Biopotential Electrode Sensors in ECG/EEG/EMG Systems

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Electrocardiography (ECG), electromyography (EMG), and electroencephalography (EEG) systems measure heart, muscle, and brain activity (respectively) over time by measuring electric potentials on the surface of living tissue. Nervous stimuli and muscle contractions can be detected by measuring the ionic current flow in the body. This is accomplished using a biopotential electrode.

A negatively charged ion is an anion and a positively charged ion is a cation. The current flow in the human body is due to ion flow, not electrons. A biopotential electrode is a transducer that senses ion distribution on the surface of tissue, and converts the ion current to electron current. An electrolyte solution/jelly is placed on the side of the electrode that comes into contact with tissue; the other side of the electrode consists of conductive metal attached to a lead wire connected to the instrument. A chemical reaction occurs at the interface between the electrolyte and the electrode.

An Introduction to the Electrolyte-Electrode Interface

Current can pass from an electrolyte to a nonpolarized electrode. (Polarized electrodes act more like a capacitor and current is displaced but does not move freely across the electrolytic interface). Current crosses the interface as the atoms in the electrode oxidize to form cations and electrons. The cations are discharged into the electrolyte, and the electrons carry charge through the lead wires. Similarly, the anions in the electrolyte travel toward the interface to deliver free electrons to the electrode. A voltage known as the *half-cell potential* develops across the interface due to an uneven distribution of anions and cations. It appears as a dc offset in ECGs, EMGs and EEGs.

A very popular electrode is *silver/silver choloride* (Ag/AgCl) because of its very low half-cell potential of approximately 220 mV and its ease of manufacturability. Ag/AgCl electrodes are nonpolarized electrodes—they allow current to pass across the interface between the electrolyte and the electrode. Nonpolarized electrodes are better than polarized electrodes in terms of their rejection of motion artifacts and their response to defibrillation currents. Both motion artifacts and defibrillation events can charge up the capacitance from the electrolyte and electrode interface. Figure 1 shows an equivalent electrical model. The AgCl layer lowers the impedance of the electrode. This is important at low frequencies near dc, where ECG and EEG measurements are taken.

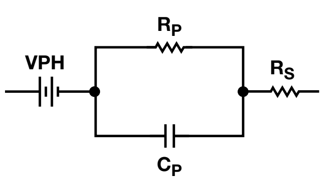

Figure 1. Equivalent circuit model for biopotential electrode.

Patient Preparation Challenges Are Relevant to System Design

Clinicians face practical challenges when making biopotential measurements. They must prep a patient's skin to make a good contact with the electrode. Dry and/or old skin creates a high impedance, which makes it difficult to acquire good readings. In addition, electrode to skin impedances vary due to ethnicity, age, and gender.

Clinicians rub the skin with a mild abrasive to remove the thin layer of dead skin to enable better ion flow between the tissue and the electrolyte on the electrode. This ensures better measurements but takes time. Problems also occur when the electrolyte dries over the course of several hours. This increases the impedance in the electrolyte, which steadily increases the dc offset that, in turn, expends the dynamic range of the instrument. Both challenges are relevant to system designers.

Skin to electrode impedances at 10 Hz using silver/silver chloride electrodes, with the skin properly prepared, are typically about 5 kΩ. This impedance will vary from manufacturer to manufacturer. When designing ECGs and other biopotential front-end circuits, the designer must remember that an impedance of 500 kΩ can be encountered frequently.

Many clinicians never take the time to prepare the skin for attaching the electrode unless they are having problems acquiring good signals. In addition, gold electrodes with paste are commonly used in EEG recordings, and these yield much higher impedances than silver/silver chloride electrodes. Placing the electrodes on the thoracic cavity will yield skin to electrode impedances approximately 2.5× lower than if the electrodes are placed on the limbs.

Designing with Overpotentials

An overpotential is the difference between the half-cell potential and the zero potential. It appears as a dc offset to the measurement instrument. In the case of an ECG, the differential voltage across a person's chest (the cardiac signal) is typically 1.8 mV in amplitude riding on a dc offset of up to 300 mV. The enormity of the dc offset, compared to the cardiac signal, limits the amount of gain applied to the front-end amplifiers. For example, applying a gain of 100 would increase a 5 mV cardiac signal to 500 mV but would also increase a 300 mV dc offset to 30 V.

Amplifiers that operate on wide supply voltages such as ±5 V are commonly used to take advantage of the larger input voltage range. In addition, the designer is able to apply more gain. Designers often use large rails of ±7.5 V to handle the severe environment that the ECG device has to work in, such as operating rooms (ORs). In an OR, an ECG front-end circuit will see interfering signals such as ablation, electric cautery, defibrillation, external pacing, internal pacing, pacemaker H-field telemetry, and a multitude of other signals. In addition, some amplifiers such as Analog Devices AD8220 and AD8224 have rail-to-rail architectures that allow designers to set higher gains.

Electrode Amplifiers

Another common problem is polarizing the electrode. The input bias current of the front-end amplifiers can polarize the electrode if there is poor skin contact. Figure 2 shows JFET input op amps such as Analog Devices AD8625/AD8626/AD8627 and AD8641/AD8642/AD8643 that have input bias currents of less than 1 pA. JFET input instrumentation amplifiers such as the AD8220 and AD8224, shown in Figure 2 and Figure 3, have input bias currents under 20 pA.

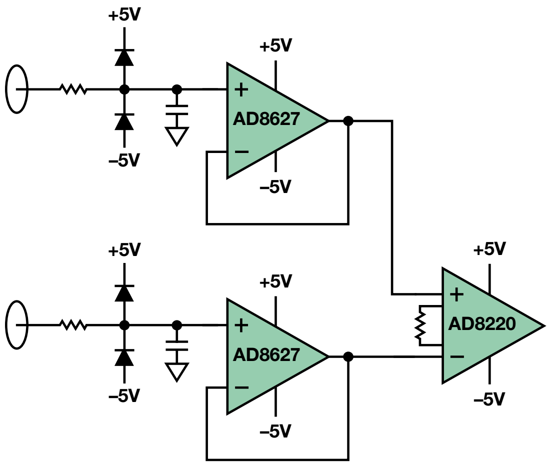

Figure 2. The AD8627 JFET operational amplifier used as a buffer for low input bias current.

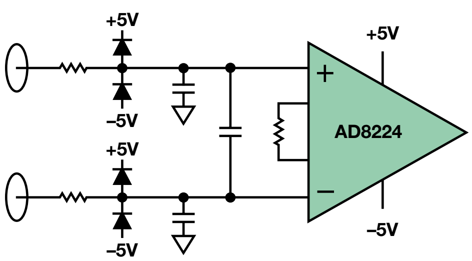

Figure 3. The AD8224 JFET instrumentation amplifier offers low input bias current.

Conclusion

Understanding the electrochemical interaction in electrodes helps clarify their behavioral nuances. In addition, it enables designers to understand the challenges clinicians face when placing electrodes on patients. A thorough understanding of the electrode to skin interface ensures that the signal acquisition is correct and reliable, enabling the clinician to correctly diagnose the patient's condition.

References

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T07465-0-4/08

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