A NEW PRINCIPLE OF CONSTRUCTION OF A PRELIMINARY AMPLIFIER FOR MICROELECTRODE POTENTIALS

(UDC 612.014.423.08)

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Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 58, No. 9,
pp. 120-122, September, 1964
Original article submitted February 24, 1964

The method of recording biopotentials by means of glass microelectrodes is being used on an increasing scale in laboratories, as one of the most accurate and objective available. However, the glass microelectrodes in use at the present time possess a number of disadvantages. Firstly, the potential of the point of the electrode is very slow to change and is difficult to control experimentally [3], thus hampering measurement of the resting potentials, and secondly, the electrical resistance of the point is high, and this, combined with the capacitance of the electrode, leads to distortion of the shape of the action potentials at the output end of the microelectrodes [4]. The available methods of correction of high-frequency distortions introduced by the microelectrode also have several disadvantages. Experimental tests have shown that amplifiers with a "negative input capacitance" cannot be used to compensate the action of input capacitance if the latter is above a certain critical level. In addition, during insertion of the electrode, a considerable increase in its resistance is very often observed, as a result of soiling of the point. In this case an amplifier witha "negative input capacitance" is usually excited. This fact, together with the development of considerable amplifier noise during attempts to introduce careful compensation, prevents an optimal level of amplification from being achieved.

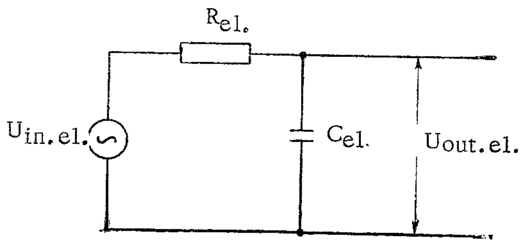

Fig. 1. Equivalent scheme of the system microelectrode—cell.

We give below an analysis and the development of an actual circuit of a preliminary amplifier for working with glass microelectrodes, which is largely free from the disadvantages enumerated above.

Analysis of the Method. The system microelectrode-cell (Fig. 1) is described by an operation equation [2,3,7].

$$U_{in.el.} = (1 + pR_{el.}\ C_{el.})U_{out.el.} \tag{1}$$

where $R_{el.}$ and $C_{el.}$ are the resistance and capacitance of the microelectrode, p the differentiation operator [2], and $U_{in.el.}$ and $U_{out.el.}$ the voltage at the input and output of the microelectrode.

One method of reducing the effect of the differential term in the equation is by introducing a feedback signal from the output of the system to its input (the method of summation of operators [2]). However, the introduction of a feedback voltage in series with $U_{in.\ el.}$ is impossible in practice.

Let us consider the variant of including a feedback in series with $U_{out.el.}$ (Fig. 2A). In this case,

$$U_{in.amp.} = U_{out.el.} + U_{fb.} \tag{2}$$

but

$$U_{fb.} = U_{in.amp.} \cdot k, \tag{3}$$

where

$$k = k_{amp.} \cdot k_{fb.} \tag{4}$$

when

$$U_{in.amp.} = \frac{U_{in.el.}}{1 + pR_{el.}C_{el.}} + U_{in.amp.} \cdot k, \tag{5}$$

or

$$U_{in.el.} = (1 - k)(1 + pR_{el.}C_{el.}) \cdot U_{in.amp.}. \tag{6}$$

For undistorted transmission of the signal it is essential that $(1 - k)(1 + pR_{el.}C_{el.}) = 1$, i.e.,

$$k = \frac{pR_{el.}C_{el.}}{1 + pR_{el.}C_{el.}} \tag{7}$$

If it is assumed that the amplifier does not introduce distortions, i.e., it possesses a linear frequency characteristic over a fairly broad band of frequencies, then the feedback circuit must also possess the same coefficient of transmission.

