Neural response

اعصابی ردِّعمل

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Every moment, your body is alive with tiny electrical signals silent, swift, and invisible. But what if you could also see them?

This experiment takes you on a journey to artificially create signals that resembles those neural impulses using a practical circuit. With just a few adjustments to the knobs, you'll bring these hidden signals to life and discover how a carefully designed electronic circuit can mimic neural activity.

What do you think allows your body to feel, react, and simply exist?

We know the body works through organs and nerves, but within those nerves are neurons Fig.1 which carry tiny voltage surges that are the body's messaging system. These impulses let you see, feel, and move.

Through this experiment, we will,

1. learn how real nerve impulses look like.
2. harness our capability to predict how circuit will behave before even building them, and
3. experience the utility of electrical circuits to model biological processes.

Ever wondered what a neuron looks like, and
what a cell membrane actually is?

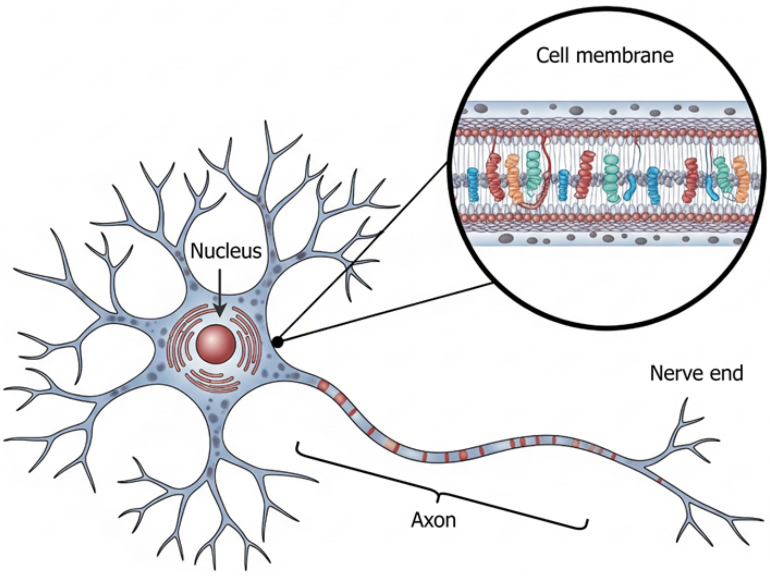


Figure 1: Illustration of a neuron, the body's messenger for carrying signals, showing the nucleus, axon, and nerve end. The magnified view highlights the cell membrane, the cell's outer layer, which has special protein channels that control what enters and exits the neuron.

1 Action Potential

Our body is a marvel of tiny electrical signals, and at the center of it all lies the action potential. For a long time, scientists did not understand how nerves talked to muscles and organs, until they discovered that nerves send messages using these brief sparks of electricity. An action potential is a rapid, temporary change in the electrical charge across a neuron's call membrane, traveling along its axon like a spark racing down a wire.

An overview of the action potential phases is illustrated in Figure 2 [1]. The electrical voltage changes in response to the movement of ions (mostly K^+ and Na^+) across the cell membrane. Thses ions move through hannels which open or close through a sophisticated mechanism of controls.

An action potential is like a light switch: either it flips on fully or doesn't happen at all. A weak push does nothing, but once the threshold is reached, the signal always remains the same size. Stronger pushes don't make the spark bigger, they just make it happen more often. That's why action potentials are "all-or-none" signals.

