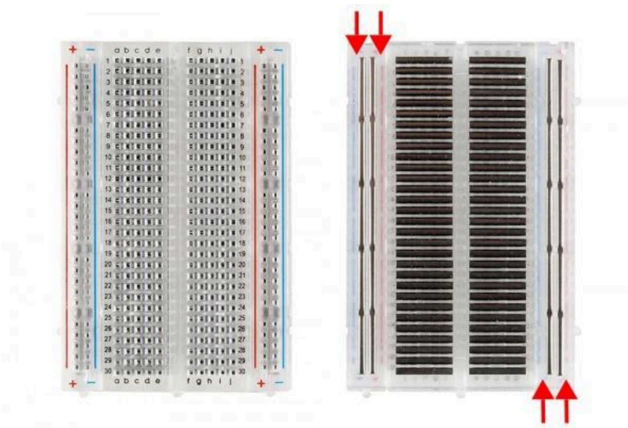
Basic Electronics Tutorial for Remote Students

Circuit Building Basics

Breadboards

Aside from horizontal rows (along columns A-E and columns F-J), breadboards usually have power rails that run vertically along the sides. These are connected internally. The red rail (+) and blue rail (-) are typically connected across your power source, with the blue rail corresponding to ground/common.



Review the tutorial, also available on the BE labs website, on using a breadboard.

Breadboarding tips:

- Organize the components and wires on a breadboard to easily identify components and wires in your circuit diagram.
- Keep wires short and close to the breadboard. This helps with visualization, debugging, and prevents noise from entering your system.
- Color code your wires. Generally, red wires are used for source voltages and black for ground voltages.

Cables and Components

A list of electrical components available in the Stephenson Lab can be found here.
Review the electrical test cables available in the lab (link).

Building Circuits

- **In a circuit, a point where any two or more circuit elements meet is a NODE. When building a circuit, all component ends connected along a row on a breadboard are connected on a node.** Measuring and verifying the voltages at these points can help with debugging.
- When building a large complex system, break it up into modules. Make one module, test, and verify that the output is what you expect. Then make the second module, and test. When you've confirmed that both modules work, interface them together.
- Debugging tips can be found here.

- ## Plusivo Digital Multimeter

Multimeters are used for checking voltages or measuring resistance, as well as several other functions. They typically have one red test lead and one black test lead.

The black probe should be plugged into the outlet labeled common (600Vmax**COM**) at the bottom of the multimeter. In general, using black colored wires for ground will make debugging much easier! The red probe should be plugged into **VΩmA**. When using the multimeter, remember to take the cover off both ends of the black and red probe to allow you to connect the probes to the multimeter and to obtain readings.

The Power Supply

You will use a 9 V battery as your power supply. On a breadboard, connect the red wire of one battery connector to a power line and connect the corresponding black wire to a different power line.

Complete the following:

1. Connect the probes to the ports for measuring voltage/resistance on your multimeter (see above).

2. Turn the dial on the multimeter to the resistor region (**Ω**) for it to read resistance.

3. Determine the resistance of the provided resistor using the multimeter.

   Resistance value using multimeter: ___________

4. Use the resistor color code calculator (link available on the BE lab website) to determine the resistor value.

   Resistance value using color code: ___________

5. Touch the ends of the two probes or the ends of the alligator clips together. What does the multimeter read? Why?

6. Now, set the multimeter to read DC voltage by turning the dial on the multimeter to the V region in the top left quadrant.

7. Connect the battery connector to the battery.

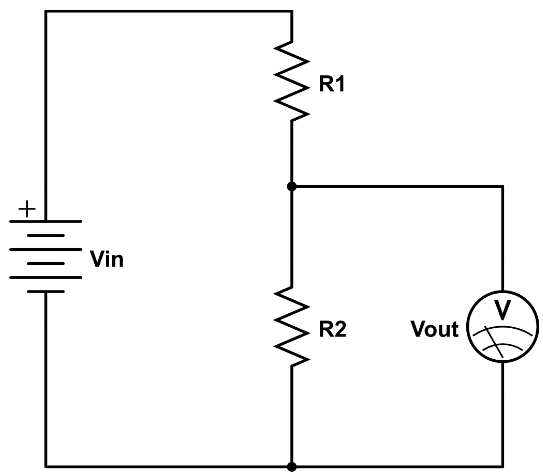
8. Measure the voltage across these wires, making sure the red probe from the multimeter is connected to the +9V and the black probe to the common ground. What do you measure?

