Technical University of Munich

Neuroprosthetics Exercise 6 Report

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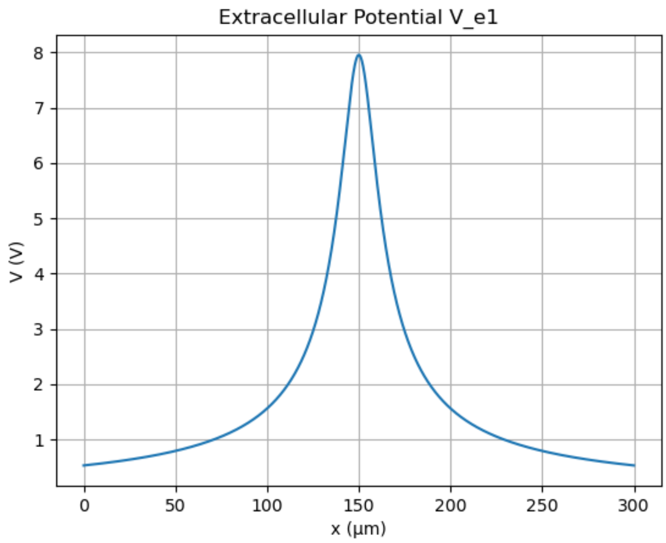
1. POTENTIAL FIELD

In exercise 6, we will stimulate the multicompartment model of the axon, similar to the last exercise. However, we will stimulate it extracellularly and not by injecting a stimulus current in the axon. The potential Φ for a point at a distance r from a current point source with the current I can be described by **equation 1**, where ρ is the resistivity of the extracellular medium.

$$\Phi = \frac{\rho}{4\pi} \cdot \frac{I}{r} \tag{1}$$

1.1. ACTIVATION FUNCTION

We substitute the parameters and currents in the exercise sheet in Equation 1 above to obtain the extracellular potential along a 300 μm straight piece of the axon. Hence, we get **figure 1** below.



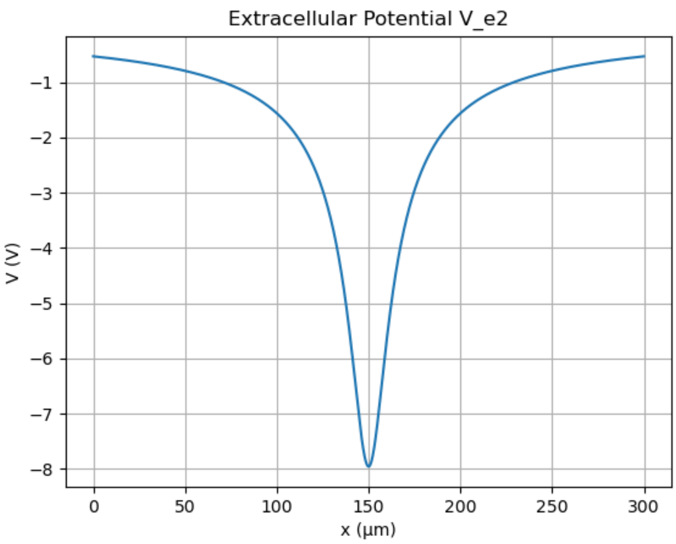


Figure 1. Extracellular potential for d = 10 μm for I = 1 mA (top) and I = −1 mA(bottom)

As we learned in the lecture, the electric field is the negative first derivative of the potential, as illustrated in **equation 2** below. It was calculated in the code, and **Figure 2** was obtained.