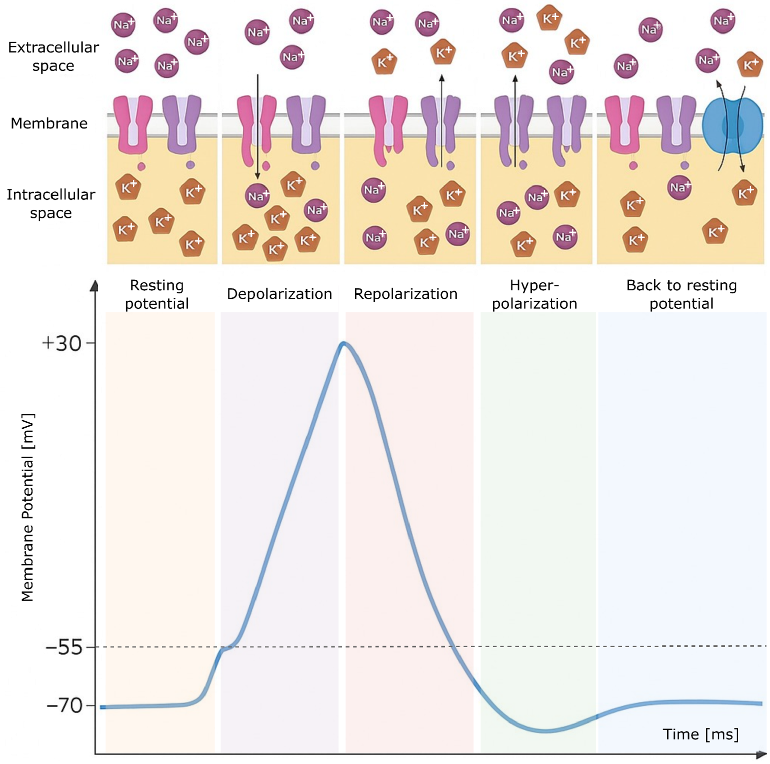
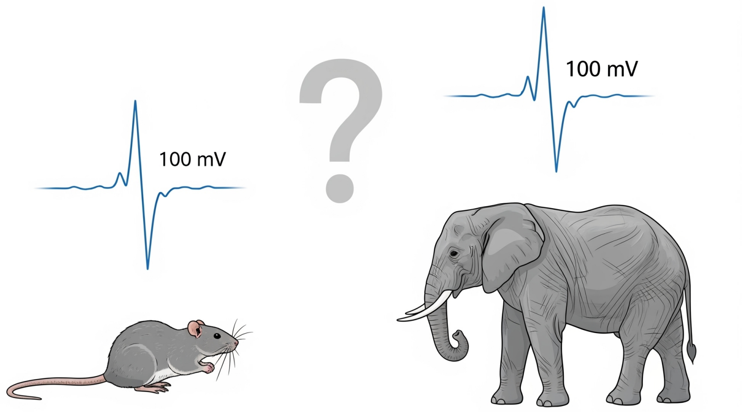


Figure 2: Nerve cells communicate through tiny electrical changes. This figure shows what that signal looks like when recorded over time. The top panel depicts approximately flow of ions corresponding to the distinct phases of the action potential.

How would the action potential in an elephant compare to that in a rat, or would it be the same?



In this Phenomenon Lab, we are not measuring action potentials from real neurons and cells, rather we are artificially creating electrical voltages whose shape resembles a typical action potential in an organism. Can a circuit, therefore, act like a neuron? So let's find out.