Voltage: ____________

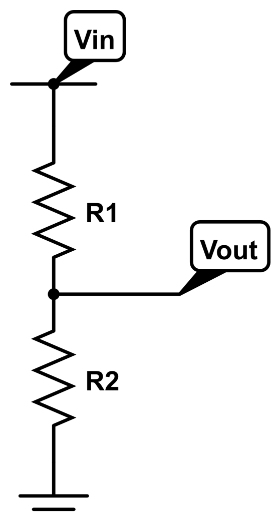
9. Now, reverse the wires that the test cable leads are attached to (i.e., Red probe is connected to common ground). What do you measure? Why?

Voltage Dividers

Voltage dividers can be useful to lower and direct different voltages to different elements in a circuit. The voltage output can be controlled with the use of two resistors in series, connected to a power source and ground as shown in the drawing.



This drawing can be simplified as the following, which is normally how circuit diagrams are drawn:



Remembering that V=IR, and that the resistors R1 and R2 are in series, we know that:

$$V_{IN} = I * (R1 + R2)$$

And since the current through series resistors is the same, we know that: $V_{OUT} = I * R2$

Therefore, solving for *I* in both equations, we have:

$$I = \frac{V_{IN}}{R1+R2}$$

And:

$$I = \frac{V_{OUT}}{R2}$$

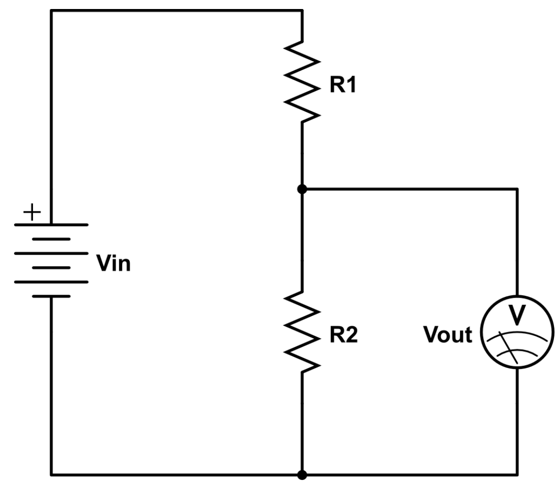
Therefore, solving for V_{OUT}, we have:

$$V_{OUT} = \frac{R2}{R1+R2} * V_{IN}$$

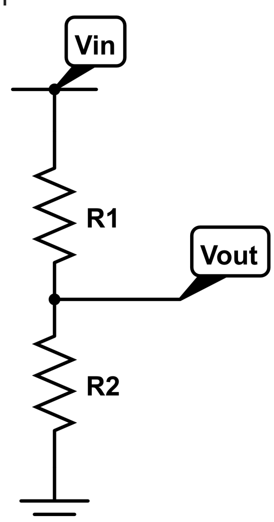
This is the standard **Voltage Divider** formula.

Complete the following:

1. Recall that in a circuit, a point where any two or more circuit elements meet is a **node**. Label the nodes in this circuit, A-Z.



2. Now, identify the nodes in the simplified circuit.



3. Construct a voltage divider circuit with R1 = 2 kΩ and R2 = 1 kΩ on a breadboard. Identify and label the nodes on the breadboard.

4. Calculate V_{OUT}.

   Calculated V_{OUT}: _____________

5. Measure the source voltage. This is the voltage from the power supply to ground.

Source voltage: ___________

6. Measure V_{OUT} using the multimeter. This is the voltage from V_{OUT} to Ground.

   Measured V_{OUT}: ___________

7. Measure the voltage "across" R1. To measure this, connect the Red terminal of the voltmeter to one end of R1, and the Black terminal on the other end.

   Voltage across R1: ________

8. What is the voltage across R2?

   Voltage across R2: ________

9. How does this voltage relate to V_{OUT}? Why?

10. Design and build a voltage divider to provide an output of ~6 Volts with a ~9 Volt source. Note that you will not be able to use precise resistor values. An output within 10% of the desired value is acceptable. Include your calculations here. Please show your work.

