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Medical Engineering & Physics 23 (2001) 235–238

Medical Engineering & Physics

www.elsevier.com/locate/medengphy

Technical note

# A single supply biopotential amplifier

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Received 22 November 2000; received in revised form 23 February 2001; accepted 5 April 2001

**Abstract**

A biopotential amplifier for single supply operation is presented. It uses a Driven Right Leg Circuit (DRL) to drive the patient's body to a DC common mode voltage, centering biopotential signals with respect to the amplifier's input voltage range. This scheme ensures proper range operation when a single power supply is used. The circuit described is especially suited for low consumption, battery-powered applications, requiring a single battery and avoiding switching voltage inverters to achieve dual supplies. The generic circuit is described and, as an example, a biopotential amplifier with a gain of 60 dB and a DC input range of ±200 mV was implemented using low power operational amplifiers. A Common Mode Rejection Ratio (CMRR) of 126 dB at 50 Hz was achieved without trimming. 

*Keywords:* Biopotential amplifiers; Single supply; Battery powered; Common mode range

## 1. Introduction

Biopotential amplifiers working with bipolar signals require dual power supplies (±) for proper operation. This is not a serious problem in line-powered amplifiers, but becomes a critical issue in battery operated applications.

A typical scheme for biopotential acquisition systems consists of a front-end amplifier followed by an analog to digital converter, both battery-powered and linked to a computer through an isolation barrier [1] (usually an optical link). Dual power supplies are required because biological input signals and common mode voltages are bipolar respect to the amplifier's common. As a single battery operation is always desirable, dual power supplies are usually obtained from a single battery using switching voltage inverters. However, these circuits could add switching noise to the recorded signal and level up power consumption.

A single supply alternative can be devised by placing a voltage bias net at the input and coupling the input signals using capacitors [2]. However, this approach leads to high value bipolar coupling capacitors. Moreover, the bias net degrades the common mode input impedance, increasing electrode impedance unbalances that in turn result in a low CMRR.

## 2. Proposed scheme

The amplifier's input voltage results from a combination of the biopotential signal source and a common mode voltage. This voltage, given by the potential difference between patient and common is mainly due to power line interference. The common mode input voltage can be controlled by a Driven Right Leg Circuit (DRL) [3,4], which uses negative feedback of common-mode voltages to reduce the potential difference between patient and amplifier's common.

The scheme herein presented uses the DRL circuit to drive the patient's body to a DC potential in the middle of the supply voltage $V_{CC}$. This is performed by comparing the common mode input voltage to a reference voltage ($V_{REF} \cong V_{CC}/2$), instead of the amplifier's common potential used in the usual approach. Thus, the input signal becomes in the range of $0-V_{CC}$, and the amplifier can work properly when powered by a single ($0-V_{CC}$) supply.

An amplifier based in the proposed approach is shown

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1350-4533/01/$20.00 
PII: S1350-4533(01)00040-6

in Fig. 1. It consists of two full differential stages and one difference amplifier. Notice its balanced structure up to the last stage, which finally provides a single-ended output.

To achieve high CMRR, a large gain in the first stage (a DC full differential amplifier) is desirable. However, this gain is limited by electrode offset voltages, which can saturate the amplifier [5]. For example, to achieve a ±250 mV DC input range, if rail-to-rail output opamps are used, the gain must be lower than 10 for a 0–5 V powered amplifier.

Common mode input voltage is picked up from the output of the first stage by means of averaging resistors $R_{DRL}$ and $R'_{DRL}$. Then, it is compared to $V_{REF}$, and fed back to the patient body (electrode E3), driving it to a $V_{REF}$ potential. Resistor $R_0$ has been included to limit the DRL's DC output current to 10 μA, in order to protect the patient from amplifier faults.

The second stage is an AC full-differential amplifier, which together with the last one provides the remaining gain.

In the last stage a DC restoring circuit was also included, to reject offset voltages from the previous stages. These offsets could be important if bipolar opamps are used, because their offset currents flow over $R_3$ and $R'_3$ and usually these resistors are of large value to achieve low cutoff frequencies.