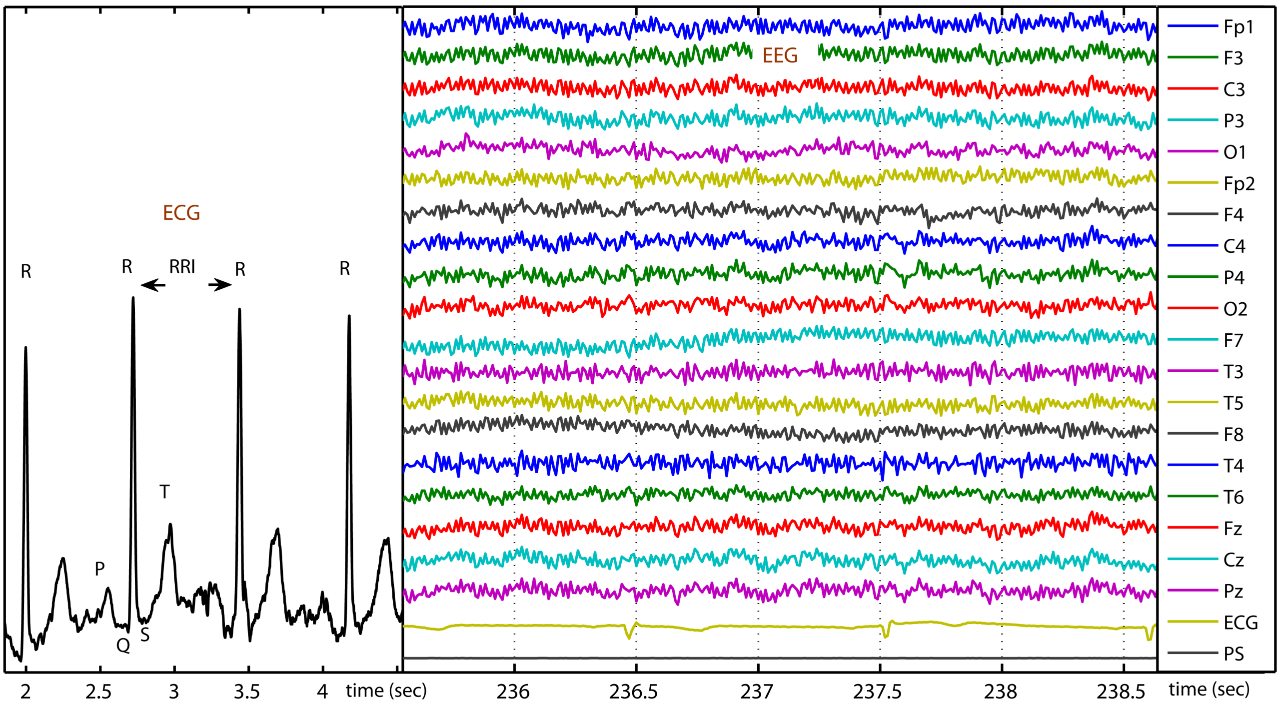


Figure 3: Examples of physiological signals based on action potential: the ECG (left) reflects electrical activity of the heart, while the EEG (right) represents collective neuronal activity in the brain [2].

2 What we need

2.1 Simulation

We start with a computer simulation. Using the software *LT Spice* (head to download [3]), you can draw a circuit on the screen and test how it reacts to an input and produces an output voltage (a guide is provided in the appendix). When a small signal is applied to the circuit, it responds by generating a sharp spike, a rapid rise in voltage followed by a quick drop. This behaviour closely mimics a real biological action potential, capturing the all-or-nothing nature of how nerve cells fire. So build the circuit shown Figure 3 on your LT Spice window.

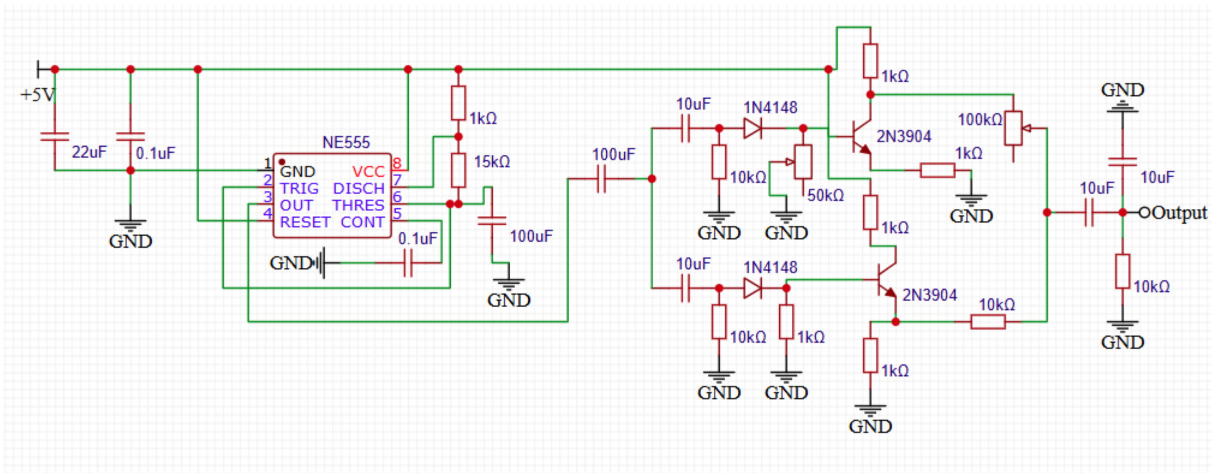


Figure 4: A diagram of the simulation circuit you will build on *LT Spice* and verify its output.