The coefficient of transmission

$$k_{fb.} = \frac{pR_{el.}C_{el.}}{1 + pR_{el.}C_{el.}} = \frac{R_{el.}}{R_{el.} + \frac{1}{pC_{el.}}} \tag{8}$$

is provided by the ordinary CR circuit (Fig. 2B). In this system the time constant of such a circuit must be equal to the time constant of the system microelectrode-cell.

In the calculations given the presence of input resistance and input capacitance of the amplifier was not taken into account. However, the use of a cathode repeater with a transmission coefficient close to 1 [5, 6] as input cascade made it possible to disregard these values without significant error in the practical calculations. Furthermore, in the presence of input capacitance of the amplifier, it is possible to deduce the equation

$$k_{fb.} = \frac{R_{el.}}{R_{el.} + \frac{1}{pC_{el.}}}, \tag{9}$$

where $C_{sum.} = C_{el.} + C_{in.amp.}$.

The relationships obtained are confirmed experimentally.

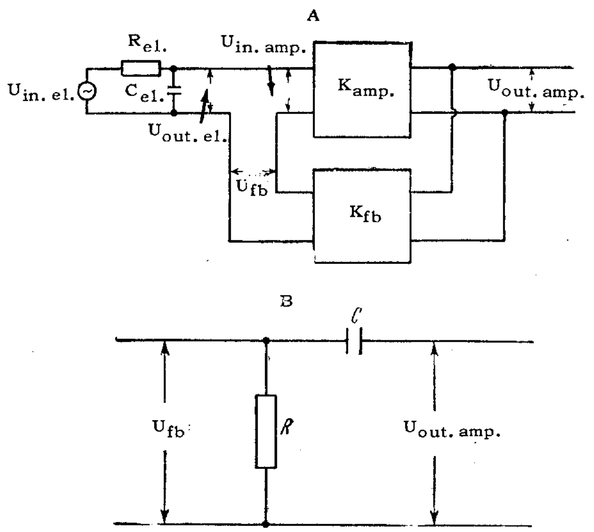

Fig. 2. Inclusion of a feedback. A) Block diagram of inclusion of feedback; B) diagram showing principle of feedback circuit.

Construction of Amplifier in Accordance with this Scheme. The original variant was to introduce the feedback signal into the circuit of an indifferent electrode. However, this made it impossible to use more than one channel of amplification at the same time. For this reason the variant shown in Fig. 3 was developed.

The feedback signal is fed into the cathode circuit of the first tube. The maximal value of the time constant of the feedback circuit is selected by the condenser C_2 and the potentiometer R_4. The first cascade is built up in accordance with the circuit of a cathode repeater on a type 6ZhIZh pentode. To obtain a transmission coefficient of the cathode repeater close to 1, and also to diminish the effect of the transfer capacitance of the tube on the screen grid, a positive feedback is supplied [5]. Its depth is regulated by the potentiometer R_6. Adjustment of the grid current of the input tube to the value of 10^{-12} A is brought about the correct choice of grid bias (resistor R_{10}), lowering the filament voltage to 4.8-5 V, and lowering the anode voltage to 60-70 V. The key P_1 is used to change the mode of operation of the input cascade. In the 1st position the circuit is brought into a