Solving the circuit of Fig. 1, the transfer function of the amplifier results in:

$$A_D(s)=A_{D1}\cdot\frac{A_{D2}\cdot\tau_2\cdot s}{1+s\cdot\tau_2}\cdot\frac{A_{D3}\cdot\tau_i\cdot s}{1+s\cdot\tau_i} \quad (1)$$

where

$$A_{D1}=1+\frac{2\cdot R_2}{R_1};\ A_{D2}=1+\frac{2\cdot R_6}{R_5};\ A_{D3}=\frac{R_8}{R_7}$$

$$\tau_2=(R_3+R'_3)\cdot\left(\frac{C_1\cdot C'_1}{C_1+C'_1}\right);\ \tau_i=R_i\cdot C_i$$

## 3. Results

A biopotential amplifier based on the proposed scheme was built and tested. Its overall specifications were: 60 dB gain ($A_V$=1000), a DC differential input range of ±200 mV, and a low cutoff frequency of 0.05 Hz.

The total gain was distributed as 10 in the first stage, 20 in the second stage and 5 in the last one. To achieve a −3 dB cutoff frequency of around 0.05 Hz, the following values were adopted:

$R_3=R'_3=R_4=10$ MΩ; $C_1=C'_1=330$ nF; $C_i=680$ nF; $R_i=10$ MΩ

The CMRR of the second stage increases with $R_4$ [6], but this is limited to practical $R_4$ values.

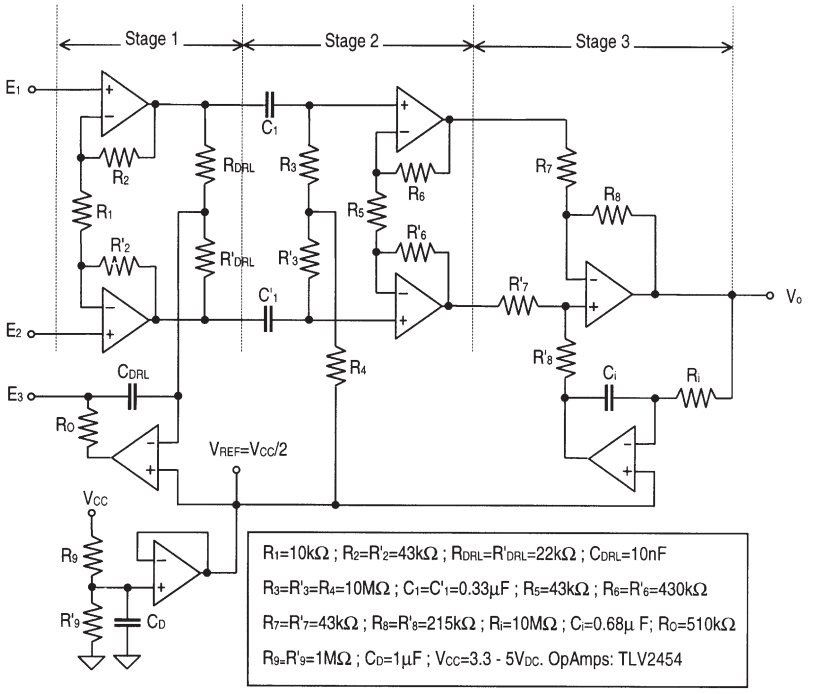


Fig. 1. Schematic circuit of a single supply biopotential amplifier based on the proposed scheme.

The amplifier of Fig. 1 was implemented with two Texas Instruments TLV2454 quad low power opamps, 1% tolerance metal film resistors and 5% tolerance capacitors. No additional trimming was made and the total supply current was 200 μA at 5 $V_{DC}$ .

The amplifier was tested at 5 $V_{DC}$ (regulated) and at 3.3 $V_{DC}$ (unregulated) voltage supplies, showing in both cases a CMRR of 126 dB at 50 Hz. Electrode impedances of 100 kΩ with unbalances of 50% and shielded cables ($C \cong 200$ pF) were used.

The reference voltage $V_{REF}$ could be taken from the analog-to-digital stage that usually follows the amplifier. Instead, to test the circuit at different voltage supplies, $V_{REF}$ was obtained by a buffered resistive divisor as shown in Fig. 1.

The frequency response is shown in Fig. 2. It presents a good agreement with the theoretical values predicted by Eq. (1). It can also be seen that at high frequencies, the finite gain-bandwidth product (GBP) of the opamps limits the amplifier's bandwidth. If a wide bandwidth is desired, the gain distribution between the different stages becomes an important issue, specially considering the usual low GBP values of low power opamps. In this test, an input differential signal of 1 mV peak–peak was used and no signal of distortion was observed provided that the DC input voltage remains between 60 mV and $V_{CC}$ −60 mV.

