

# BioE 101 – Lab 1

## **Objectives:**

- 1) Learn how to use an oscilloscope and function generator.
- 2) Learn to use breadboard to build and test simple circuits like resistive voltage divider, and RLC filter.
- 3) Learn how to use MyDAQ to acquire and output signals.

## **1. Setup**

- We should generally have 2 people per lab station.
- Your team should have the following items on your station: oscilloscope (with one test probe), function generator, power supply, MyDAQ (with black and red test probes), multi-meter, breadboard, jumperwire kits, pliers, BNC cable and adaptors.
- You can get the electronic parts such as the resistors, capacitors, diodes, etc. at the supplies desk by the white board.
- Please keep all the lab equipment in lab only.
- Before you leave the lab, make sure the power for all the equipment is switched off.

## **2. Introducing the Oscilloscope and Functional Generator**

- a) The oscilloscope allows us to view electrical signals (voltages or currents). Sometimes, it is used in conjunction with a function generator to observe the effect that a test signal has at one or more point(s) in our circuit. This is very useful in determining, for example, the input/output characteristics (i.e. the transfer function) of an amplifier. Despite their age, these scopes are very powerful tools. These oscilloscopes are digital, meaning they convert the analog signals at their inputs into numeric waveforms with the sampling rate and scaling parameters that you specify. This offers some very important advantages over analog oscilloscopes of the old days.
- b) The function generator allows us to apply test signals to our circuit such as sine waves, square waves, pulses, triangle waves, and even waveforms which we define ourselves (referred to as “arbitrary waveforms”). We can control frequency and amplitude, and we can even sweep through many frequencies/amplitudes in order to test our device with a range of conditions.
- c) Take a good look at your oscilloscope and answer the following questions:

**Question 2.1:** What is the bandwidth of this oscilloscope? What does that mean for the signals you will be able to observe with it? What would the sampling rate of the ADC inside the scope have to be in order to achieve this bandwidth?

**Question 2.2:** What is the input impedance of this scope? Why would that matter?

- d) Use the BNC cable to directly connect the output of the function generator to channel 1 of the oscilloscope. Make sure channel 1 is on and the scope is acquiring signals.

- e) Set the function generator to a 100 Hz, 1V sine wave with 0V offset. Turn on the output by pressing the “disable” button so the light goes off.
- f) Adjust the scope time and voltage scales to comfortably see several periods of the waveform. To do this, you will need to familiarize yourself with 3 controls:
  - Volts/Div: This sets the Y scale of each channel (channel 1 and 2 are set independently). The current scale is in the upper left corner of the screen. A value of 500mV, for example, means that each horizontal line in the grid corresponds to 500mV.
  - Time/Div: This sets the X scale of both channels (they must be the same). The current value is in the upper right corner of the screen. Note that as you “zoom out” on the waveform, the sampling rate drops.
  - Voltage Position: Each channel has an additional knob that lets you move the waveform up and down on the screen. This is useful when you want to display multiple waveforms.
  - Trigger Source, Mode, and Level: The trigger is useful for synchronizing your display to the signal so it doesn’t scroll across your screen. Edge triggering (also called “normal” triggering) causes the display to refresh only when the signal crosses the threshold amplitude. You can trigger on either channel 1 or 2, and you can adjust the triggering threshold. You can also specify whether you want the signal to trigger on a low-high transition or a high-low transition. If “auto” is selected, the trigger values are ignored and the screen constantly refreshes. Auto triggering can be useful initially for setting up scope parameters. Try adjusting the trigger parameters and see what happens to your signal.

**Question 2.2:** What is (roughly) the largest and smallest voltage that you could observe with this scope (hint: try changing the volts/div knob to see the limits). What is (roughly) the fastest and slowest frequency that you could observe with this scope.

**Question 2.3:** What happens when you set the trigger to a voltage that your sine wave never reaches?

- g) Play with the function generator and see how the signal changes. Try changing the frequency, amplitude, offset, and waveform type (sine, square, triangle). When you’re done, set it back to 100 Hz, 1V sine.
- h) Cursors are a handy way to measure signal voltages and timing on the oscilloscope. Pressing the “cursors” button will turn them on. Make sure the “Source” for the cursors is set to channel 1. Use the buttons below the screen to select which cursor you want to move and the knob near the cursor button to move the cursor. The positions and distances appear at the bottom of the screen. Using the cursors, verify that the amplitude is 1V and the period is  $1/100 = 10\text{ms}$ .

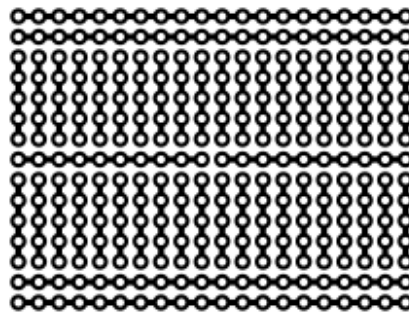
**Question 2.4:** Is 1V the peak-to-peak amplitude, the RMS amplitude, or the peak amplitude?

