Technical note

Amplification of biosignals by body potential driving

Keywords—*Biomedical amplifier, Electrocardiography, Electroencephalography, Interference reduction, Multichannel system, Surface mapping*

1 Introduction

THE amplification of biosignals with a differential amplifier is a current practice in medical electronic equipment. This method effectively rejects 50 Hz electrical interference due to the imperfect connection to the earth of the subject's body by an electrode. These problems are extensively discussed elsewhere (e.g. HUHTA and WEBSTER, 1973).

The differential amplifier has also some inconveniences which may become important, especially when a large number of channels are needed as with surface mapping in electrocardiography. The necessity of trimming the common-mode rejection ratio (c.m.r.r.) of 48 or 120 differential amplifiers, together with the need for careful balancing of the input stages may be shown as example. The number of operational amplifiers used (at least three per channel, according to the so called instrumentation amplifier circuit) may also be of some importance.

Facing these problems, we have tried to develop a simpler circuit having similar or better performances, compared to the classical differential amplifier.

2 Description of the method

Fig. 1 shows the circuit proposed. It is a combination of the well known driven right-leg configuration and the non-differential amplifier. The driven right-leg circuit effectively removes the potential difference between the body and the earth, and the 50 Hz noise is eliminated from the amplifier input. Two electrodes are used ($B1$ and $B2$) to drive the potential of the body. They can be placed very close to each other and can be considered as a single electrode B. The output voltage from the amplifier is proportional to the potential difference between electrode A and equivalent electrode B.

An estimate of this method can be made by analysing the possible interferences. A comparison is made with the noise immunity of a differential amplifier, taking into account the skin-electrode impedances, electrode offset potentials and capacitive couplings to the a.c. line.

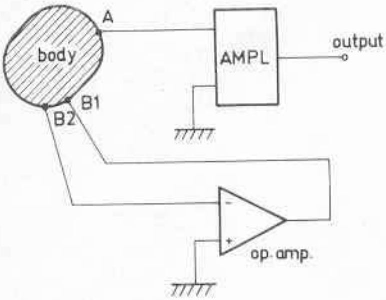

Fig. 1 *Amplification of biopotentials by non-differential amplifier. The potential difference between the body and the earth is effectively eliminated by the action of the operational amplifier*

3 Analysis of 50 Hz interference

A simple model will be described to simplify the analysis. The model is a good approximation to the real process and it is based on the following assumptions:

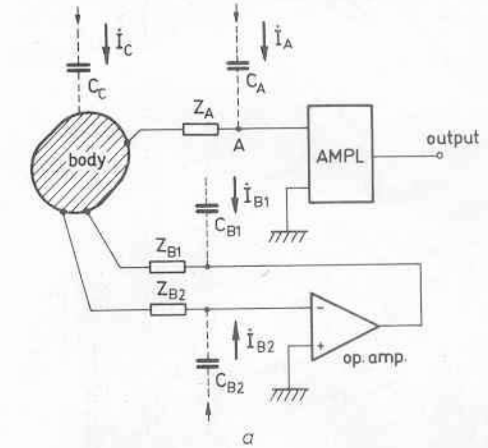

Fig. 2 *Equivalent circuit where capactive couplings and electrode-skin impedances are considered. The body is assumed to be an equipotential surface*

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(*a*) The electric and magnetic component of the a.c. field are independent. Only the electric component will be taken into account. The equivalent circuit is with lumped parameters.

(*b*) The body of the subject is an equipotential surface for a.c. currents.

The equivalent circuit of the system is shown in Fig. 2*a*. All essential capacitances and electrode-skin impedances are taken into consideration. Another equivalent circuit is shown in Fig. 2*b*, but this time all capacitive couplings are replaced by equivalent current sources. The capacitive impedances are always greater than 100 MΩ, and it is very convenient to represent the a.c. interference as a current source. The analysis becomes much easier and it is thus possible to obtain quantitative results without solving complicated equations. The equipotential body surface is represented by the point *C*. $\dot{V}_C$ is the voltage between the body and the earth. The non-differential amplifier is denoted as *AMPL* in the figure. Further it will be referred to simply as 'the amplifier'.

The circuit is linear and the superposition principle can be applied.

