Two-electrode non-differential biopotential amplifier

D. Dobrev
Centre of Biomedical Engineering, Bulgarian Academy of Sciences, Sofia, Bulgaria

Abstract—A circuit is proposed for a non-differential two-electrode biopotential amplifier, with a current source and a transimpedance amplifier as a potential equaliser for its inputs, fully emulating a differential amplifier. The principle of operation is that the current in the input of the transimpedance amplifier is sensed and made to flow with the same value in the other input. The circuit has a simple structure and uses a small number of components. The current source maintains balanced common-mode interference currents, thus ensuring high signal input impedance. In addition, these currents can be tolerated up to more than 10 μA per input, at a supply voltage of ±5V. A two-electrode differential amplifier with 2×10 MΩ input resistances to the reference point allows less than 0.5 μA per input. The circuit can be useful in cases of biosignal acquisition by portable instruments, using low supply voltages, from subjects in areas of high electromagnetic fields. Examples include biosignal recordings in electric power stations and electrically powered locomotives, where traditionally designed input amplifier stages can be saturated.

Keywords—Bio-electric amplifier, Non-differential circuit, Electromagnetic interference

1 Introduction

The use of conventional unsymmetrical amplifier circuits in biomedical engineering is very limited, owing to their inadequacy in suppressing interference from the power-line. One of the patient electrodes being the common reference point of the amplifier, the interference current flows to this point through the respective electrode impedance. The voltage drop on this electrode impedance is amplified and leads to circuit saturation or to masking of the bio-electric signal.

Many applications connected with biosignal acquisition could benefit from the use of only two electrodes, Electrocardiogram monitoring in intensive care wards, ambulatory monitors, defibrillators etc. are among the most common examples. Recently, a circuit of a two-electrode differential amplifier was developed, using controlled current sources at its inputs. Its main feature was a drastic reduction in common-mode input voltage (DOBREV and DASKALOV, 2002).

An amplifier circuit is presented here, whose performances are quasi-equivalent to the ones of the above-cited differential amplifier. It is of a much simpler and more economical structure. These two circuits, using current sources at their inputs, are unable to compensate for electrode imbalance, resulting in transformation of part of the common-mode voltage to differential signal. However, this is a drawback to all types of biosignal amplifier, unless very special, but complicated and not quite efficient, measures are taken (see, for example, BREDEMANN and SEITZ (1990) and YONCE (2000)).

2 Amplifier circuit

An equivalent circuit of the body–amplifier interface is presented in Fig. 1. Part of the interference current flows through the power-line–body stray capacitance $C_p$ , the body impedance $R_{b}$ (presented as resistance for simplification) and the stray capacitance to ground $C_b$ . The skin–electrode impedances are $Z_{ea}$ and $Z_{eb}$ , (incorporating $R_{ea}$, $C_{ea}$ and $R_{eb}$, $C_{eb}$, respectively), and $C_{f}$ is the capacitance between the reference point and ground. Another part of the interference current $(I_a + I_b)$ traverses the impedances $Z_{ea}$, $Z_{eb}$, and $C_{f}$ to ground. The interference current $I_a$ is converted to voltage $V_1$ at the output of operational amplifier $A_1$, which drives the potential of input $b$ to the common point. On the other hand, $V_1$ is used to control the current source, connected to amplifier input $a$. It can be seen that $V_b \cdot Z_{fb} = V_1$; $V_1 \cdot g_m = I_a$, where $g_m$ is the transconductance of the current source. The circuit is quasi-symmetric with respect to the interference currents, if

$$g_m = 1/Z_{fb}$$

Assuming $Z_{ea} = Z_{eb}$, the voltage drops on them will cancel, thus cancelling the interference. However, $Z_{ea}$ and $Z_{eb}$ are not equal, and the interference current multiplied by their difference will result in an unwanted input signal to $A_2$. As commented above in Section 1, this is a drawback of most biosignal amplifiers.

Operational amplifier $A_1$ maintains the potential of input $b$ equal to the reference point (virtual ground), and thus $A_2$ amplifies the voltage from inputs $a$ and $b$.

As one of the electrodes is directly connected to the inverting input of $A_1$, any capacitance inserted at the input would thus introduce a phase shift. Thus a potential instability can arise, which is typical for any potential equalisation circuit involving connection to the subject’s body with its unknown impedances.
The problem of ensuring stability has been considered by LEVKOV (1988), for three-electrode amplification. In the case of a two-electrode amplifier, an appropriate selection of the feedback impedance $Z_{fb}$ is to be considered. The equivalent circuit of the current-to-voltage converter is shown in Fig. 2a. The interference current is represented by the current source $I_{pl}$, and its output impedance is represented by $C_o$, with $C_o$ being the equivalent of the series connection of $C_g$, $C_b + C_y$, and $C_{eb}$, which is the capacitance component of $Z_{eb}$. Practically, $C_o \approx C_g$ for non-screened patient leads.

The closed-loop transfer function $A_{cl}$ for the circuit of Fig. 2a, assuming the operational amplifier $A_1$ as ideal is

$$A_{cl} = \frac{1 + s(C_f C_o) \cdot R_{fb}}{1 + s \cdot C_f \cdot R_{fb}}$$

with a zero for $w_z = 1/(R_{fb}(C_f + C_o))$ and a pole for $w_p = 1/(R_{fb} \cdot C_f)$. 

**Fig. 2**  Potential-equaliser amplifier: (a) equivalent circuit; (b) gain-frequency characteristics by simulation. Vertical scale is in dB. 'I-V gain' is current-to-voltage transverter gain ($\Omega$) (or transimpedance); $A_{ol}$ and $A_{cl}$ are open-loop and closed-loop gain, respectively, with and without feedback capacitor $C_{fb}$. 

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