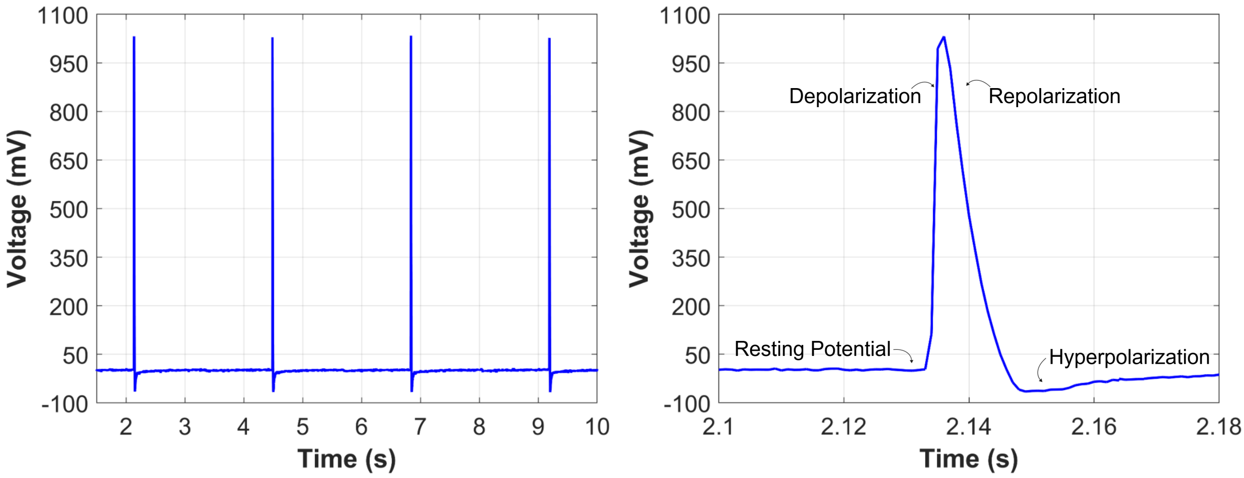


Figure 5: Waveform of the action potential circuit generator at a fixed frequency of 0.45 Hz: (left) overall output, (right) close-up view, showing the phases inside a single firing activity.

The output whose waveform is shown in Figure 5, resembles an action potential. Its characteristics can be further modified by changing the values of the 50 kΩ and 100 kΩ resistors.

Can we control the shape of an action potential?

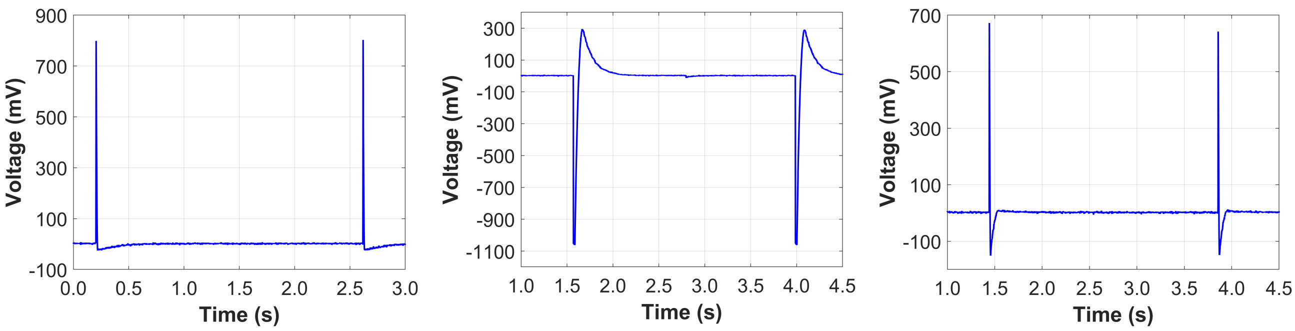


Figure 6: Example of different waveforms that can be generated by adjusting the resistor values: (left) 50 kΩ set to 0, (middle) 100 kΩ set to 0, and (right) 50 kΩ and 100 kΩ set to 50%.

Try to play with the circuit elements (variable resistors of 50 kΩ and 100 kΩ) in the simulation and see how it effects the shape of action potential. You'll see how the shape and speed of the spike changes, just like how nerves can behave differently under conditions of stress, cold, or medication.

