# Noise Reduction for Non-Contact Electrocardiogram Measurement in Daily Life

KM Lee[1], SM Lee[1], KS Sim[2], KK Kim[3], KS Park[4]

[1]Interdisciplinary Program of Bioengineering, Seoul National University, Seoul, Republic of Korea
[2]Advanced Biometric Research Center, Seoul National University, Seoul, Republic of Korea
[3]Interdisciplinary Program in Medical and Biological Engineering, Seoul National University, Seoul, Republic of Korea
[4]Department of Biomedical Engineering, College of Medicine, Seoul National University, Seoul, Republic of Korea

## Abstract

*Electrocardiogram (ECG) measurement without skin-contact is essential for u-healthcare. ECG measurement using capacitive-coupled electrode (CC-electrode) is a well-known method for unconstrained ECG measurement. Although the CC-electrode has the advantage of non-contact measurement, common mode noise is increased, which decreases the signal-to-noise ratio (SNR). In this study, we proposed non-contact ECG measurement system using CC-electrode and driven circuit to reduce noise. The components of driven circuit were similar to those of driven-right-leg circuit and conductive sheet was employed for driven electrode to contact uniformly to the body over clothes. We evaluated the performance of the driven circuit under different conditions, including a contact area to the body and a gain of the driven circuit to find out a relationship between them and the SNR of ECG. As the results, as contact area became larger and gain became higher, SNR increased.*

## 1. Introduction

With improving quality of life of human beings, there has been increased awareness and concern about ubiquitous healthcare (u- healthcare). In the field of u-healthcare, an unconstrained monitoring of physiological signals has been studied steadily [1]. Among the physiological signals, electrocardiogram (ECG) is a prevalent signal, because it detects the condition of cardiovascular system, and thereby it is a useful signal for diagnosing cardiovascular function. However, ECG measurement using Ag/AgCl electrodes employs conductive adhesive to keep good contact with the skin. It makes a person feel uncomfortable, and thereby it is inadequate for long-term monitoring.

Capacitive-coupled electrode (CC-electrode) is a method for unconstrained ECG measurements. Using CC-electrode, ECG can be measured over clothes as a result of a capacitor formed between electrode and skin and an ultra high input impedance of the electrode [2, 3]. The ultra high input impedance of the electrode is required since the impedance between skin and electrode increases according to the thickness and type of the clothes. Because the CC-electrode does not use a conductive adhesive that makes a person feel uncomfortable, it is adequate for long-term monitoring. There have been previous studies on ECG recording without direct skin-contact on some objects like bed or chair using CC-electrode [4, 5].

Although the CC-electrode has the advantage of long-term monitoring, the missing data increase because it is sensitive to power-line interference and motion artifact compared with the Ag/AgCl electrode. Stray capacitances induced between power line and body make interference currents which flow through the body and also into the amplifier. Therefore, reduction of the common-mode voltage is highly required to reduce interference [6, 7]. One of the practical ways to reduce common-mode voltage is driven-right-leg circuit. [8].

In this study, we proposed non-contact ECG measurement system using CC-electrodes and driven circuit to reduce common-mode voltage. The driven circuit is similar to driven-right-leg circuit. It is required to adjust the driven signal and the driven electrode to minimize the missing data. We evaluated the driven circuit under different conditions, including a contact area to the body and a gain of the driven circuit.