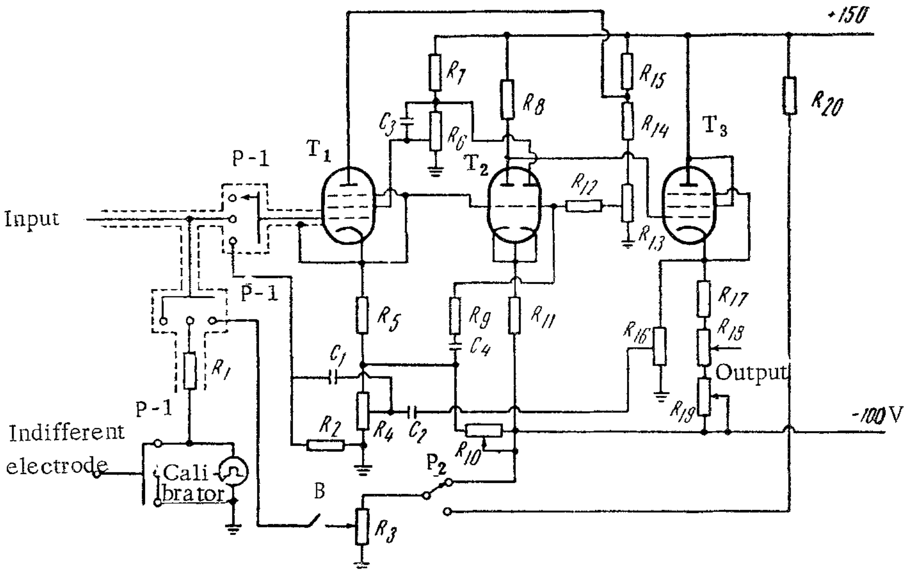

Fig. 3. Scheme showing the principle of the amplifier. T_1) 6ZhIZh; T_2) 6N2P; T_3) 6Zh1P; R_1) 30 kΩ; R_2) 360 kΩ; R_3) 330 kΩ; R_4) 33kΩ; R_5) 75 kΩ; R_6) 470 kΩ; R_7) 270 kΩ; R_8) 360 kΩ; R_9) 150 kΩ; R_{10}) 100 kΩ; R_{11}) 220 kΩ; R_{12}) 110 kΩ; R_{13}) 1.5 kΩ; R_{14}) 33 kΩ; R_{15}) 47 kΩ; R_{16}) 120 kΩ; R_{17}) 24 kΩ; R_{18}) 2.2 kΩ; R_{19}) 68 kΩ; R_{20}) 180 kΩ; C_1) 1000 pF; C_2) 10,000 pF; C_3) 220 pF; C_4) 2200 pF.

working state; in the 2nd position compensation is carried out [1, 5]; and in the 3rd position the microelectrode is "cleaned" by pressing the button B. The process of "cleaning" consists of passing a constant current of any polarity (key P_2 and strength controlled by potentiometer R_3) through the microelectrode, which leads to the removal of any possible particles from the point of the microelectrode, causing a large increase in its resistance. In the same position, an electrophoretically staining substance may be introduced from the point of the microelectrode in order to mark its situation. The key P_1 and the whole assembly of the first cascade must be mounted on an insulator to create minimal input capacitance relative to earth. The input cable is coaxial, and 50 cm in length.

The second cascade is assembled in accordance with a balanced circuit on a 6N2P double diode. To exclude the action of the feedback signal directly on the second cascade, the feedback voltage is supplied from the dividers formed by the resistor R_5 and tube T_1 and the resistors R_9 and R_{12}, to both grids of the balanced cascade, respectively. The potentiometer R_{13} is used to select the grid bias for the right half of the tube.

The third cascade also is constructed in accordance with the circuit of a cathode repeater on a 6Zh1P tube. The choice of a tube with a fairly steep gradient enabled the output resistance to be lowered. The amplitude of the feedback signal is controlled by the potentiometer R_{16}. The potentiometers R_{18} and R_{19} are used to give fine and coarse selection of zero potential relative to earth.

The amplifier is fed from electronic stabilizers with a high (2000-3000) coefficient of stabilization, or from a battery.

Experimental trials of the circuit showed that it is capable of compensating the action of much larger input RC couplings, with a lower noise level than a circuit with a "negative input capacitance." A distinguishing feature of the circuit is the absence of excitation during a sharp increase in the resistance of the point of the electrode. The circuit is transformed into a self-oscillating system only if the point of the microelectrode is broken, i.e., as a result of a sharp decrease in its resistance. This enables the feedback voltage to be selected more carefully during compensation.

The frequency characteristic of the circuit is linear from 0 to 20 kcps. The intrinsic noise level does not exceed 10 μV. The coefficient of amplification is around 10.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.