2.2 Hardware implementation of Action Potential Synthesizer

Now that you've explored the simulation and understood the behavior of the action potential circuit, it's time to observe it in a real implementation.

Your hardware setup has already been pre-built and packaged. All necessary components have been properly connected and tested, so you can focus directly on experimentation. For data loging we can use PhysLogger (head to Qosain Scientific's website [5] to access the setup guide for the PhysLogger).

Follow these steps to generate and acquire the artificially mimicked action potential:

1. Use the USB-C connector to connect the Action Potential Synthesizer to one of the digital channels of PhysLogger. This powers the Action Potential Synthesizer and prepares it for data acquisition.

2. Connect the output pins using green connector to one of the analog channels of PhysLogger. This allows you to observe the action potential waveform on your computer screen.

3. Use the two variable resistor knobs on the device to explore the behavior of the signal. Try adjusting them slowly and observe how the waveform changes. While the overall shape stays consistent, you'll notice shifts in the steepness, duration, or timing just like how real neurons respond under different conditions.

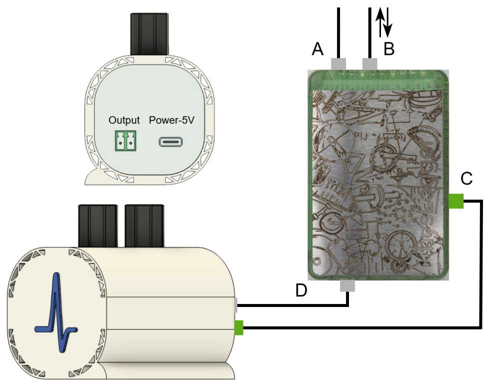
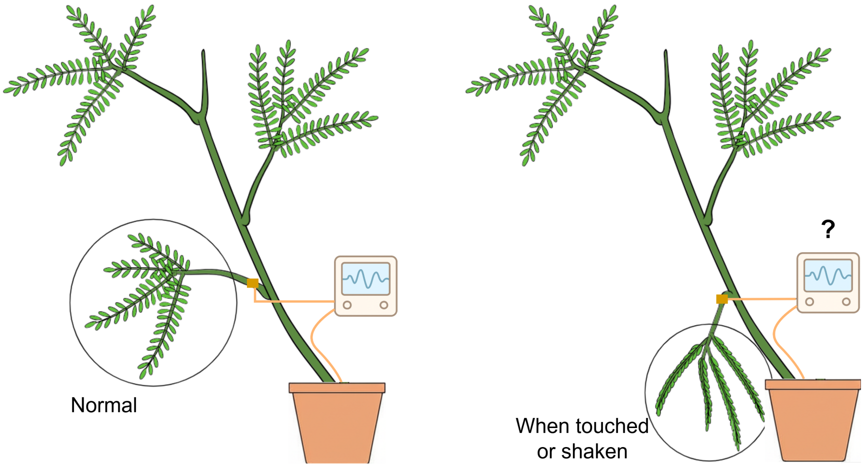


Figure 7: The Action Potential Synthesizer: (left) real photograph showing three synthesizer, and (right) the synthesizer and PhysLogger connections, comprising A: to the PhysLogger adapter, B: to PC, C: output to one of the analog channel, and D; to 5V power or to any PhysLogger digital channel.

Table 1: Synthesizer and PhysLogger connections.

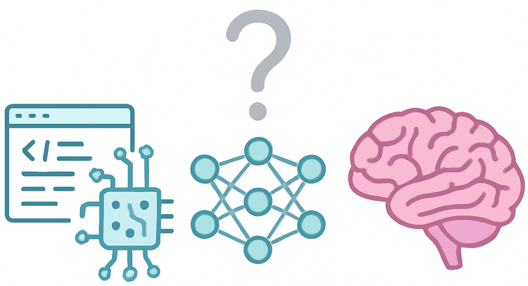
A	From PhysLogger to its adapter.
B	PhysLogger to PC.
C	Synthesizer output to one of the analog input channels of PhysLogger.
D	Source of 5V power or to any PhysLogger digital input channel.

Do plants also carry electrical signals like our brain?