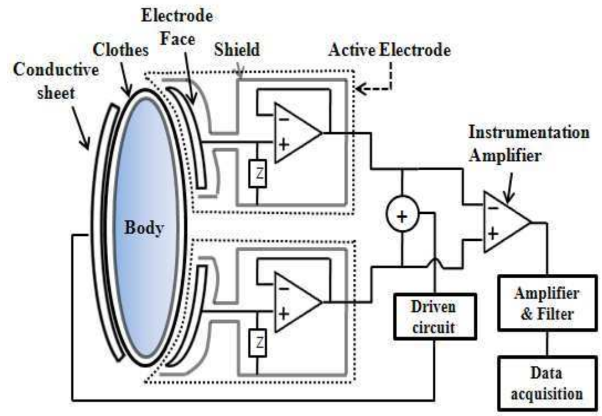
## 2. Materials and methods

### 2.1. Active electrode

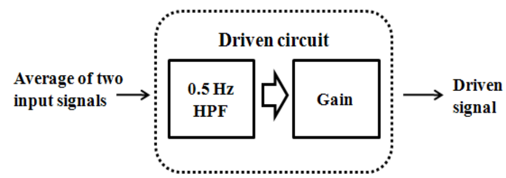
Active electrode consisted of a pre-amplifier, electrode face and plate for shielding circuit. The size of active electrode was 12 $cm^2$ (4 cm x 3 cm) and thickness was 8.82 mm. Compared with commercial Ag/AgCl electrode, the impedance between skin and electrode increases according to the thickness and types of clothes. Therefore, ultra high input impedance is required to obtain good signal quality over clothes. Input impedance of preamplifier was 100 TΩ. The resistor Z given in Fig. 1 is for discharging the static charge on the cloth, and its resistance is 5GΩ.

### 2.2. Measurement system

Fig. 1 and 2 show the block diagram of developed capacitive-coupled ECG measurement system. The system consisted of two CC-electrodes, instrumentation amplifier (INA114, Burr-Brown), filters, an amplifier with a total gain of 510 and driven circuit that conductive sheet was employed for driven electrode. The driven circuit was composed of 0.5 Hz high pass filter and an amplifier. The signal was digitized at the sampling rate of 1000 Hz with 16bit resolution using Biopac system (MP-150) and was not processed by digital filter.




(a)




(b)

Figure 1. (a) A block diagram of the overall system. (Biasing impedance z= 5GΩ) (b) A block diagram of the driven circuit

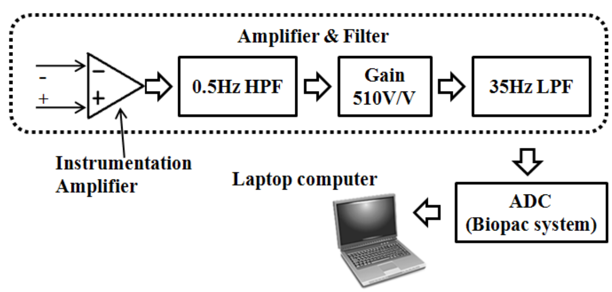



Figure 2. A block diagram of a module for signal processing and data acquisition

## 3. Experiment setup

Conductive sheet was connected to driven circuit and was embedded in a sit cushion on the chair. CC-electrodes were fixed at chest by a belt. ECG signals were measured from one healthy male subject wearing a normal cotton cloth. To validate the performance of the CC-electrodes, ECG obtained from the CC-electrodes was compared with ECG obtained from Ag/AgCl electrodes. ECG from Ag/AgCl electrodes was filtered by 35 Hz low pass filter and digitized by Biopac system (MP-150) with 1000 Hz sampling rate. Also, contact area of driven circuit was 144 $cm^2$ (16 cm x 9 cm) and driven gain was 1000 V/V.

We focused on the effect of contact area and gain of the driven circuit to evaluate the performance of the driven circuit. Data were measured for twenty seconds.

**1) Effect of a gain of the driven circuit:** We carried out this experiment changing a gain of the driven circuit with the conductive sheet in the size of 8cm x 9cm. The gains of 30, 60, 100, 300, 500 and 1000 V/V were used. Also, a capacitive ground was used as third electrode for comparison with the results of driven circuit.

**2) Effect of contact area**: It was similar to the experiment for evaluating an effect of a gain of the driven circuit. We carried out this experiment changing the area of conductive sheet with the driven gain of 300 V/V. Conductive sheets whose sizes were 12 $cm^2$ (4 cm x 3 cm), 36 $cm^2$ (4 cm x 9 cm), 72 $cm^2$ (8 cm x 9 cm), 144 $cm^2$ (16 cm x 9 cm) were used for confirming the effect of contact area. Also, the capacitive ground was used for comparison with the driven circuit.