11. Draw your design. Remember, when building a circuit ALWAYS draw out the circuit diagram. This will help with debugging and discussing your circuit with others (particularly, instructors and TAs).

12. Verify that your circuit is working. Provide appropriate measured values. Demonstrate your working circuit to an instructor, TA, or Lab Staff.

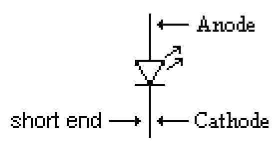
Working circuit? _______________ (Instructor, TA, or Lab Staff)

LED Switch

The Light Emitting Diode (LED)

The LED is a diode designed to produce light when a current passes through it. They are often used as indicators and as cost-effective lighting sources since they produce more light than heat, in contrast to traditional incandescent light bulbs. Like all diodes, the LED is a semiconductor device and allows current to flow only in one direction. The diode has two terminals, an anode (normally the longer terminal) and a cathode; the anode is to be connected to the higher potential point of a circuit in order for current to flow. The voltage drop across and LED can range from about 1.5 V to 2 V.

LEDs come in a variety of colors, several of which are available in the laboratory. The symbol is given below:



As the current flows through, the LED is able to emit light. However, the effective resistance of a diode is zero and from Ohm's law, we know that:

$$I = \frac{V}{R}$$

If we put a constant voltage source across the diode, we will have a short circuit as excessive amounts of current passes through the diode (beyond the allowable limit), which in turn will destroy the LED. In order to avoid this, a resistor is placed in series with the LED, limiting the current that is able to flow through the LED. Thus, if a 100 Ω resistor is placed in series with an LED, and they are placed across a 5V source, the current through the LED will be 0.05 A. By varying the current through the diode, the intensity of light produced can be changed.

7805 Voltage Regulator

Many power sources are unable to provide a stable voltage signal appropriate for the needs of your experiments. A voltage regulator can help us with this. It is a three terminal device which takes as an input a voltage from an external source, and produces a constant voltage, several volts lower than that of the input voltage. The third terminal (usually the middle one) acts as the common ground. The characteristics of this device can be found in the device's data sheet. For these experiments, we will use a 5 V regulator (7805), and use a 15 V supply as the source (although, only 7.2 V is required).

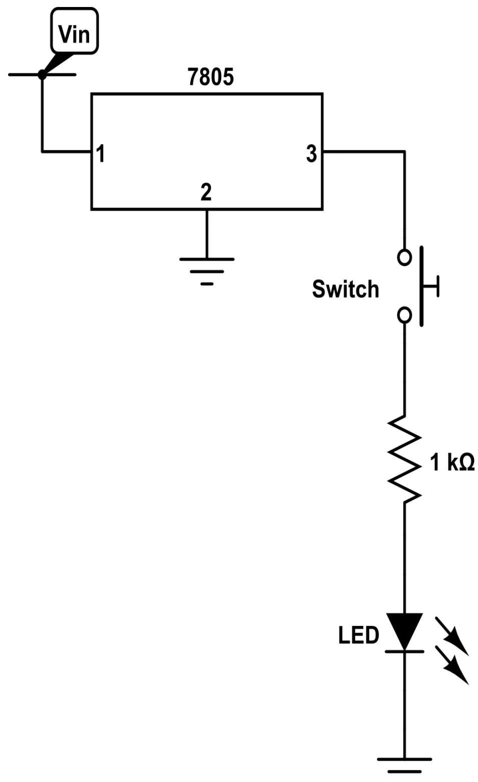
Review the manufacturer's specifications (available on the Stephenson Foundation Undergraduate Laboratory website) to determine the pin-out to the device (that is, which terminal corresponds to input, output, and ground).

Complete the following:

1. Take an LED (use red, green, or yellow, only) and using the multimeter, measure the voltage drop using the diode feature, with the multimeter's red terminal connected to the anode of the LED and the black terminal to the cathode. What do you read? Now reverse the terminals. What do you observe and why? How can you use this to determine the polarity of an LED?

Voltage drop: __________

2. Label the nodes on the circuit below (A-Z; Hint: there are 5). Have the instructor, TA, or Lab Staff check.



3. List out the nodes below and provide the expected voltage at each node (with and without the switch pressed down). Provide reasons and show any calculations. See a TA or Lab Staff for help.

