Biopotentials

BME 360 Lecture Notes   Ying Sun

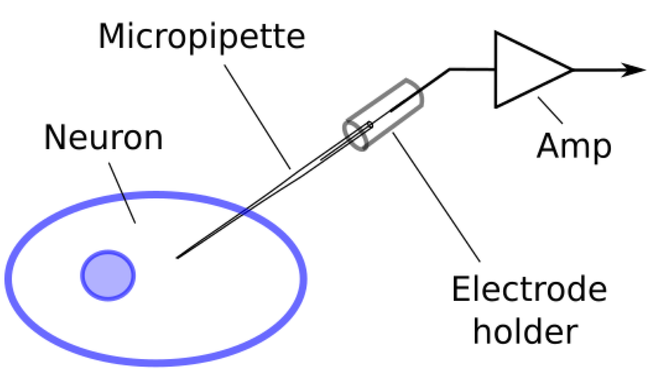
Signal Amplitudes and Frequency Ranges of Biopotentials

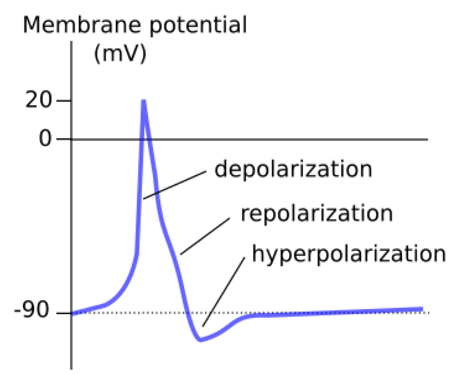
	Signal amplitude	Frequency Range	Electrode
Electrocardiogram (ECG)	0.1 – 5 mV	Diagnostic: 0.05 – 100 Hz Monitoring: 0.5 – 40 Hz	surface electrode
Electromyogram (EMG)	0.1 – 100 mV	25 – 5,000 Hz	surface, needle
Electroencephalogram (EEG)	0.025 – 0.1 mV	0.1 – 100 Hz	surface electrode
Electrooculogram (EOG)	0.4 – 1 mV	0 – 50 Hz	surface electrode
Action potential	50 – 100 mV	0 – 10 KHz	glass micropipette

Measurement of Action Potentials

The action potentials can be measured by inserting a sharp microelectrode into the neuron. The micropipette electrode is prepared by use of a glass electrode puller as shown. A glass pipette is heated up in the middle section and pulled apart. As the glass pipette tapers and eventually breaks, two sharp electrodes are formed. The tip of the electrode is on the order of 1 μm, which is at the limit of the light microscope. The lumen maintains open through the tip, allowing for electrical connection into the cell via ionic fluid.

Figure below shows an micropipette electrode inserted into a neuron and the action potential waveform. The proximal end of the electrode is inserted into an electrode holder that has a silver (Ag) wire into the pipette. The silver wire is coated with Ag Cl. The micropipette is filled with an ionic solution, typical 3M potassium chloride (KCl).





Junction Potentials

What not simply stick a sharp metal electrode into the neuron? A junction potential exists at the interface between the metal and the solution. Depending on the type of metal and what ions in the solution and their concentrations, the junction potential can vary from few mV to ~40 mV (typically 20 mV). The junction potential is reduced because the multistage interface: silver wire – AgCl coating – KCl solution – intracellular fluid.

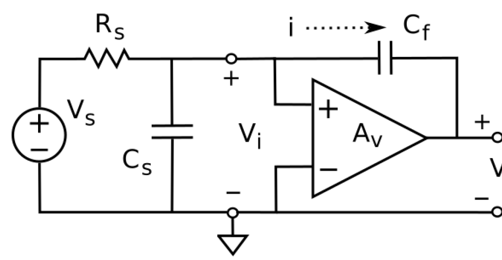
Electrode Resistance and Capacitance

While a sharp glass electrode makes insertion into the neuron easier, it is associated with a large resistance R_s. The typical value for electrode resistance is 50 MΩ. The stray capacitance C_s arising from inside the electrode across microelectrode walls to bath solution is typically 10 pF. This RC circuit acts like a low-pass filter with a cutoff frequency at:

$$f_c = \frac{1}{2\pi R_s C_s} = \frac{1}{2\pi(50\,\mathrm{M\Omega})(10\,\mathrm{pF})} = 320\,\mathrm{Hz}$$

This low cutoff frequency is often undesirable because the frequency range of the fast action potentials is between 0 and 10 KHz.

