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Portable Amplifier Design for a Novel EEG Monitor in Point-of-Care Applications

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Abstract

The Electroencephalography (EEG) is a common diagnostic tool for neurological diseases and dysfunctions, such as epilepsy and insomnia. However, the current EEG technology cannot be utilized quickly and conveniently at the point of care due to the complex skin preparation procedures required and the inconvenient EEG data acquisition systems. This work presents a portable amplifier design that integrates a set of skin screw electrodes and a wireless data link. The battery-operated amplifier contains an instrumentation amplifier, two noninverting amplifiers, two high-pass filters, and a low-pass filter. It is able to magnify the EEG signals over 10,000 times and has a high impedance, low noise, small size and low weight. Our electrode and amplifier are ideal for point-of-care applications, especially during transportation of patients suffering from traumatic brain injury or stroke.

I. Introduction

Electroencephalography (EEG) is a common diagnostic tool in clinical practice. It provides a vital window to observe the functional activity within the brain. Recent developments in wireless devices and cellular telecommunication networks have allowed a real-time data connection between EEG devices to remotely located hospitals. However, the current EEG system requires complex procedures to install electrodes on the scalp. These procedures include removing the top layer of the skin (stratum corneum) by abrading, application of electrolyte, and gluing electrodes on the scalp. In addition, most commercial EEG data acquisition systems are large and heavy. These problems prevent the EEG to be applied as a powerful diagnostic and monitoring tool at the point of care, such as at homes of patients, in the battlefield, and during the transportation of patients.

II. Skin Screw Electrode and Portable EEG Device

Our new EEG data acquisition system contains a set of skin-screw electrodes and a data port (see Fig. 1). Skin-screw electrodes (represented as five small circles in Fig. 1) are used to acquire bioelectric potential signals from the scalp. Each electrode has a cylindrical shape assembling a cup with the bottom up. Microscopic teeth are present along the rim of the electrode (edge of the cup). When the electrode is twisted clockwise, the micro teeth hook on the painless top layer of the skin through hairs, making electrical contacts (less than 5 k Ω on average) without the need of applying electrolyte. Therefore, this electrode can be

securely attached to the scalp in approximately one second as opposed to several minutes in the case of traditional electrodes. Detailed description of the skin screw electrode is provided in [1].

The large central circle in Fig. 1 represents the data port which hosts a low-noise amplifier and additional electronic circuitry that performs wireless data communication with a mobile device, such as a smart cell phone. The standard Bluetooth port is utilized to establish this communication. In the following, we describe the design of a portable EEG amplifier which is one of the key components in our EEG system.

III. Amplifier Design

Fig. 2 shows the schematic diagram of the EEG amplifier.

A. Instrumentation Amplifier INA118

The first amplification of the EEG signal uses INA118 instrumentation amplifier, which offers excellent accuracy. The amplifier has a high common mode rejection ratio (CMRR) and is able to amplify the small signal difference down to microvolts range. The high CMRR (around 110 dB) is critical because of the relatively high half-cell potential in the skin screw electrode. The amplifier has a 50 μV offset voltage, a 5 nA input bias current of and a 0.5 $\mu\text{V}/^\circ\text{C}$ drift voltage [2]. Its low power consumption property is ideal for battery operation. An external resistor R_G allows adjustable gain. The gain for this stage is set to be 6. The first stage gain cannot be too large since the input produces a small differential signal between two input terminals. A large gain would drive the amplifier output to near the supply voltage, which may saturate the amplifier.

B. High Pass Filter

A high pass filter is implemented after the first stage amplification to remove DC offsets, which is important for the skin screw electrodes. We place another identical high pass filter after the second stage amplifier, since the DC components generated during the second stage amplification also needs to be eliminated in order to remove the offset and stabilize the output signal.

C. Operational Amplifier TLC277CP

The operation amplifier used for the second-stage amplification is TLC277CP. Non-inverting configuration is utilized to ensure that the output signal has the same polarity as the input EEG signal. A potentiometer is utilized to allow adjustable gain. The second-stage amplifier amplifies the signal in a gain between 5.76 to 101, adjusted according to the EEG signal strength provided by the skin screw electrodes. This stage can have a high gain since it does not generate significant noise after the initial stage amplification.

D. Butterworth Low Pass Filter

The third stage is a Butterworth filter [3] utilizing the Sallen–Key topology which allows the filter amplifies the signal while suppresses the high frequency components. The cutoff frequency for the low pass filter is 49.4 Hz which indicates that the filter attenuates

frequencies higher than this frequency. Therefore, the electromagnetic interference (EMI) from the electrical power system at 60Hz is suppressed effectively.

IV. Results

After the implementation of the circuit, we conducted an experiment to demonstrate its performance. One subject was asked to sit in a chair and relax. One skin-screw electrodes were installed in his left frontal region and another one in his left occipital region. The two electrodes were connected to the two inputs of the amplifier and one commercial disc electrode placed on the forehead was used as the ground. The EEG signal was digitized and stored in computer using LABVIEW. During the experiment, the subject was asked to keep eyes open and closed for ten seconds respectively. Two segments of the recorded signals are shown in Figs. 3 and 4. These recordings indicate that our circuit design meets the requirement for detection and amplification of the EEG signal.

V. Discussion

A low noise, high impedance portable EEG amplifier for the skin screw electrodes has been designed and implemented. This amplifier provides a gain on the order of 105 and a pass band between 0.1 Hz to 50 Hz, with a common mode rejection ratio larger than 110 dB. Although this amplifier works properly, noises and interferences still exist if a certain force impacts on electrodes or the system is placed in a noisy environment. Further improvements include the use of more advanced noise-suppression circuitry and sophisticated signal processing algorithms to filter the acquired EEG signal.

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Fig. 1.

Structure of EEG data acquisition system: It consists of a set of skin screw electrodes (small circles) and a data port (central large circle).

Fig. 2.
Schematic diagram of the EEG amplifier

Fig. 3.
Acquired EEG signal when eyes are open

Fig. 4.
Acquired EEG signal when eyes are closed