4. Build this circuit on a breadboard. Identify and label the nodes. If the circuit does not work, measure the node voltages and use this as an aid to help you debug your circuit.

5. Measure and record the voltage at each node when the switch is pressed down and when it is not pressed.

6. Demonstrate your working circuit to an instructor, TA, or Lab Staff.

   Working circuit? _______________ (Instructor, TA, or Lab Staff)

Oscilloscopes and Function Generators using the miniDSO

Oscilloscope

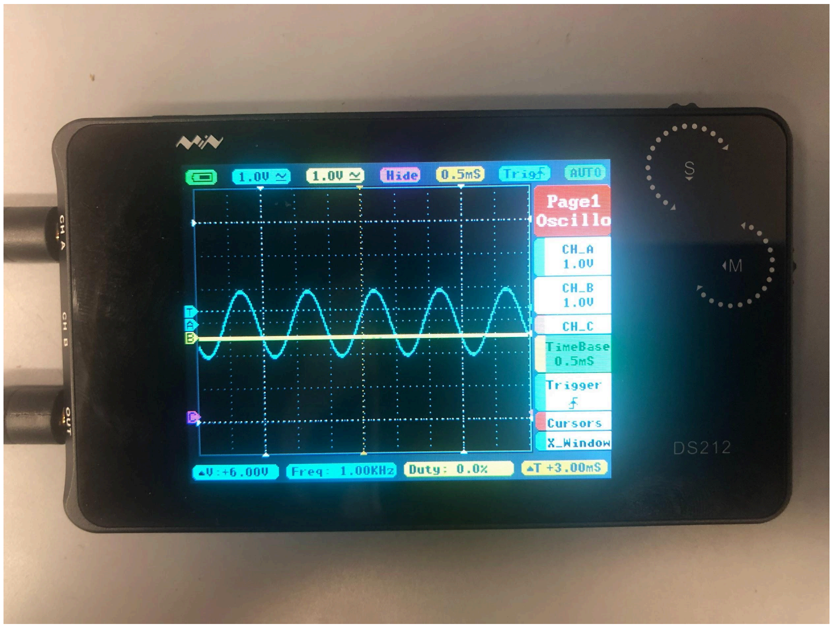
A multimeter is an appropriate device to measure DC voltages, however, when a signal alternates at relatively fast rates (3 Hz or greater), it becomes increasingly difficult to measure. For this purpose, an oscilloscope (shown below) is used. It displays data as a two-dimensional graph with time on the x-axis and voltage on the y-axis.

This lab is equipped with portable oscilloscopes using the Mini DSO DS212 digital storage oscilloscope. The device can also be used as a signal generator. A screenshot is given below. The display shows a sine wave across a graph made up of 10x10 squares.

The device has three ports on the left, CH A, and CH B for the oscilloscope, and OUT for the signal generator (see below) [which is usually connected to the input to your circuit], The on/off switch is on the top right, and two pushable scroll wheels are also there. On the right is a micro-USB port to charge the device.

- Press S to go through the three pages of menus.
- Turn S to adjust a selected menu item or setting of a selected menu item..
- Press M to review all the settings of a selected menu item. Press M again to get out of the settings list for that menu item.
- Turn M to scroll through menu items or settings for a selected menu item.

Confused? Play with it, or watch this video: https://www.youtube.com/watch?v=vkU56XWVLhw