Fig. 3 shows the sequence of steps needed to solve the problem involved. Initially, the input impedance of the amplifier is assumed to be very high and consequently it can be neglected. The current source I_{B1} can also be neglected since it is coupled to the operational amplifier output where the resistance is very low.

The current caused by the capacitance between the body and the a.c. source (Fig. 3*a*) is fully compensated by the operational amplifier and $\dot{V}_C$ is equal to zero. There is no a.c. voltage at the amplifier input.

The current caused by the capacitance between the electrode *B*2 and the a.c. source, is fed directly to the operational amplifier summing point. The potential of the summing point is approximately zero and the current flows through the feedback impedance $Z_{B1}+Z_{B2}$. The potential of the body $\dot{V}_C$ will be: $\dot{V}_C = \dot{I}_{B2}Z_{B2}$. The potential at the amplifier input will be the same. (Fig. 3*b*.)

The last step is shown in Fig. 3*c*. The body potential $\dot{V}_C$ will be kept to zero by the operational amplifier. The voltage drop across the electrode impedance Z_A caused by the capacitive current $\dot{I}_A$ will be the amplifier a.c. input voltage.

It can be seen from this analysis, that the a.c. voltage at the input of the amplifier is produced by the capacitive currents of the electrodes *A* and *B*2. The total a.c. voltage at the input of the amplifier is given by the equation

$$\dot{V}_A = \dot{I}_A \, . \, Z_A - \dot{I}_{B2} \, . \, Z_{B2} \qquad (1)$$

4 Analysis of the electrode offset potential variations

It is a well known fact that some of the noise when recording biopotentials is due to the variations of electrode offset potential of the electrodes involved. These variations are known to be the main reason for the low-frequency noise (drift) (STRONG, 1970). It is therefore important to assess the system's sensitivity to such variations.

Fig. 4 shows the equivalent circuit where the electrode offset potentials (E_A, E_{B1}, E_{B2}) are considered. The total noise voltage at the input of the amplifier is given by the equation

$$V_A = E_A - E_{B2} \qquad (2)$$

Therefore the potential variations of the electrode *B*1 do not affect the input voltage V_A.

5 Biopotential difference between the driving electrode *B*1 and the sense electrode *B*2

At the beginning of the article it was mentioned that the electrodes *B*1 and *B*2 must be placed close to each other.

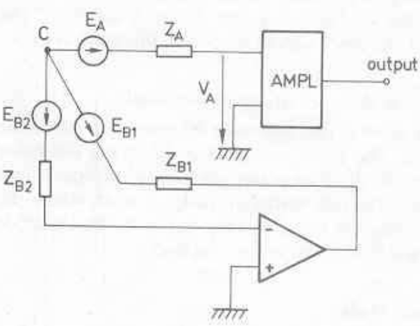

Fig. 4 *Equivalent circuit where electrode offset potential variations are considered*

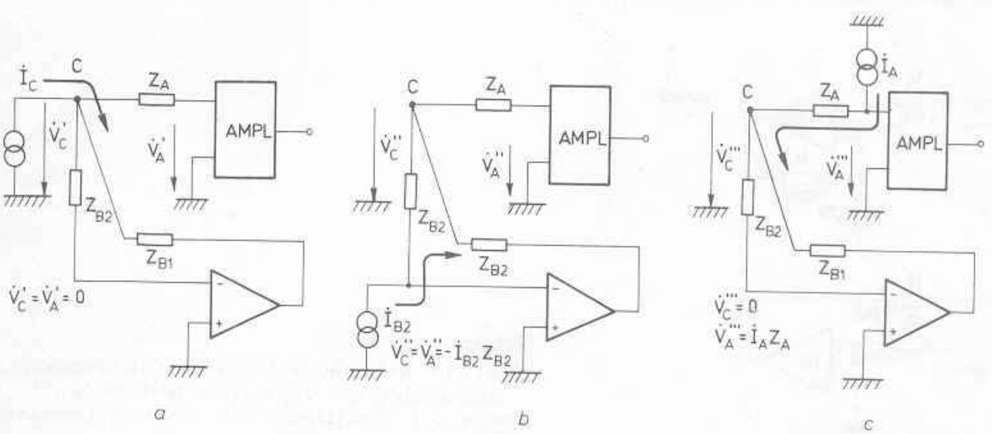

Fig. 3 *Influence of the capactive currents can be analysed separately. The total a.c. noise voltage at the input of the amplifier is:* $\dot{V}_A = \dot{I}_A \, . \, Z_A - \dot{I}_{B2} \, . \, Z_{B2}$

