Method for Power Line Interference in Electrocardiography

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SYNOPSIS

This paper describes a new measurement method and principle of power line interference elimination in ECG signal using inverse loop and AC power line configuration (APC). First, we considered that magnetic induction effect not only depend on a conductive loop area that formed by shielded wires that connect the object and amplifier but also effect of body area effective must be considered. It is simple and useful because interference can be eliminated to very small value though in worst condition and it can be applied in a real ECG signal recording. Second, results show that the contribution of displacement currents into the object especially APC in vertical configuration is smaller than it in other one. Because this method is so easy that it is convenient to be used to understand some aspects of power line interference elimination phenomenon. Hence we expect that this method can be used as one of improvement method in measurement system of ECG signal recording.

INTRODUCTION

Power line interference may corrupt biopotential signals and it is common problem during the measurement biopotential signals such as the ECG. This cause of different ways that interference could enter to the system such as magnetic induction, displacement currents into the electrode leads, displacement currents into the body and non ideal of biopotential amplifier. The analysis of interference is complicated by the fact that not all sources will produce noticeable interference in all situations. Huhta and Webster explained that power line interference by electromagnetic induction can be eliminated to very low value by making a conductive loop area as small as possible that formed by two leads that connect the object and amplifier [1]. Then, some general techniques to reduce this interference had ever been described by some authors such as: differential amplifier; driven right leg; isolation and grounding; analog filtering; digital filtering; and composition.

In this work, we propose a new measurement method to eliminate of this interference by using inverse loop and AC power line configuration (APC)[10]. This idea originates from the following reasons: First, previous method have been considered that interference can be eliminated to very low value by making a conductive loop area as small as possible that formed by two leads that connect the object and amplifier, however we assumed that interference not only depend on a conductive loop area but also an effective object area. Second, if interference can not be eliminated to very low value although the leads are twisted, so this problem can be overcomed by using inverse loop method. And finally, we supposed that displacement currents, I_{d1} and I_{d2}, which is coupled by coupling capacitors through the two of electrode leads system and the body can not be the same, this reason is the electrode leads can not be closed together completely and often leaving a few centimeters of unshielded leads. Thus, by these method we expect that the power line interference can be rejected from ECG signals as small as possible.

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2. GENERATION OF POWER LINE INTERFERENCE AND GENERAL VIEW OF INTERFERENCE REDUCTION TECHNIQUE

2.1 Generation of Power Line Interference

Huhta and Webster analyzed the problem of power line interference by separating it into two independent categories: magnetic and electric. First, a changing magnetic field ***B*** produced by power line can induce in any near by conductive loop an electromotive force (EMF), which results in an AC potential [1]. In other word, the magnetic field passes through the loop which formed by two electrode lead and induces voltage into the circuit. This voltage is proportional to the strength of the magnetic field. Thus, solution of this problem are to minimize the loop of electrode leads area as small as possible, keep it close together and parallel. Second, the electric field ***E*** can enter the electrode leads and the body. The capacitive coupling induces displacement current from the power line into the electrode leads, then it flows through the skin impedance and the resulting voltage drop causes 60 Hz interference within the amplifier sensing loop. One solution of this problem is to abrade the skin to reduce skin impedance to less than 5 kΩ and another solution is to shield the leads as far as possible [2].

2.2 General View of Power Line Interference Reduction Technique

2.2.1 Differential amplifier

In order to reject power line interference due to external signals and also due to the injected current , and to prevent loading effects that would result in nonlinearity, a differential amplifier is required for biosignal measurement [3]. Differential input amplifier are commonly used in the measurement of biopotential signal. This is because their ability to reject power line interference and other common-mode signals which follows from their high common mode rejection ratio (CMRR) [4][5].

2.2.2 Driven right left

Power line interference can be also produced by the skin-electrode impedance unbalance. This impedance unbalance converts the common mode voltage to differential voltage, which result in interference. This interference can be reduced by using the driven-right-leg (DRL) [1]. By this reason that in many ECG systems the patient is not grounded at all. Instead, the right-leg electrode is connected to the output of an auxiliary op-amp. This DRL is also valuable in terms of electrical safety because the current feed back never exceeds the current already flowing in the patient due to capacitive coupling of the power line , and current is typically less than 1 μA under normal operating conditions [6].