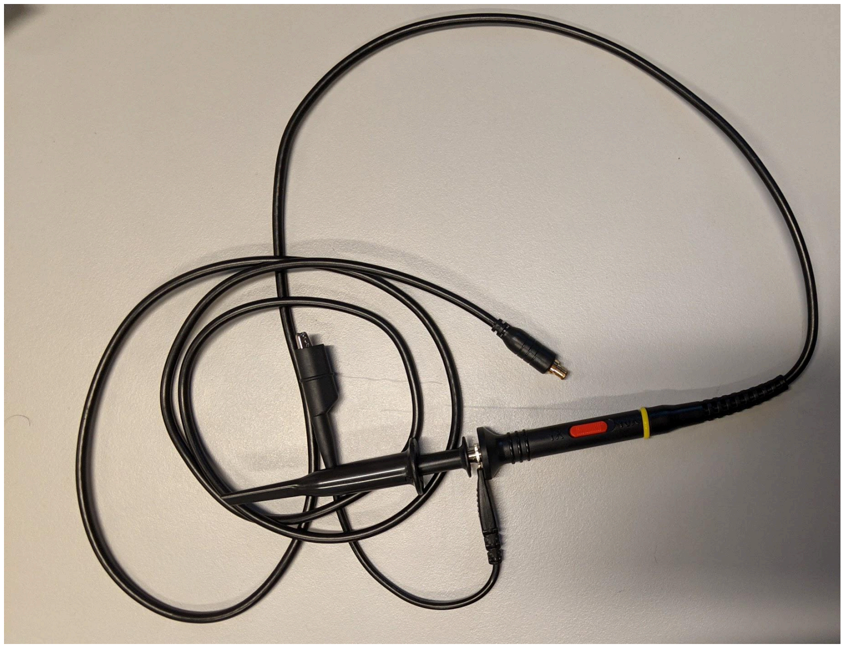
On the mini DSO, channel A and Channel B are the inputs of the oscilloscope. You can connect the probe to Channel A (see below)

Step 1: Attach black alligator cable, attach a gold tip to the probe, and screw on the connection cable.

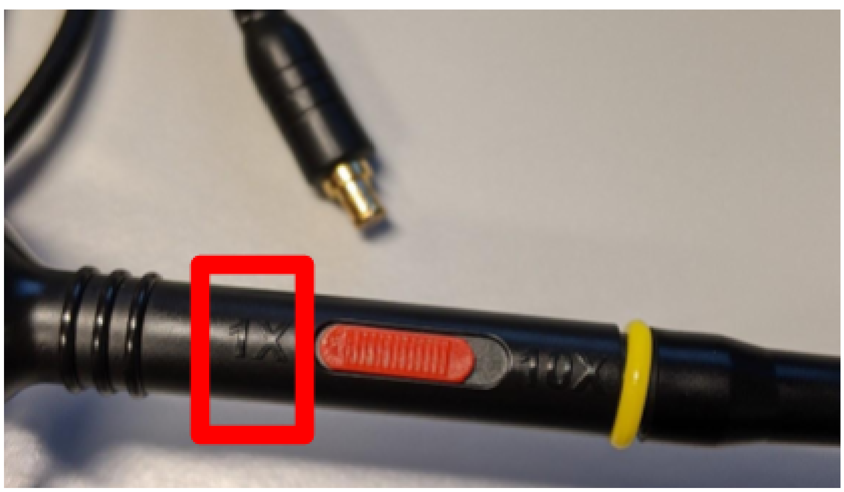
Step 2 (if needed): Make the tip of the probe **longer** (if you do not, the hook can't read the signal).

Step 3: Attach the black hook.

You may have received this probe instead:



In this case simply make sure that you set the probe to 1X as shown below



NOTE: The default coupling setting on the miniDSO is AC [This means that your signals baseline is subtracted to center the signal]. If you are interested in looking at a DC baseline you will need to change this setting to DC. Navigate to the Channel of interest (CH_A or CH_B) → Select with the M dial → scroll to AC/DC → Use the S dial to shift this

to DC → Confirm with the M dial. If you don't know what we're talking about when referring to AC and DC coupling, try doing an internet search.

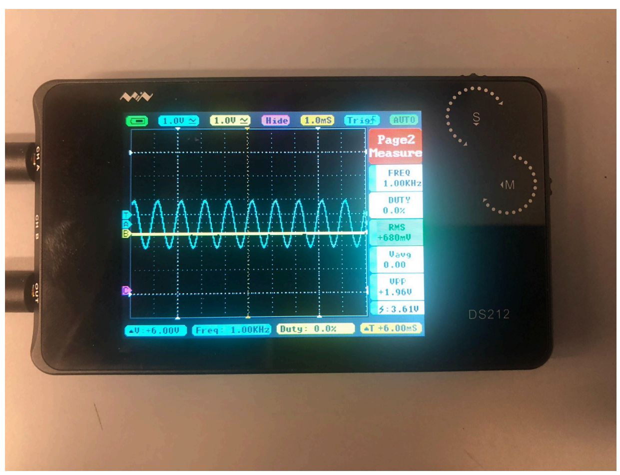
More details can be found on the Mini DSO DS212 Manual.