$$-\frac{\partial V_e}{\partial \mathrm{x}} = \vec{E} \tag{2}$$

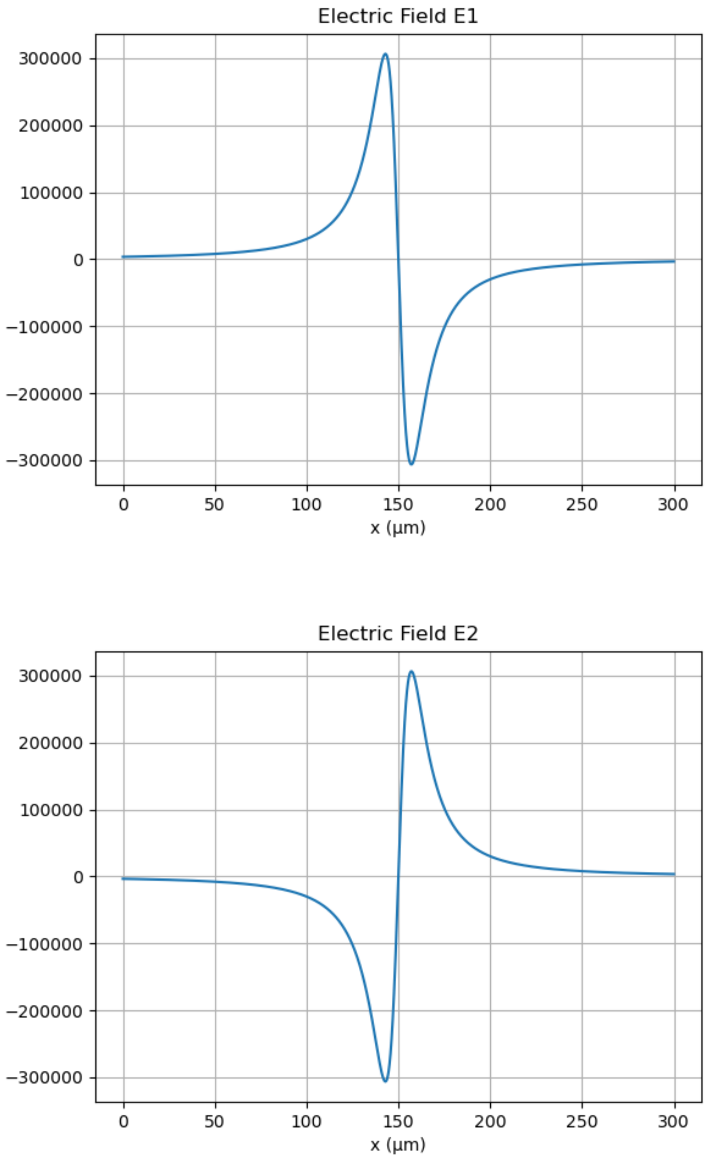


Figure 2. Electric field for d = 10 µm for I = 1 mA (top) and I = −1 mA (bottom)

Also, we learned in the lecture that the activation function along an axon is the negative first derivative of the potential, as illustrated in **equation 3** below.