2.2.3 Isolation and Grounding

Wood et.al [6] have been analyzed clearly about the effect of isolation and ground in eliminating of power line interference using four common recording configurations. They proposed that the degree of magnetic induction and levels of displacement currents induced into the electrode leads and the body may affect interference levels on the biopotential signal significantly and isolation also reduces levels of interference.

2.2.4 Analog filtering

Electrical interference from local 60 Hz power line can corrupt biopotential signals such as the ECG. Low pass filter with cutoff frequencies below 60 Hz can remove this type of interference. However considerably reduce the bandwidth of the signal and ECG waveform would be distorted [7].

2.2.5 Digital filtering

Some biopotential instrumentation often use 60 Hz notch filters to remove a portion of the harmonic noise waveform, but this filter can remove or distort frequency component in the bandwidth of interest. To overcome this problem, digital filters based on a 60 Hz sinusoid can be used to retain the signal bandwidth but do not remove the upper harmonics present in some interference waveforms [7]. Another filter can be also used as noise cancellation is adaptive filtering. The adaptive filter essentially minimizes the mean-squared error between a primary input, which is the noisy ECG, and a reference input, which is either noise that is correlated in some way with the noise in the primary input. The most significant feature of this filter is that it allows estimation of spectral properties of the signal and noise [8].

2.2.6 Composition

In experimental situations, noise and artifact results in inaccurate detection of the QRS complex. In this case, wavelet analysis may prove to be helpful in removal of electrical interference from ECG signal. A more challenging application would be in distinguishing artifact from signal. Since wavelet analysis naturally decomposes the signals at different scales at well-localized times, the artifactual events can be localized and eliminated [9].

3. CONVENTIONAL METHOD OBTAINING INTERFERENCE FREE SIGNAL

3.1 Principle of Determining of Interference Elimination

A general equation for power-line interference in ECG system using three electrodes with the subject grounded is as follows,

$$V_n = \underbrace{2\pi fSB}_{\text{magnetic induction}} + \underbrace{\left(I_{d1}Z_{e1} - I_{d2}Z_{e2}\right)}_{\text{displacement current in leads}} + \underbrace{I_bZ_t}_{\text{displacement current in tissues}} + \underbrace{V_{cm}}_{\text{common mode potential}}\left[\frac{1}{CMRR} + \underbrace{\frac{Z_{e_1} - Z_{e_2}}{Z_{cm}}}_{\text{potential divider effect}}\right] \tag{1}$$

where,

f	frequency of power-line
S	area of loop
B	magnetic flux density
$CMRR$	common-mode rejection ratio
I_b	displacement current coupled into object
I_{d1}, I_{d2}	displacement current coupled into input leads
V_{cm}	common-mode body potential with respect to ground
V_n	AC power-line interference
Z_{cm}	amplifier common-mode input impedance
Z_{e1}, Z_{e2}	skin-electrode impedance
Z_t	internal body impedances between electrode.

Then, Webster and Huhta [3] comment that not all sources of power-line interference will produce noticeable interference an all situation, that means are: (a) interference from magnetic induction can be minimize by twisting of the electrode leads; (b) displacement currents of the two lead are supposed equal, $I_{d1}=I_{d2}=I_d$, and skin-electrode impedance unbalance $(Z_{e1}- Z_{e2})$ can be reduced to a few kilo-ohms by abrading the electrodes sites; (c) interference from displacement currents through the body tissue is neglected because the internal body impedances is very small; (d) interference by common-mode body potential with respect to ground is partly on the common-mode input impedance of the isolation amplifier can be negligible. However, in a practical system, the electrode leads are can not closed together completely and often leaving a few centimeters of unshielded leads. Thus, the displacement currents in this condition may be larger than expected. Based on this comment, we described another method to reduced interference by magnetic induction and displacement currents effect using inverse loop so that the electrode leads without twisting and the displacement effect AC power line configuration (APC), respectively. In this case we supposed that I_{d1} is not equal with I_{d2} and by this method, eqn. 1 can be simplified to

$$V_n = \underbrace{2\pi fSB}_{\text{magnetic induction}} + \underbrace{(I_{d1}Z_{e1} - I_{d2}Z_{e2})}_{\text{displacement current in leads}} \quad (2).$$