***IMPORTANT NOTES: Read carefully about how the 'S' and 'M' dials work.* Also, note that original settings are not retained between power cycles.**

This scope's time base is set to 0.5 ms per division, referring to the denomination of each square across the x-axis. You can use the M-dial to select TimeBase, and then use the S-dial tol modify the time base for both Channels A and B. Thus, if it were adjusted to 1 ms/div, twice as many cycles of the sine wave will be seen.

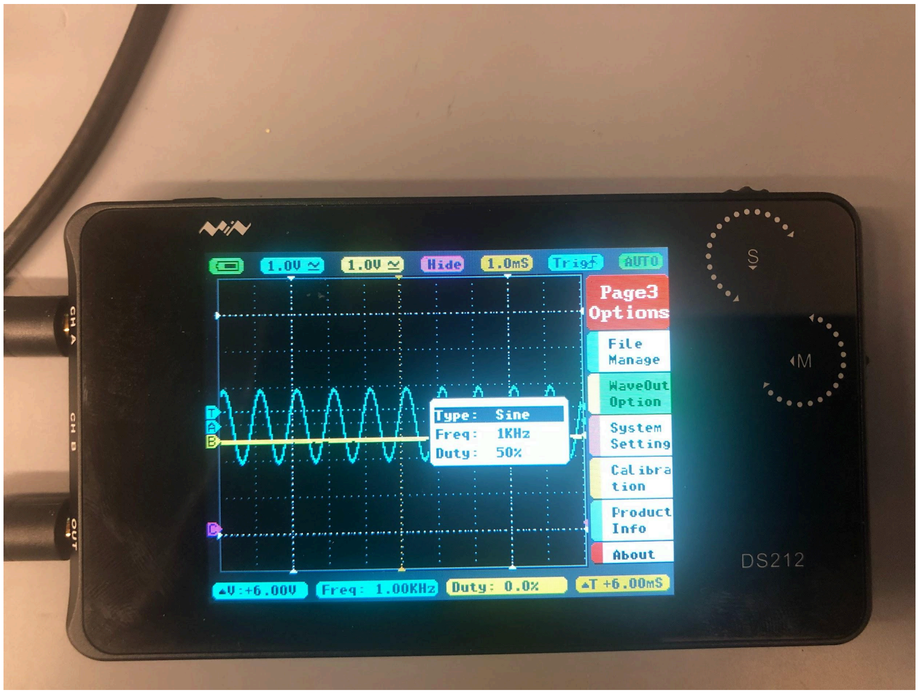
The magnitude of the signal is seen across the y-axis. The units can be seen with the CH_A or CH_B dial (on page 1). In this case, each square represents 1V.

By pressing down on the S dial in the top right corner of the device, you can move to Page 2 which is the measure page (see image below). You will be able to measure the frequency, RMS and peak-to-peak voltage (Vpp). When using the meters, make sure that at least one full period of the signal of interest is visible on the screen; otherwise the meter may not give the correct reading.



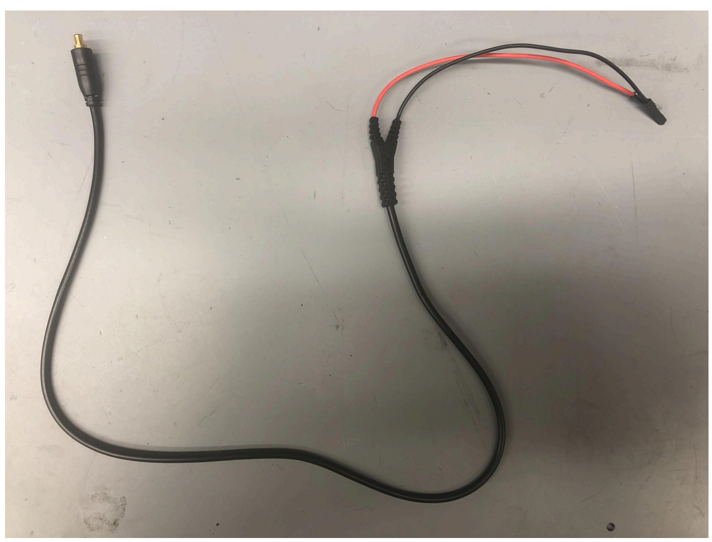
The Function Generator

A function generator (or signal generator) can be used to create oscillating signals. Most Signal generators produce Sine, Square, and sawtooth waves. This lab also uses the Mini DSO DS212 for the function generator:



On Page 3, under the WaveOut Options, you can adjust the type of waveform, frequency, and duty of the signal. Although you can set the frequency on the function generator (OUT port), measure it on the oscilloscope (CH_A and CH_B ports) to get the actual value.