# 4. Results

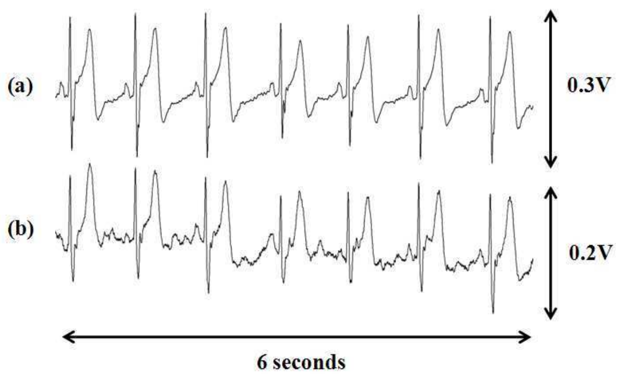



Figure 3. ECG recordings obtained by (a) Ag/AglCl electrode, (b) CC-electrode

ECG recordings obtained by Ag/AgCl electrodes and CC-electrodes are illustrated in Fig. 3. It shows that ECG waveform using CC-electrode is synchronized to the waveform obtained by Ag/AgCl electrode. Therefore, ECG measurement using CC-electrode is proven to be a reliable method. Fig. 4 (a) shows the ECG waveform with the various driven gain values and (b) shows the power spectral density of each case when the conductive sheet in the size of 8cm x 9cm was used. The higher gain of the driven circuit increased the SNR more. Fig. 5 (a) shows the ECG waveform with the various contact areas and (b) shows the power spectral density of each case when the driven gain was 300 V/V. The larger contact area increased the SNR more. When the capacitive ground was used as third electrode instead of driven circuit, the SNR was greatly decreased in both cases. Therefore, the driven circuit with large contact area and high gain was helpful in increasing the SNR.

# 5. Discussion and conclusions

When the conductive sheet in the smallest size of 4cm x 3cm was used, the system was sensitive to power-line noise. Therefore, the SNR was greatly decreased as the subject got close even a little to the electronic products. ECG waveform when the subject got close to the electronic products is given in Fig. 6. It is difficult to see the ECG waveform. In this case, the high gain of driven circuit was helpful to make the system stronger to power-line-noise and the ECG quality became better. However, the noise was still increased when the subject got close to the electronic products because the sensitivity to power-line interference was still high. Therefore, the large contact area is required for stable system.

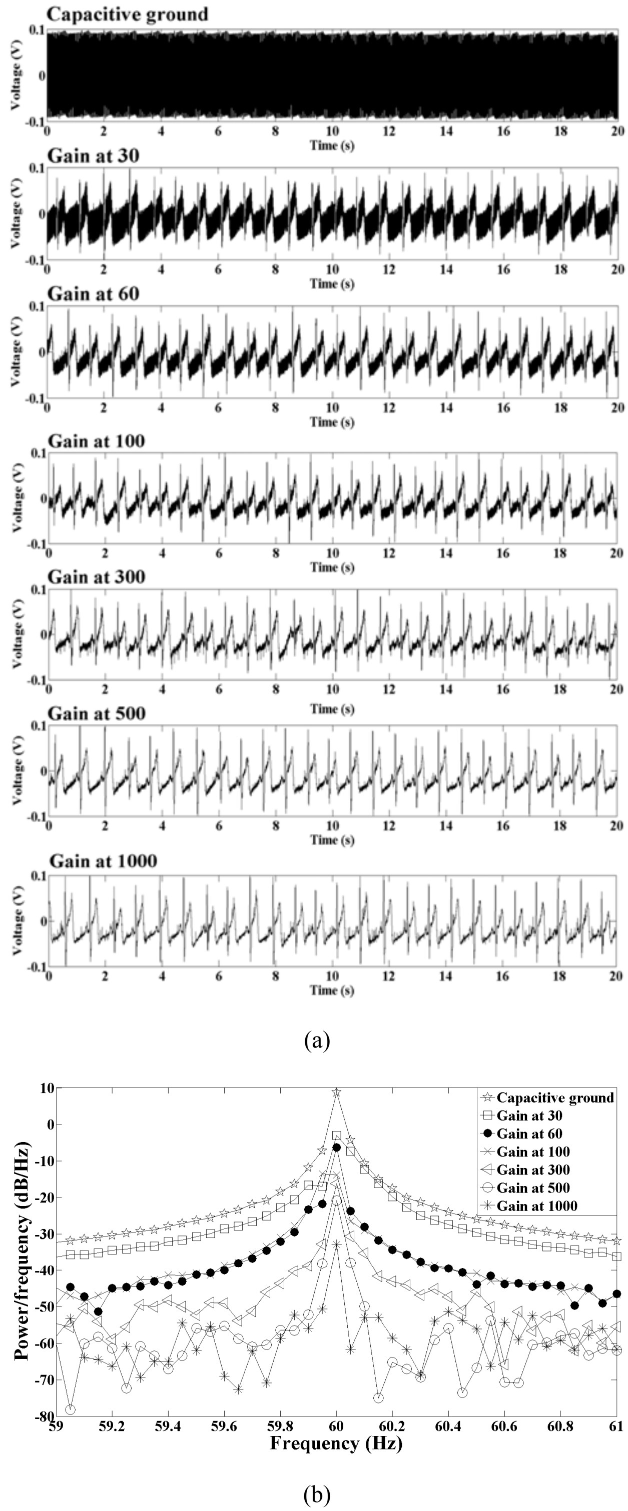



Figure 4. ECG signals obtained by the presented method at the same contact are, 8cm x 9cm, (a) ECG waveforms from different gain of the driven circuit, (b) power spectral density at the 60 Hz power-line noise.