- i) You can also have the scope automatically measure voltage and timing parameters by pressing the Voltage/Time buttons under the “Measure” label. You can have it display 3 different quantities at a time. Try displaying the average voltage value, RMS voltage value, and frequency of your waveform. Make sure “Source” is set to channel 1.
- j) Try changing the function generator to a square wave, then to a sawtooth wave.

**Question 2.5:** How do the 3 measurement quantities on your scope (average value, RMS value, and frequency) change for a sine, square, and triangle wave? Explain what you see.

### **3. Introducing the Breadboard**

- a) The breadboard is a powerful tool to test and debug the circuit design since no soldering is required. A typical breadboard consists of a perforated block of plastic with metal spring clips under the perforations. The clips are interconnected following a certain pattern underneath the plastic block (see an example in Fig 1). The holes connected by a common black line means that they are shorted. Electronic parts can be connected by plugging into the interconnected holes or by jumper wires.



**Figure 1:** Breadboard Example Connections

- b) Take a look at the interconnection pattern in Fig 1, the layout of a typical breadboard is made up from two parts: terminal strips and bus strips. Terminal strips are the main areas to hold the most electronic components. The holes are usually grouped into five in a column. Bus strips, usually run on the long side and are typically used for providing power to the circuits being built within the terminal strips area.

**Question 3.1:** How can you test your own breadboard to determine its interconnection pattern? Draw a simple diagram to explain how the holes in your breadboard are interconnected.

- c) Jumper wires with 22 AWG (American wire gauge) can be used to connect two electronic parts. The wire ends should be stripped 3/16” to 5/16”. Shorter stripped wires might result in bad contact with the board’s spring clips (insulation being caught in the springs). Longer stripped wires increase the likelihood of short-circuits on the board. Needle-nose pliers and tweezers are helpful when inserting or

removing wires, particularly on crowded boards. One tip for keeping your circuit neat and readable is to use different color wires for different signal paths.

- d) The breadboard is reusable after each time by removing all the parts and jumper wires from the board.

#### 4. Build Circuits and Measure Circuit Parameters

In this lab, we will build two circuits – (1) resistive voltage divider, and (2) a simple RC filter. Keep your circuits on the breadboard until the end of the lab, since we need the circuits throughout the rest of the experiment.

- Voltage divider: it is a simple linear circuit that produces an output voltage ( $V_{out}$ ) that is a fraction of its input voltage ( $V_{in}$ ). A simple example of a voltage divider consists of two resistors in series (Fig 2(a)). It is commonly used to create a reference voltage, and may also be used as a signal attenuator.
- Build the circuit on the breadboard using two resistors. Choose  $R_1 = 3.3k\Omega$ ,  $R_2 = 10k\Omega$ . Use a multi-meter to make sure that the resistors are of the correct values. Note that resistor values are printed on the outside as a series of colored bands. Take a look at the chart below to verify that you have a 3.3k and 10k resistor.
- One hint to manage your power supply and ground system is to use the strip bus: make sure you connect the strip bus to the banana plugs which connect to the external power supply.

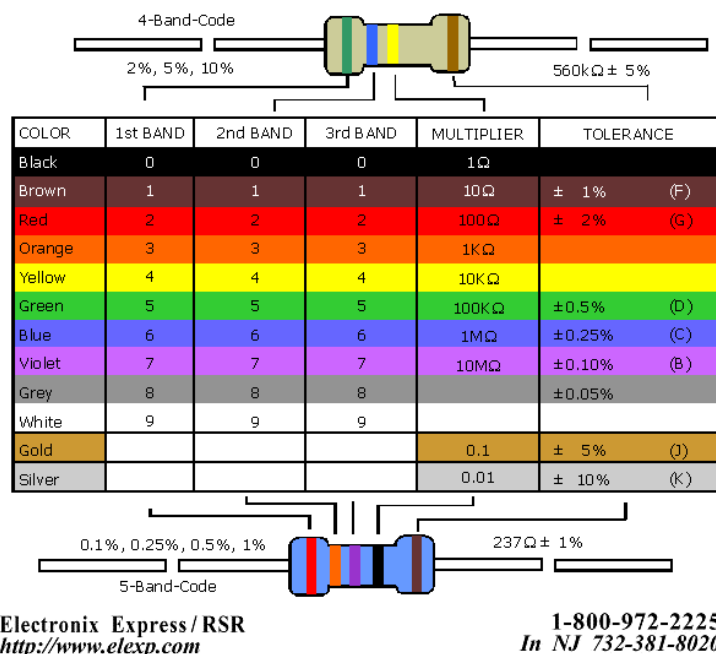
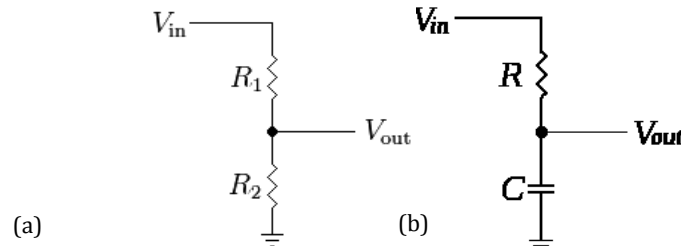


Figure 2: Resistor Color Code Chart

**Question 4.1:** Suppose you accidentally picked up a 33kΩ and a 100Ω resistor. What would the color bands look like instead?