The amplifier's noise depends mainly on the opamps composing the first stage. Their selection results from a compromise between admissible noise, consumption and cost. The voltage noise spectral density (input referenced) of the amplifier built is shown in Fig. 3.

The circuit was also tested successfully with real biomedical signals. Fig. 4 shows an ECG record picked up by the proposed amplifier. The signal was digitized by a general-purpose microcontroller and transmitted to the computer using an optic link.

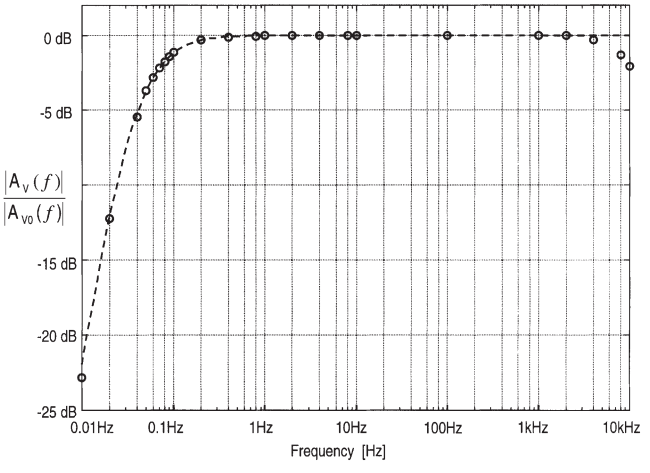


Fig. 2. Frequency response of the proposed amplifier. The theoretical curve is shown by a dashed line, and experimental data with markers.

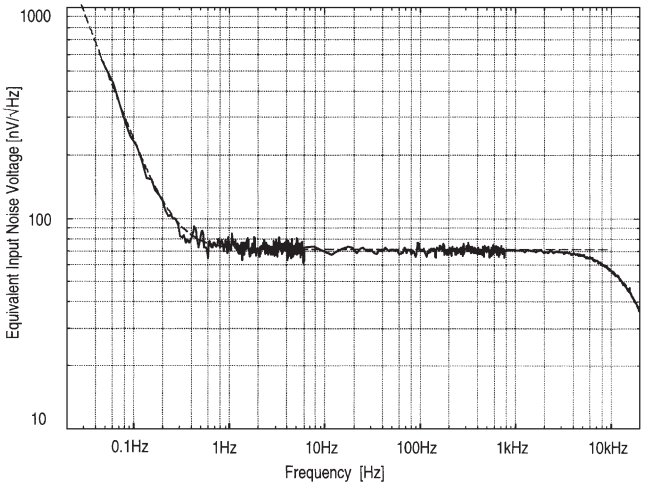


Fig. 3. Equivalent input noise voltage density of the biopotential amplifier.

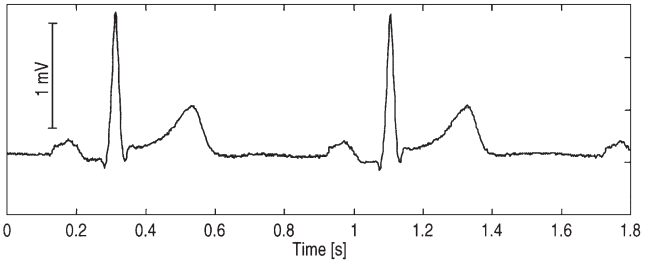


Fig. 4. ECG signal acquired by the proposed amplifier. No other signal processing except for a bandwidth limitation to 128 Hz was performed.

## 4. Conclusions

The proposed topology results in a simple solution for single supply biopotential amplifiers. If built using low power opamps, it also results in a low consumption scheme well suited for battery powered amplifiers.

A prototype with a gain of 1000, a bandwidth from 0.05 Hz to 10 kHz was built, showing a CMRR up to 126 dB at 50 Hz.

The proposed scheme requires driving the patient's potential to work properly. Thus, it can't be used if this potential must be fixed for any reason, for example if patient and amplifier are grounded. However, this does not represent a serious limitation, provided that grounding is usually avoided for the patient's safety.

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