$$\frac{\partial V_e^2}{\partial x^2} = Activation\ Function \tag{3}$$

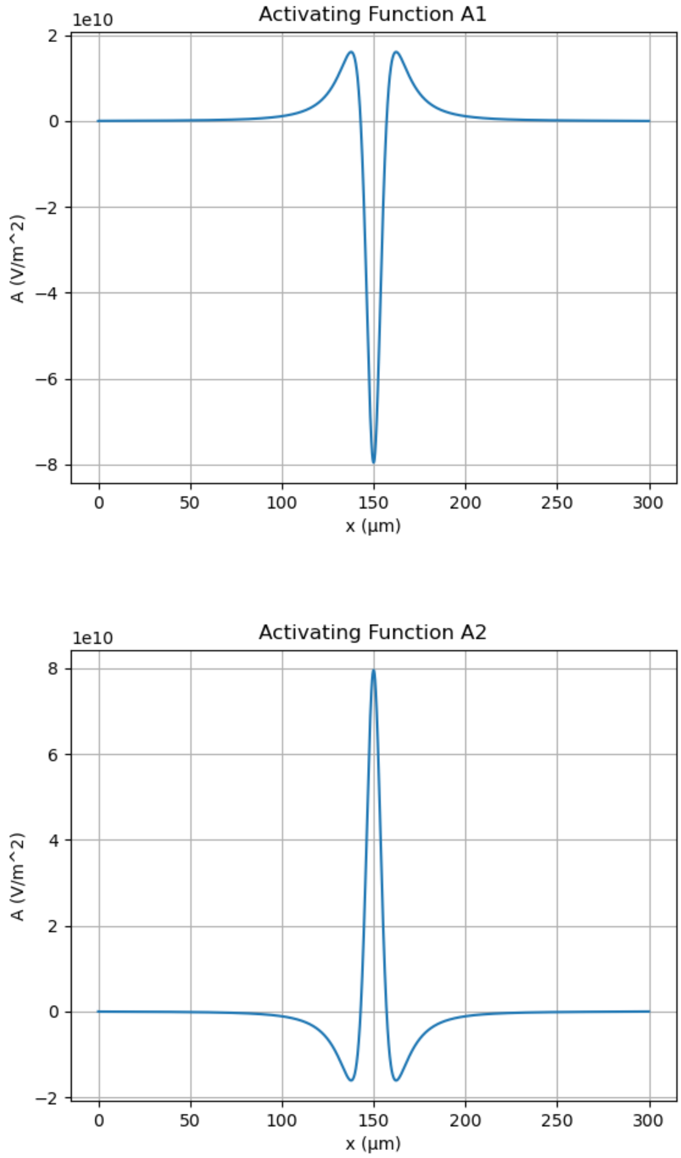
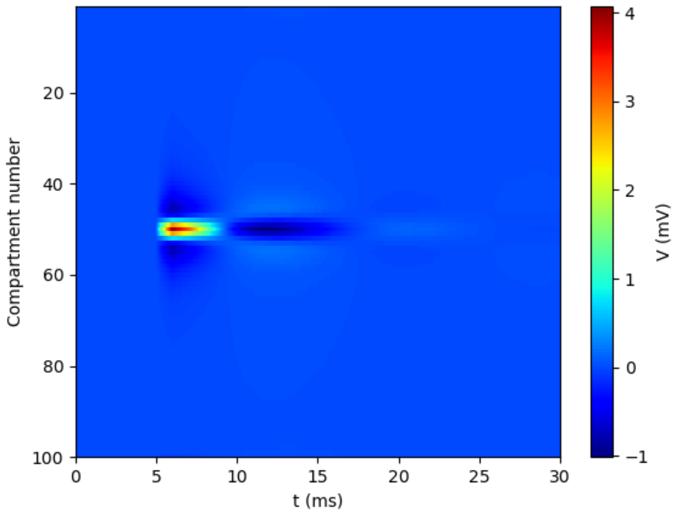


Figure 3. Activating function for d = 10 μm for I = 1 mA (Top) and I = −1 mA (Bottom)

2. Neuron Model

The code was updated to match the new parameters in the exercise handout and adapt it for the extracellular stimulation. A function named "ex potential" was created to calculate the formula given in **Equation 1**. An extra line of code in the function hh_model was added to calculate the extracellular potential for a future timestep, $V_e(t + \Delta t)$, which is used later in the potential function, hh_potential. The input current I_{stim} was eliminated as instructed in the exercise. This is because the axon will be stimulated only by the extracellular potential.

We ran the simulation for every stimulation sequence for 30 ms with a timestep Δt = 25 μs with a starting pulse at t – 5 ms. The results are illustrated in Figures 4, 5, and 6 below.