Negative Capacitance

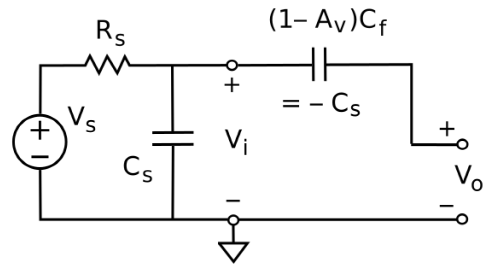


An effect of negative capacitance can be created by use of positive feedback with the intention to cancel out the electrode capacitance. As shown on the right, a positive feedback is established by connection C_f from output to the positive terminal of the input. The amplifier has an adjustable gain of A_v. We have:

$$V_i = V_o + \frac{1}{C_f}\int_{-\infty}^{t} i(\tau)\,d\tau =$$

$$A_v V_i + \frac{1}{C_f}\int_{-\infty}^{t} i(\tau)\,d\tau \quad \Rightarrow$$

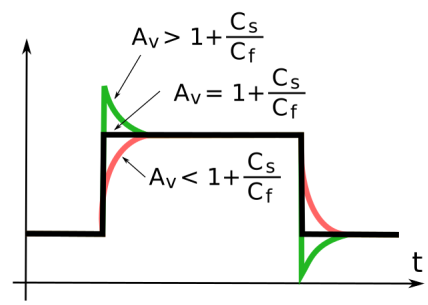
$$V_i = \frac{1}{(1-A_v)C_f}\int_{-\infty}^{t} i(\tau)\,d\tau$$



The equivalent circuit is as shown. We adjust the gain to

$$A_v = 1 + \frac{C_s}{C_f}\text{, resulting in}$$

$$(1-A_v)C_f = -C_s .$$

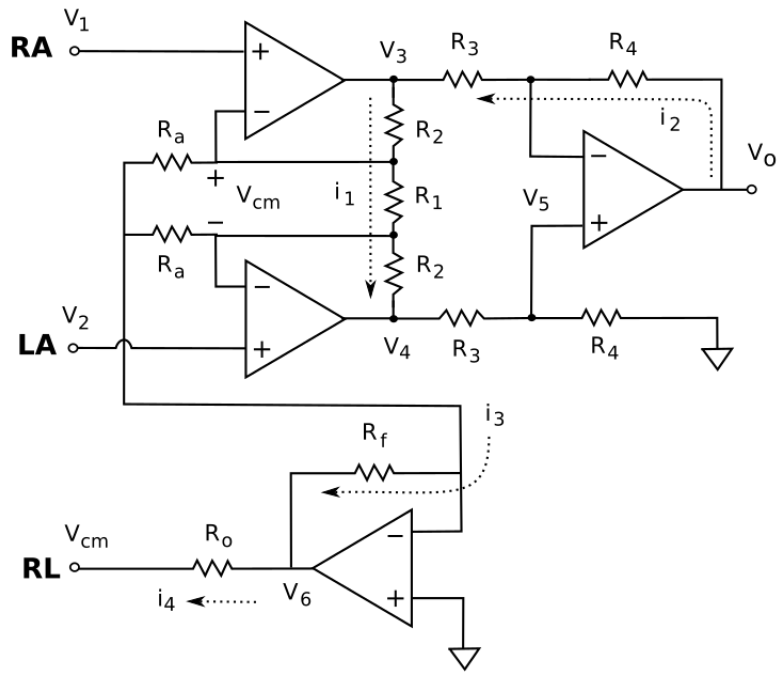


A negative capacitance $-C_s$ is created to cancel out the source capacitance C_s.

The adjustment of A_v is typically done by sending a calibration square wave to the bath solution in which the electrode is placed. It is similar to the adjustment of an oscilloscope probe as shown.

This example represents a rare case of using positive feedback in amplifier design.

Driven Right Leg Circuit



For making ECG measurements, grounding the right leg of the patient could reduce the 60 Hz line noise. However, it is a practice no longer allowed due to the potential risk of electrical hazards. The driven right leg circuit is a negative feedback circuit that cancels out the common mode signal and effectively reduces the 60 Hz noise. As shown in the figure, the common signal V_{cm} is obtained by summing the two inputs (V_1 and V_2) through the two resistors R_a . We have

$$i_3 = \frac{V_{cm}}{R_a/2} = -\frac{V_6}{R_f}$$

$$V_6 = -\frac{2R_f V_{cm}}{R_a}$$

The driven right leg electrode is also at the common mode voltage V_{cm} . Thus,

$$V_{cm} = -R_o i_4 + V_6 = -R_o i_4 - \frac{2R_f V_{cm}}{R_a} \quad \Rightarrow$$

$$(1+\frac{2R_f}{R_a})V_{cm} = -R_o i_4 \quad \Rightarrow$$

$$V_{cm} = -\frac{R_o i_4}{1+\frac{2R_f}{R_a}}$$

From the above equation, we see that $V_{cm} \rightarrow 0$, as $R_f/R_a \rightarrow \infty$. Thus, R_f should be a large resistor. R_o should also be a large resistor for patient protection. Typical values for the resistors are as follows:

$$R_f = 5\,\mathrm{M}\Omega$$

$$R_a = 25\,\mathrm{K}\Omega \quad (\frac{R_f}{R_a} = 200)$$

$$R_o = 5\,\mathrm{M}\Omega$$