3.2 Construction and Design

Fig. 1 shows a general block diagram of measurement of interference elimination using inverse loop and APC. We adopted, for recording of interference signals, Lead I configuration using Ag-AgCl electrodes (skin surface electrode, Nihon Kohden Co. Ltd., Japan), unpolarized and 10 mm in diameter. The electrode paste used was a cream (gelaid electrode paste, Nihon Kohden Co, Ltd., Japan). And bioamplifier specification that is used in this work is as in Table 1 [11]. Inverse loop and APC method are considered in detail in next section as follows.

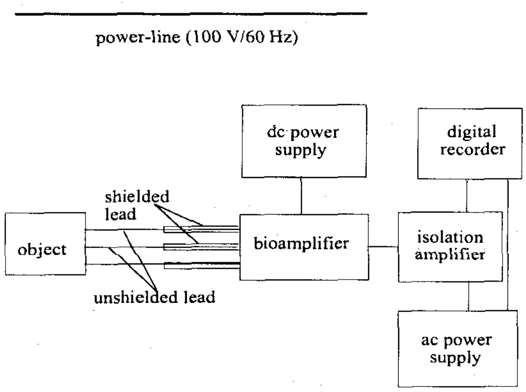


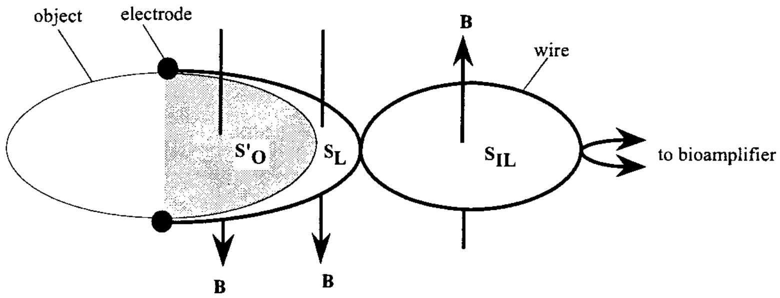
Fig. 1 A general block diagram of measurement system.

TABLE 1 Bioamplifier specification

- CMRR (dB at 60 Hz)	99
- total gain	500
- input noise (μ Vpp)	6
- cutoff frequency (Hz)	113
- time constant (msec)	1.5

3.2.1 Inverse loop

An inverse-loop is a loop formed by half -turn of the leads and this area then is called as S_{IL}. This inverse loop area S_{IL} must be made in such a way that its area is about the same with each area in the volume conductor S'_O. This inverse loop is proportional to its orientation, therefore both S'_O and S_{IL} area must be parallel to floor and ceiling during recording be done. In the practical case, S'_O in the volume conductor of the body that is formed by the two main electrode sited on the skin, then S'_O is called as effective area. And S_L is small area that it formed between body surface and the electrode leads. This inverse loop area S_{IL} must be about the same with $(S'_O + S_L)$ during measurement being done as shown in Fig. 2 and Fig. 3 shows this measurement system for real ECG signal recording.



B = peak-to-peak magnitude of magnetic field

Fig. 2 Induced potential into object and conductive loop using inverse loop method.