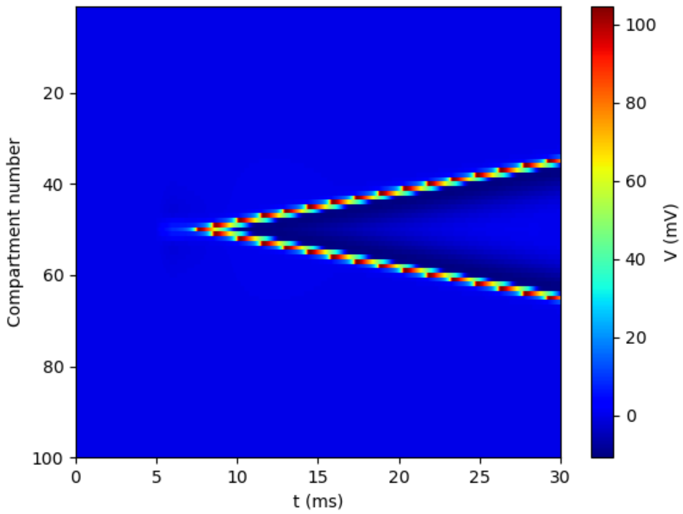


Figure 4. Mono-phasic current pulses with negative intensity. Top: I = -0.05 mA. Bottom: I = -0.1 mA

As we can see from the results in Figure 4, the axon can be stimulated with a negative current. However, the activation function must reach the firing threshold to excite an action potential. **Figure 4(top)** shows that the activation function did not reach the firing threshold, so an action potential was not excited along the axon, as the potential had a minimal value. However, **Figure 4(top)** shows that the activation function reached the firing threshold, and an action potential was excited in both directions along the axon. This is because the stimulating current had a larger absolute value.

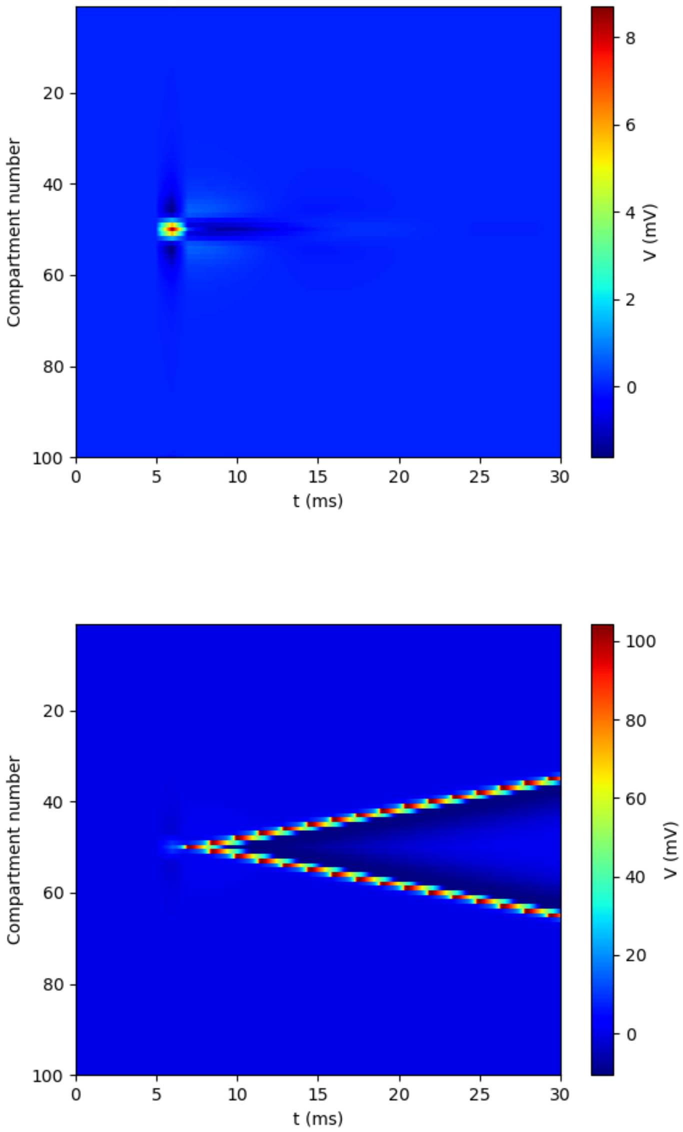


Figure 5.Bi-phasic current pulses with negative intensity. Top: I = -+0.1 mA. Bottom: I = -+0.15 mA