Again, we can analyse how the biopotential difference between $B1$ and $B2$ affects the input voltage of the amplifier. The result is very easy to obtain and it shows that the voltage between $B1$ and $B2$ does not in the least affect the input voltage of the amplifier. This input voltage is equal to the biopotential difference between electrodes A and $B2$. The electrodes $B1$ and $B2$ must be placed close to each other for two reasons:

(*a*) It is easier to work with one electrode rather than two, so $B1$ and $B2$ can be mounted mechanically as one electrode.

(*b*) Parasitic oscillations can at times occur if $B1$ and $B2$ are placed apart due to the unknown impedance of the feedback loop of the operational amplifier.

6 Comparison between the proposed circuit and the differential amplifier.

6.1 *a.c. interference*

Eqn. 1 gives the total noise a.c. voltage at the input of the amplifier. HUHTA and WEBSTER (1973) present an equation for the total a.c. voltage at the input of the differential amplifier. After comparison it can be seen that the proposed circuit is equivalent to the differential amplifier with infinite c.m.r.r. and infinite impedance between differential inputs and earth. In our case the a.c. noise voltage will not be increased if the input impedance of the non-differential amplifier is reduced.

It is obvious that a.c. interference is due to the capacitive couplings of the electrodes A and $B2$ with a.c. line. The capacitance of the electrode $B1$ does not affect the system.

6.2 *Variations of the electrode offset potential*

Eqn. 2 shows that the electrode $B1$ does not affect the amplifier input. The input voltage is equal to the difference between the electrode offset potentials of the electrodes A and $B2$ just as when the differential amplifier is used, where the input noise voltage is the difference between the electrode offset potentials of the two active electrodes.

7 Experimental study

To verify the method an experimental circuit shown in Fig 5 was set up. Several experiments by recording the e.c.g. of a man in the presence of strong a.c. field were conducted. Simultaneously a recording with high-quality differential amplifier was made. The comparison shows that in all cases the a.c. noise level was approximately the same.

There is no need to connect the electrode $B1$ with a shielded cable. Every electrode is connected to the circuit via safety resistors of 47 kΩ. An additional analysis was made showing that these safety resistors do not impair the noise immunity of the circuit.

8 Floating amplifier

When analysing the a.c. interference, we assumed that the system was connected to the earth. The analysis is much more complicated if the system is floating, i.e. insulated from the earth. The a.c. interference voltage strongly depends on the capacitive balances of all points exposed to the a.c. electric field. The values of the capacitance are unpredictable and a small change of one of them can provoke significant changes of the input noise voltage. Nevertheless, good results are obtained with this circuit in floating mode too, due to the fact that the potential difference between the body and the common point of the amplifier is eliminated.

9 Application of the circuit

The proposed circuit can replace the differential amplifier in all cases where a good a.c. noise immunity is needed. But the most attractive applications are those where a large number of electrodes are used, for example in e.e.g. or e.c.g. surface mapping. If a 120 electrode system is to be built, 360 operational amplifiers will be needed for 120 instrumentation amplifiers. With the new method only 120 operational amplifiers will be needed plus one for driving the body potential.

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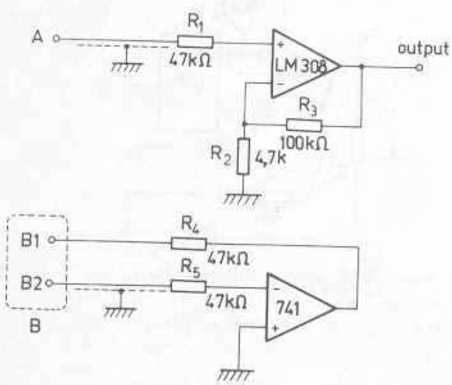

Fig. 5 *Practical circuit. The connecting cable to B1 is unshielded*

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