- d) Feed  $V_{in}$  with 5V from the power supply. Turn on the power supply, press and hold the “6V” button to limit the output range of the power supply from 0V to 6V. Then tune the dial to set the output voltage to 5V. You can tell the actual output voltage by reading the number on the display panel. Hook the output of the power supply to the breadboard. Test the voltage output using the multi-meter.



**Figure 2:** (a) Resistive Voltage Divider; (b) RC filter.

**Question 4.2:** What is the output voltage? Explain how this circuit can be worked as a voltage divider? Can I use small resistors (like 1Ω) for this application and why?

- e) RC filter: you can turn the resistive voltage divider into a filter by simply replacing  $R_2$  by a capacitor (Fig 2(b)). Choose  $R$  to be 3.3kΩ and  $C$  to be 0.01 μF. Build the RC circuit on the breadboard. Analyze this circuit and answer the following questions.

**Question 4.3:** What type of filter is it (high-pass, low-pass, band-pass, band-stop)? What is the cut-off frequency of this filter (here we use the -3dB definition)? Sketch the Bode plot of your filter.

- f) Connect the input  $V_{in}$  of this filter to the function generator and hook the output to the oscilloscope. Tune the function generator to output a sine wave of frequency 9kHz, 5 Vpeak, 50 % duty cycle, 0V offset.

**Question 4.4:** What does the output signal look like? How does it compare to the input signal? Is this what you would expect? How would you experimentally get the Bode plot?

## **5. Introducing the MyDAQ**

- First, watch a short tutorial video of MyDAQ online at <http://decibel.ni.com/content/docs/DOC-13041>.
- The MyDAQ has four ports: USB port, I/O ports, audio ports and test probe ports. In this lab, the USB port is already connected to the desktop and is responsible for communicating with the computer. We will focus on the usage of the probe port and the analog I/O ports for now. The audio and digital I/O interface will be covered in the next couple labs.
- Google “NI MyDAQ User Guide and Specifications”, and download the .pdf document. Quickly scan the document to see what it offers.

**Question 5.1:** What is the bandwidth of the analog inputs? What is the accuracy of the DMM when measuring a DC voltage around 5V? How many bits are in the ADC of the analog inputs? What is the output impedance of the analog outputs?

Launch “NI ELVISmxInstrument launcher” software. The pop-up bar shows all the built-in functions that the MyDAQ has. Choose multi-meter (DMM) from the list and the virtual multi-meter panel will show up. Connect the test probes to the MyDAQ and click the “RUN” button (the green arrow) on the bottom of the panel. Now you are ready to test the voltage divider circuit! (Remember to click “RUN” before using the virtual device, since the “RUN” button functions as the power button of the real device)

d) Connect the power supply to Vin of the voltage divider. Set the power supply to 5V.

**Question 5.2:** What is the output voltage of the voltage divider? What is the difference between the MyDAQ DMM and the actual DMM voltage reading? (Talk to GSIs if the difference is large). Using the MyDAQ to measure current, what is the current through the voltage divider circuit (this will involve disconnecting one lead of the circuit)? Does this current value match the theoretical value?

e) Disconnect the power supply from your breadboard. Open the MyDAQ function generator. Output a triangular wave from the MyDAQ with frequency 10 Hz. Apply the 10 Hz triangle wave from the MyDAQ to the RC filter that we built earlier. Monitor the signal from Vout of the circuit using the MyDAQ oscilloscope. Since the analog input ports of the MyDAQ use screw terminals, you will need jumper wires to connect the filtered signal with the analog input ports. Make sure the ground signal is properly connected to pin AGND of the MyDAQ card. Refer to the Oscilloscope section and Function Generator section of the “NI MyDAQ User Guide and Specifications” for details on these instruments.

**Question 5.3:** How does duty cycle affect the waveform? Try to change the duty cycle and observe how the waveform changes.

f) Now, increase the output frequency of the function generator to 1 kHz.

**Question 5.4:** What change do you see in the signal in terms of its amplitude and shape? What do you see at 10 kHz? Explain what is happening.

g) Connect channel AO 0 to AI 0+. Connect AI 0- to AGND. Close the function generator and open the arbitrary waveform generator. Click the open folder button for channel A0. Select 1Vsine1000.wdt. Increase the update rate to 10 kS/s.

**Question 5.5:** Zoom in to look at the signal, why is it not continuous? If you connect the signal through the filter, what does Vout look like?

h) Look up the “NI MyDAQ User Guide and Specifications” and create a bode plot from your filter.

**Question 5.6:** What is the -3dB frequency of your actual filter? How well does this match theory?