We can see from the results in Figure 5 that the axon had almost the same behavior when stimulated with a bi-phasic current. **Figure 5(top)** shows that the activation function did not reach the firing threshold, and an action potential was not excited along the axon. On the other hand, **Figure 5(bottom)** shows that the activation function reached the firing threshold, and an action potential was excited along the axon. However, we can observe a lower potential in general when comparing the profile for |I| = 0.15 mA and the one for I = -0.1 mA. The main reason is that the second positive phase, which comes 1 second after the first one, opposes the negative one. Hence, the resulting action potential for the bi-phasic stimulating current pulse was less than the mono-phasic stimulating current pulse.

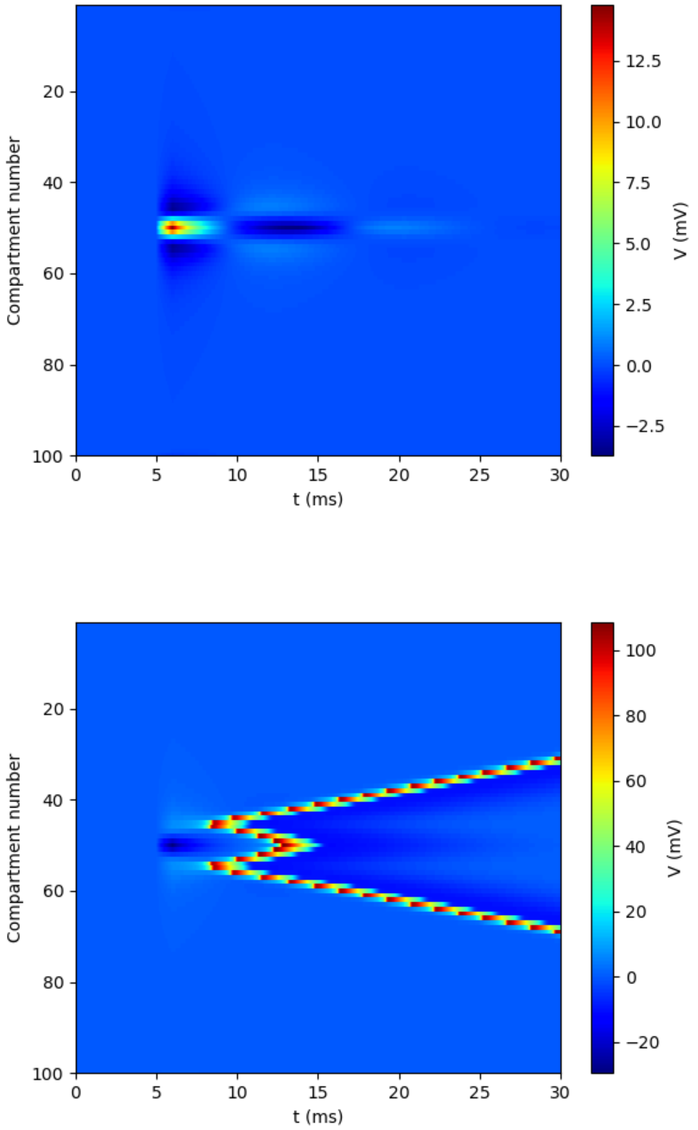


Figure 6. Mono-phasic current pulses with negative intensity. Top: I = 0.2 mA. Bottom: I = 0.4 mA

As we can see from the results in **Figure 5**, the axon has a different behavior when stimulated with a mono-phasic current pulse. Figure 6(top) shows that the activation function did not reach the firing threshold, and an action potential was not excited along the axon. However, in Figure **6(bottom)**, two action potentials are meeting at compartment 50. Let's take a deeper look at **Figure 3(top)**. We can see that the activation function has two peaks, which means that the activation function reaches the firing threshold two times, spreading action potential in two different directions. In the middle of the axon at compartment 50, the two action potentials from the left and right sides meet and cancel each other out, so the action potential dies out (the left and right sides were in a refractory period).