Your brain processes information through electrical spikes called action potentials, an idea that inspired modern artificial intelligence. Like neurons, AI systems rely on signal patterns, responses, and learning. By studying these signals in circuits, you're uncovering the principles behind how both brains and machines learn to think.

Are AI neural networks just smart code or digital brains in disguise?



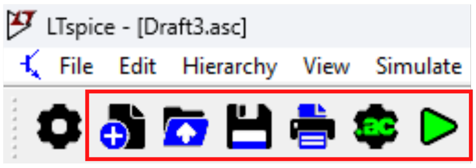
A LTspice Simulation

LTspice is a free tool for designing and simulating electronic circuits, widely used by engineers, students and teachers.

Figure 8: The LTspice user interface.

We will go through functionality of some of the basic functions available one by one. Below images contain some options encircled in read rectangle, description for each is mentioned below each figure as well as keyboard shortcut keys to use them.

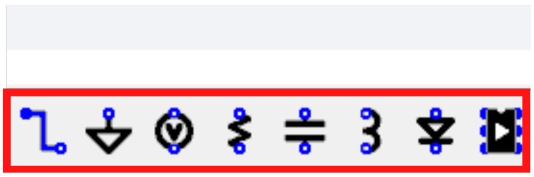
A.1 Basic Operations



If we move through options from left to right highlighted in the red rectangle, we have the following:

1. **New Schematic (Ctrl+N):** To create new circuit sketch.
2. **Open (Ctrl+O):** To open existing LTspice circuit sketch.
3. **Save (Ctrl+S):** To save your design.
4. **Print (Ctrl+P):** To print your circuit design on A4.
5. **Configure Analysis (A):** To set the simulation options e.g simulation time, start/ end time, etc.
6. **Run/Pause (Alt+R):** To start or pause the simulation.

A.2 Circuit Design Tools



You can select any option using mouse **Left click**, but if you want to unselect the component or option just use mouse **Right click** or the keyboard's **Esc key**. To configure value of any components such as resistor, capacitor, voltage source, etc just use mouse **Right click** and a menu will popup. The circuit design elements shown in the red rectangle are described here:

1. **Wire (W):** Create wire, to connect two components or wires.
2. **Ground (G):** Select ground element, to make sure all points have common ground if needed.

3. **Voltage Source (V):** A DC voltage source, however it can also be configured to generate pulses at a required frequency.

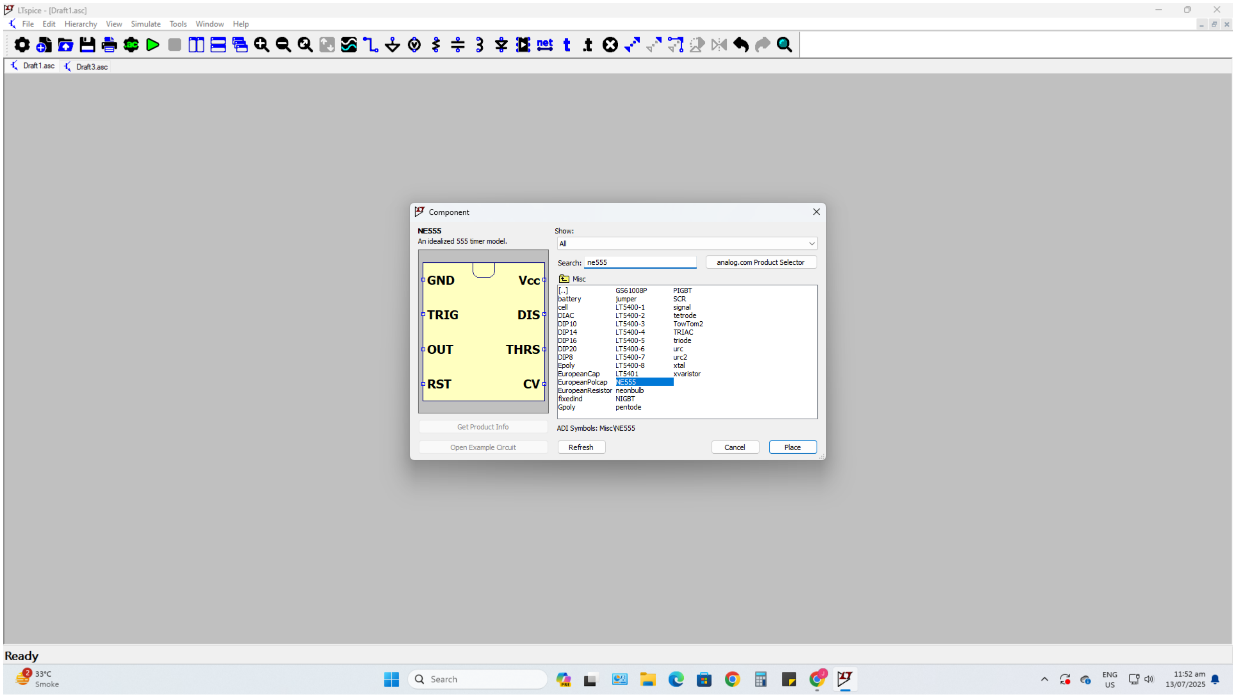
4. **Resistor (R):** A circuit design element.