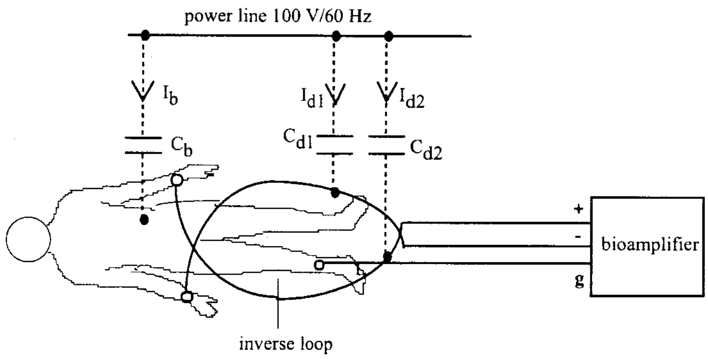


Fig.3 Measurement system for ECG signal recording using inverse loop method

3.2.2 AC power line configuration

AC power-line configuration (APC) is a simple circuit model that it used as a new source point of power-line interference. The purpose of this model is to make a dominant effect of interference sources because the sources of power-line interference came from many sources including lighting apparatuss, AC wiring and outlets, and other equipment operating nearby [3].

In this work, we conducted two configuration of APC, namely: APC is moved in horizontal and vertical position to object. And for safety reason distance between object and APC is 50 cm. Fig. 4 shows the measurement system for real ECG signal recording using this method.

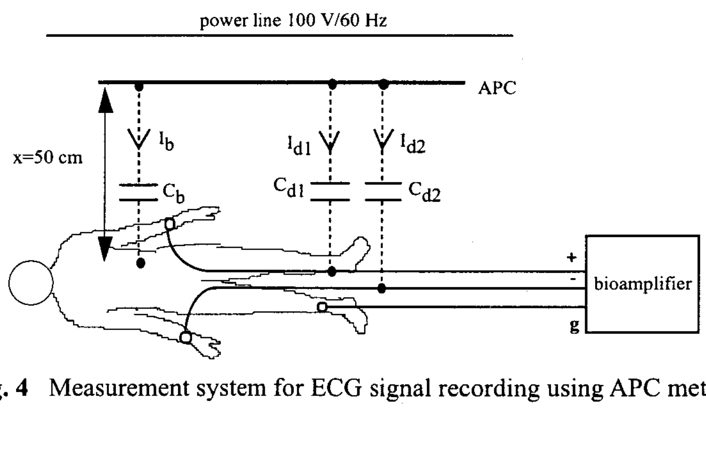


Fig. 4 Measurement system for ECG signal recording using APC method.

3.3 Results

We proposed three methods for recording of ECG signals which were recorded based on inverse loop, APC and combination of inverse loop and APC method. By these method we get two types of signals, namely : (a) ECG + big interference and (b) ECG + very small interference. Results are shown in Fig. 5, Fig. 6 and Fig. 7, respectively. And in order to analyze interference in ECG signal recording, we made FFT analysis with a 4 ms sampling interval and 8192 sampling points as shown in Fig 8.

4. DISCUSSIONS

We have described the performance of inverse loop in eliminating of interference to very low value in effective object of volume conductor of the body as it is mentioned previously. This value is about the same with bioamplifier noise (6 μ V). Thus, we propose that interference for this model is nearly zero. This case can be achieved if effective object and inverse loop area can be matched so that both the area are the same. This condition can be assumed that induced potential into S'_O and S_{IL} area cancel each other. Then, we have conducted that if inverse loop area S_{IL} is turned more than half turn, the interference will increase instantly. Yet, the inverse-loop position is very sensitive to its orientation. To overcome this characteristic, orientation of inverse-loop must be always parallel to floor and ceiling during measurement being done. Based on this result, we propose that this method is applicable to eliminate of interference in biopotential signal recording, such as ECG.

The phenomenon of power-line interference on the object using the APC can be explained as follows: (a) Power-line interference depends some factors such as, distance of the APC, length of unshielded leads; (b) There are contrasts value of this interference on the object between horizontal and vertical position of the APC, these values in vertical position are smaller than the others. This case can be assumed that displacement currents are symmetry from the APC's position into leads; (c) The power-line interference considered by using eqn. 2 and the experiment results show that interference is nearly zero if the APC is in vertical-position; (d) Based on this experiment, it was known that there are some reductions of power-line interference.