On the mini DSO, the function generator's default output is the OUT port and the cable shown below is to be connected to said port.



The cable above should have the red mini alligator clip connected to the red female header and the black male mini alligator clip to the black female header. The black lead will be ground.

If you are still confused about how to operate the miniDSO please review this video

Complete the following:

1. Turn on the mini DSO.

2. Connect the red alligator clip from the OUT to the "hook" of the cable coming from the probe attached to CH A; connect the black alligator clip from OUT to the alligator clip of the probe.

3. Set the function generator to produce a 1 KHz sine wave from the Output channel of the miniDSO. Adjust the oscilloscope's Channel A, Scale (Volts) and Timebase (Time) to view two full periods on the oscilloscope screen. Demonstrate your working set up to an instructor, TA, or Lab Staff.

   Working set up? ______________ (Instructor, TA, or Lab Staff)

   Instructor: Make sure to see two full periods!

4. Switch Channel A's coupling (the setting **AC/DC:** in **CH_A**) from the default of **AC** to **DC.** You will see that the signal now moves completely above 0, rather than being centered around 0. Unfortunately, the signal generator on this device can only generate a positive 2 Vpp signal. AC coupling removes the 1 VDC component forcing the signal to look like it is centered around zero. DC coupling shows the actual signal.

5. Test out the oscilloscope's Cursor Settings and Display Measurements.

6. Design a circuit to reduce the gain of an input AC signal by one half (Gain = Vout/Vin). Draw out the circuit and label the input and output. Your input will be a sine wave generated by the function generator. Write out the values of the resistors (do not use resistors with values less than 1000 ohms).

7. Build your circuit. Input a 50 Hz 2 Vp-p sine wave and verify that your circuit is working. Use channel A to read the input signal and channel B to read the output signal. You may want to consider changing the post (the setting **Post** in **CH_A** and **CH_B**) to be the same value to see the full effect of the voltage divider. Demonstrate your working circuit to an instructor, TA, or Lab Staff.

Working circuit? _______________ (Instructor, TA, or Lab Staff)

Instructor: Make sure to see two signals, input and output and that it is set to DC coupling!

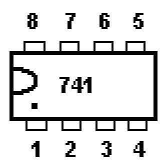
The Operational Amplifier (Op-Amp) using the miniDSO

Consider trying to interface two devices, one with output ranges from 0 to 10 Volts, and a second device that can only accept an input with a range of 0 to 1 Volts. By conditioning the signal we can alter the signal to produce such a signal. As you saw earlier, the simplest method of attenuating the signal would be through a simple voltage divider circuit. Since the divider uses only resistors, which are passive devices, the circuit will not affect the frequency of the signal.

Now, consider the inverse situation. If a device with an output of 0 to 1 Volt is supplied to a device with an input of 0 to 10 Volts, most likely information will be lost. To solve this problem, an amplifier circuit must be used. However, unlike a voltage divider, an amplifier will often make use of an operational amplifier IC (op-amp).

In order for the op-amp to operate, it needs to be powered using a DC supply voltage, normally indicated as V+ and V-, and oftentimes powered with a positive and negative DC signal (when using the batteries, this would be +9 and -9, respectively). The input signal is normally referred to as Vin, and the output signal as Vout.