In our measurement system, ECG was successfully measured over clothes. We evaluated the performance of the driven circuit and found out that the noise of signal can be decreased by enlarging contact area to the body or enlarging gain of the driven circuit through the experiments. The driven circuit was greatly helpful in reducing the noise, and therefore it would be a useful method for long-term ECG monitoring. On further study, we will do experiments by changing the degree of the gain and area more variously, and try to find out the relationship between electrode size and contact area of the driven circuit.

## Acknowledgements

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Address for correspondence:

Kwang Suk Park
College of Medicine, Seoul National University, 110-799, 28, Yongon-dong, Jongno-gu, Seoul, Republic of Korea
E-mail: pks@bmsil.snu.ac.kr


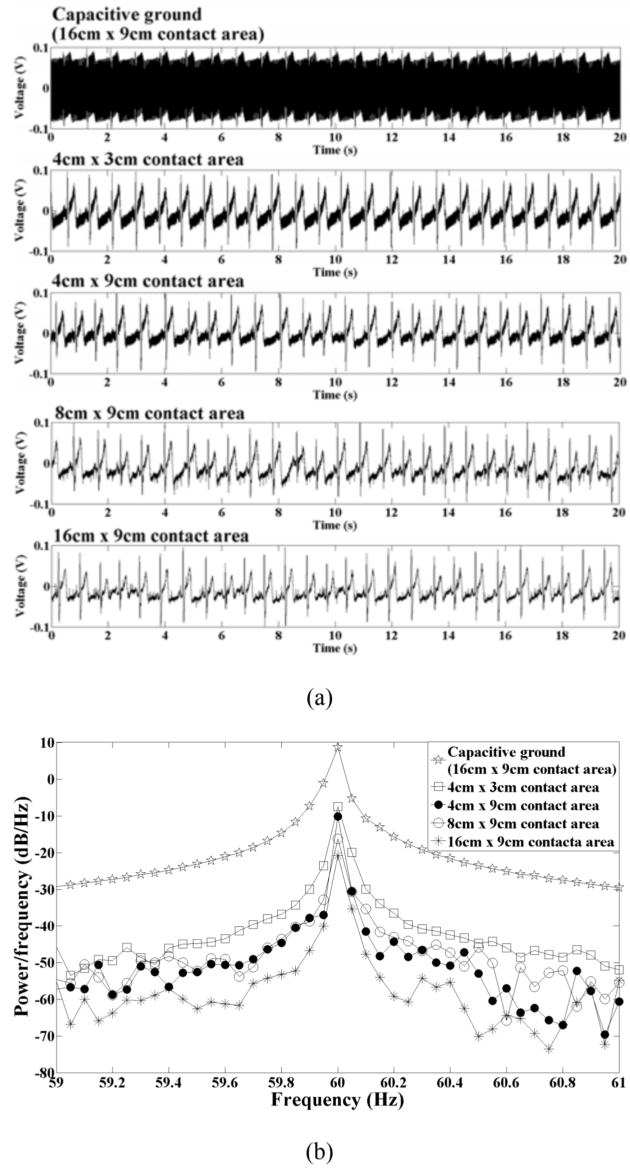


Figure 5. ECG signals obtained by the presented method at the same driven gain of 300, (a) ECG waveforms from different contact area, (b) power spectral density at the 60 Hz power-line noise.

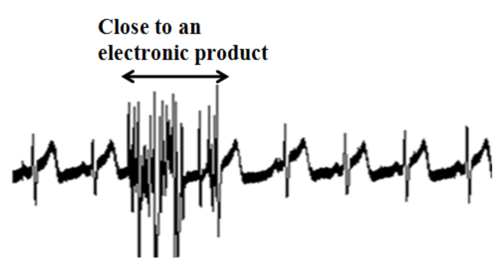


Figure 6. ECG waveform when a subject got close to an electronic product. (4 cm x 3 cm contact area and gain of 300)