6. CONCLUSIONS

This paper describes a new principle and measurement method of power line interference elimination in ECG signal using inverse loop and AC power line configuration (APC). There is strong relationship between using this inverse

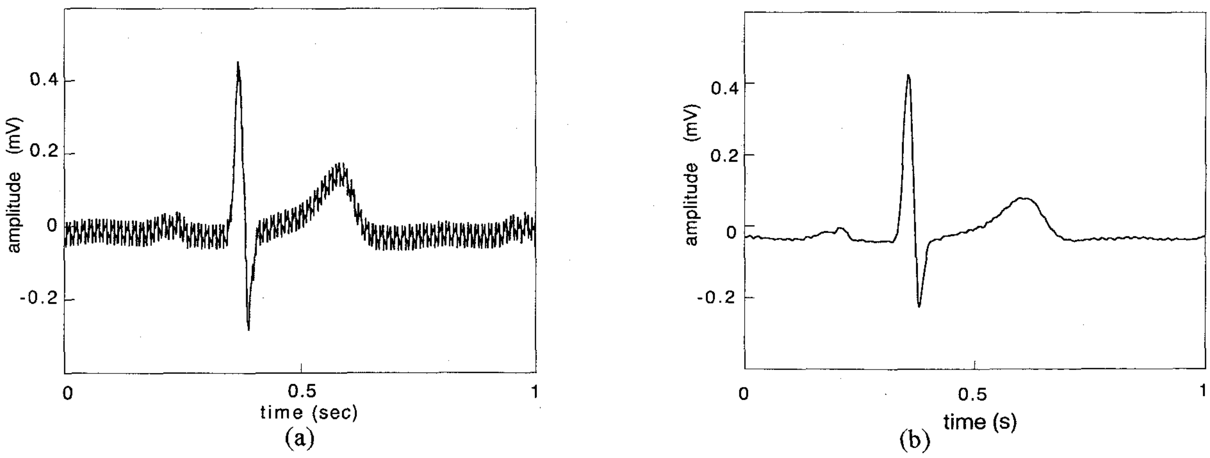
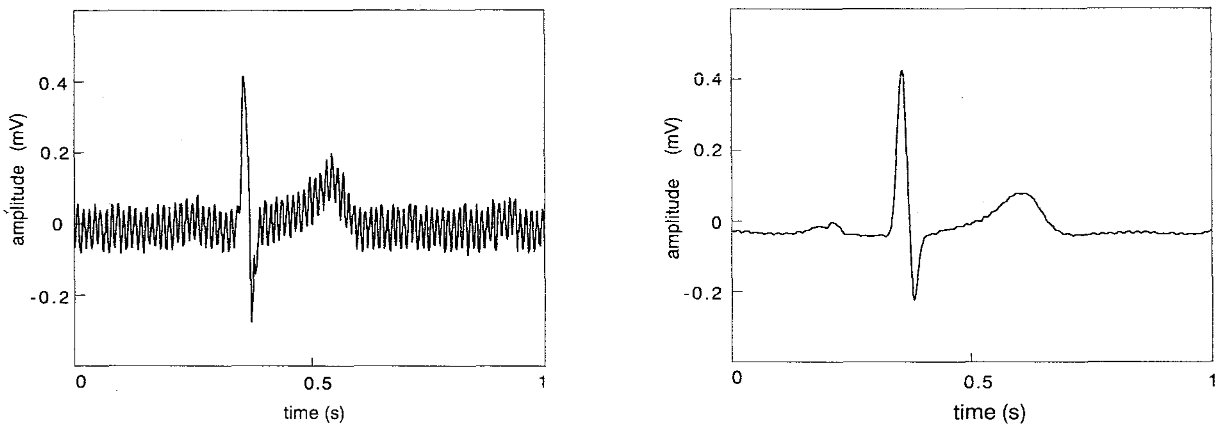
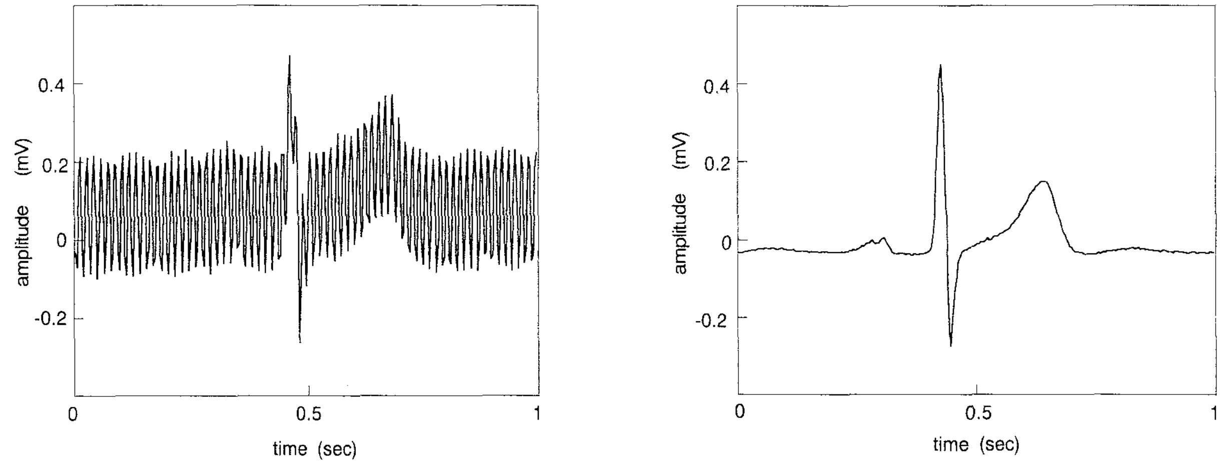