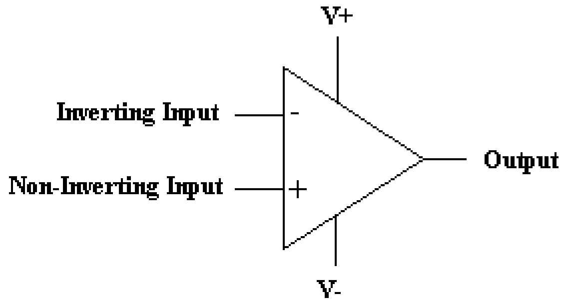
Here is a drawing of a typical op-amp, the LM741:



Here, the pins represent:

1. Offset Null
2. Inverting Input
3. Non-inverting input
4. Negative supply voltage (V-)
5. Offset Null
6. Output
7. Positive supply voltage (V+)
8. No Connection (NC)

Symbolically, it is represented as a triangle:

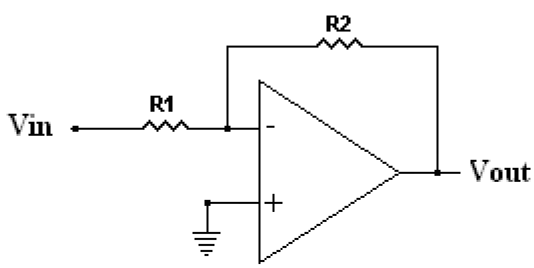


The following are important notes regarding an op-amp:[1]

- V+ and V- are the supply voltage for the op-amp. The output voltage cannot exceed the values for V+ and V-.
- The op-amp makes the voltage difference between the inverting and non-inverting inputs zero.
- The inputs do not draw any current.

Note that these rules are general assumptions made about an op-amp and are valid for most applications that make use of feedback.

A common configuration of an op-amp is as an inverting amplifier. Consider the circuit below:



The branch of the circuit with R_2 provides feedback to the input. Here, since the non-inverting input is 0 Volts, as it is tied to ground, the op-amp makes the inverting input 0 Volts also. Now, let us call the current through R_1 and R_2 as I_1 and I_2, respectively. Since the point where the R_2 connects to R_1 is 0 Volts, from Ohm's law, we know that:

$$I_1 = \frac{V_{in} - 0}{R_1}$$

[1] Paul Horowitz and Winfield Hill, *The Art of Electronics*, Second Edition (Cambridge: Cambridge University Press, 1994).

And

$$I_2 = \frac{V_{out} - 0}{R_2}$$

The current would flow from V_{in} and V_{out} to the inverting input, since its voltage is zero. Thus:

$$I_{inverting-input} = I_1 + I_2$$

However, since the inputs do not draw current, $I_{inverting\text{-}input}$ is equal to zero. Solving for V_{out}, we get:

$$V_{out} = -V_{in} \times \frac{R_2}{R_1}$$

In the case of an alternating signal, like a sine wave, the negative in the formula means that the signal is inverted, or is 180° out of phase.

Complete the following:

1. Design an amplifier circuit with a gain of -2 (Gain = Vout/Vin). **Draw out the circuit** using the triangle representation and label the input and output. Your input will be a sine wave generated by the function generator. Write out the values of the resistors (do not use resistors with values less than 1000 ohms). **In your circuit diagram, make sure to include the V+ and V- pins, and include all pin numbers.**

2. Set up your power supply - To obtain +9V and -9V, put battery connectors on your batteries. On a breadboard, connect the red wire of one battery connector to a power line and connect the corresponding black wire to a different power line. From the second battery connector, connect the red wire to the same power line as the black wire from the first battery connector and finally connect the remaining black wire to a new power line. This will create +9V, -9V and common ground.

   Note: *To help, you can connect the red wire from the first battery connector to the positive power line and the black wire from the second battery connector to the negative power line so you can keep track of your +9V and -9V power supplies.*

   Verify that the +9 and -9 Volt rails are working! How would you do that?

3. Build your circuit. Remember to connect the V+ and V- pins of your op-amp to the +9V and -9V terminals on the breadboard supplied with two 9V batteries, respectively (see 2 above). Input a 50 Hz 2 Vp-p sine wave and verify that your circuit is working. Use channel A of the miniDSO to read the input signal. Use channel B of the miniDSO to read the output signal. Make sure you can see both signals on your miniDSO. (you may want to make sure that both signals have the same post [the setting **Post** in **CH_A** and **CH_B**] to fully see the effect of your circuit). Demonstrate your working circuit to an instructor, TA, or Lab Staff.

   Working circuit? _______________ (Instructor, TA, or Lab Staff)

   Instructor: Make sure to see two signals, input and output.

Soldering

Review this tutorial on soldering and watch the two accompanying videos (total of 10 minutes). You can request headphone splitters if necessary.

Complete the following:

1. Solder a resistor onto the board.

2. Now, de-solder one of the resistors.