5. **Capacitor (C):** A circuit design element.

6. **Inductor (L):** A circuit design element.

7. **Diode (D):** A circuit design element.

8. **Component (P):** You can search any circuit design component using this option as well.

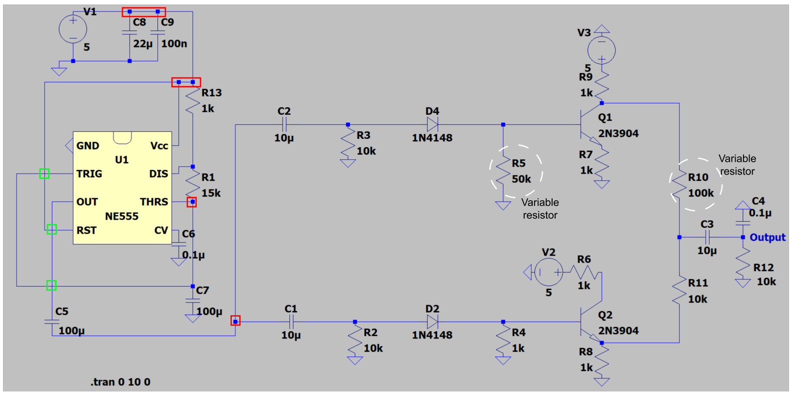


1. **Delete Mode (Backspace or DEl key):** To delete a component such as wire or other circuit element.

2. **Duplicate Mode (Ctrl+C):** To make a copy of whole circuit or part of circuit.

3. **Move Mode (M):** To move a component such as wire or other circuit element but it will disconnect the selection from rest of schematic.

4. **Stretch Mode (S):** To stretch or extend a component such as wire or other circuit element without breaking connection from rest of circuit.



When designing your schematic in LTspice, ensure proper connections: red rectangles mark points that are connected, while green rectangles show wires that are not connected. Always double-check these indicators to avoid connection errors.

B PhysLogger

To setup the PhysLogger, follow the step-by-step instructions in the PhysLogger Quick Start Guide [5].

References

[1] KenHub, *Action Potentials*, Retrieved from `https://www.kenhub.com/en/library/physiology/action-potential`, Accessed June 12, 2025.

[2] P.-F. Lin, M.-T. Lo, Y.-C. Chang, C. Lin, and Y.-L. Ho, "Correlations between the Signal Complexity of Cerebral and Cardiac Electrical Activity: A Multiscale Entropy Analysis," *PLOS ONE*, vol. 9, no. 2, p. e87798, 2014. doi: 10.1371/journal.pone.0087798.

[3] *Simulation Software*, Retrieved from `https://www.analog.com/en/resources/design-tools-and-calculators/ltspice-simulator.html`, Accessed June 12, 2025.

[4] S. W. Harden, *Analog Action Potential Generator Circuit*, Retrieved from `https://swharden.com/blog/2017-08-12-analog-action-potential-generator-circuit/`, Accessed June 12, 2025.

[5] Dr Sabieh Anwar, *PhysLogger-Qosain Scientific*, Retrieved from `https://qosainscientific.com/product/physlogger/`, Accessed June 12, 2025.

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