Fig. 5 ECG signal recording: (a) without using inverse loop; (b) by using inverse loop.



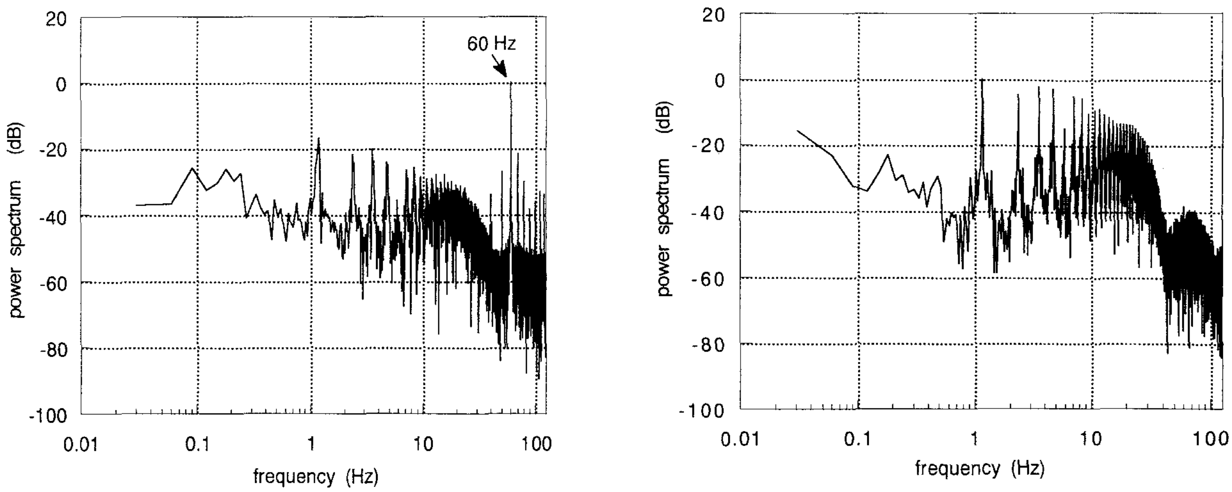
(a) (b)

Fig. 6 ECG signal recording: (a) without using APC; (b) by using APC.



(a) (b)

Fig. 7 ECG signal recording: (a) without using combination of inverse loop and APC; (b) by using combination of inverse loop and APC.



(a) (b)

Fig. 8 FFT analysis of ECG signal recording: (a) without using combination of inverse loop and APC; (b) by using combination of inverse loop and APC.

loop and AC power line configuration (APC) method in eliminating of interference. Based on this work, we expect that this method can be used as one of improvement method in measurement system of ECG signal recording.

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