Method of recording bioelectrical signals using a capacitive coupling

V A Simon, V A Gerasimov, D K Kostrin, L M Selivanov and A A Uhov
Department of electronic instruments and devices, Saint Petersburg Electrotechnical University “LETI”, 197376, Saint Petersburg, Russia

E-mail: vsev.simon@gmail.com

Abstract. In this article a technique for the bioelectric signals acquisition by means of the capacitive sensors is described. A feedback loop for the ultra-high impedance biasing of the input instrumentation amplifier, which provides receiving of the electrical cardiac signal (ECS) through a capacitive coupling, is proposed. The mains 50/60 Hz noise is suppressed by a narrow-band stop filter with an independent notch frequency and quality factor tuning. Filter output is attached to a ΣΔ analog-to-digital converter (ADC), which acquires the filtered signal with a 24–bit resolution. Signal processing board is connected through universal serial bus interface to a personal computer, where ECS in a digital form is recorded and processed.

1. Introduction
The commonly used contact method of ECS registration is a reliable and widely applicable technique for the diagnosis of many heart diseases. However, this method has several disadvantages. First, standard conductive gels can dry over time and thus don’t provide long-term reliability of the electrical contact. Second, metal contact electrodes can cause skin irritations in case of a metal allergy. Third, the patient’s mobility is often limited during the registration process.

However, the electrical contact can be replaced by a capacitive coupling, as shown in [1–8]. It represents a capacitor formed by an electrode surface, skin surface and dielectric layer (e.g. cotton textile). The coupling capacitance depends on the electrode’s size and the type of a fabric. In [1], where electroencephalographic electrodes are used, the coupling capacity is in the range from 1 to 50 pF. In [2], where electrocardiographic (ECG) electrodes are used, the coupling capacity is 92 pF.

Thus, the impedance of the coupling capacitor can be as much as $10^{10}$ Ω in the typical ECG frequency range (from fractions to tens of Hz). In order to receive the ECS via capacitive coupling the instrumentation amplifier (IA) with ultra-low input bias current and high input impedance can be used. One of the best examples of IA is the INA116 amplifier with the typical value of the input bias current as low as $3\cdot10^{-15}$ A and with input impedance of more than $10^{15}$ Ω.

However, the ECS itself doesn’t contain the constant component. Therefore, the inputs of the IA should have a direct current (DC) biasing to prevent saturation of the amplifier. The value of a biasing resistor should be at least $10^{10}$ Ω for the reliable reception of the low-frequency harmonics [8]. Unfortunately, the resistors with an ultra-high value are quite expensive and hard-to-buy goods.

2. Feedback loop for the input stage amplifier
In [3] an original circuit, which appears as an equivalent to the ultra-high value biasing resistance, was described. This circuit contains only inexpensive general purpose components (figure 1).
A resistive divider with the transmission factor \( a = R_2/(R_1 + R_2) = 0.999 \) is connected to the output of the operational amplifier (op-amp). A 9.1 MΩ resistor is connected between the input of op-amp and the output of the resistive divider. The current through the resistor \( R_3 \) can be represented as the current through the virtual resistor \( R_{bias} \) with resistance value given by the formula:

\[
R_{bias} = \frac{R_3}{1-a}.
\]

The operation of the biasing feedback loop was verified through SPICE simulations and experiments on the breadboard. Then, the biasing circuit was connected to the INA116 amplifier, as shown on figure 2.

3. Mains noise filter

One of the main problems with the registration of bioelectrical signals (such as ECS) is the suppression of various interferences. This problem becomes much more important when the ECS is received via capacitive coupling. The greatest negative impact on the quality of the received ECS has the mains 50/60 Hz noise [7]. Usually a stop filter is used to remove this type of interference. The filter design should provide an independent tuning of the quality factor and notch frequency. In this work an original stop filter
comprising of two cascaded all-pass filters, symmetrical voltage divider and a feedback loop with a variable depth (figure 3) was designed.

![Figure 3. Circuit of the narrow-band stop filter.](image)

After the signal had passed through the all-pass filters, it is added to its own original by a symmetric divider ($R_7 - R_8$). Herewith the amplitudes of all harmonics of the signal are reduced according to the changes in the phase of the signal.

The phase of the harmonic with maximum suppression is changed by 180°. The frequency of the harmonic with maximum suppression is equal to the geometric mean of the two frequencies:

$$\omega_1 = R_3 C_1 - 1$$
$$\omega_2 = R_6 C_2 - 1$$

This is the notch frequency of the filter $\omega_n = \sqrt{\omega_1 \omega_2}$.

The output signal of the filter is applied through the buffer op-amps to the potentiometers $R_3$ and $R_6$. The resistor $R_9$ varies the depth of the feedback $d$ (from 0 to 100 %) and thus changes the quality factor $Q$, given by the equation

$$Q = 0.5 \frac{2\sqrt{\omega_1 \omega_2}}{1 - d \frac{\omega_1 + \omega_2}{\omega_n}}.$$

The gain-transfer characteristic of the filter is

$$H(s) = \frac{s^2 + \omega_n^2}{s^2 + \frac{\omega_n}{Q} s + \omega_n^2},$$

where $s = i \omega; i = \sqrt{-1}$.

4. Experimental verification of the proposed method

An experimental setup for the ECS acquisition includes the following (figure 4):
- cotton T-shirt with two embedded capacitive sensors;
- input stage circuit with IA and two feedback loops (as shown on figure 2);
- mains 50/60 Hz noise filter (see figure 3);
- ADC with a 24-bit resolution and ΣΔ architecture;
- personal computer with Audacity software.
The output signal from the mains noise filter is acquired and digitized by the ADC. The digital signal is recorded on a personal computer using the Audacity software. Higher harmonics of the 50/60 Hz interference are removed by the digital processing. The form of the processed ECS in 1–100 Hz frequency range is presented in figure 5. The QRS complex, T–wave and P–wave [9] are all visible on the electrocardiogram record.

![Figure 4. Layout of the experimental setup.](image)

![Figure 5. Electrocardiogram record obtained using a capacitive coupling.](image)

5. Conclusion
The technique of the electrophysiological activity registration using a capacitive coupling is useful for real-time monitoring, as well as for continuous data collection. This method can be used for monitoring the health status of people working in stress conditions (rescue workers, firefighters, truckers), in sport medicine and fitness.

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