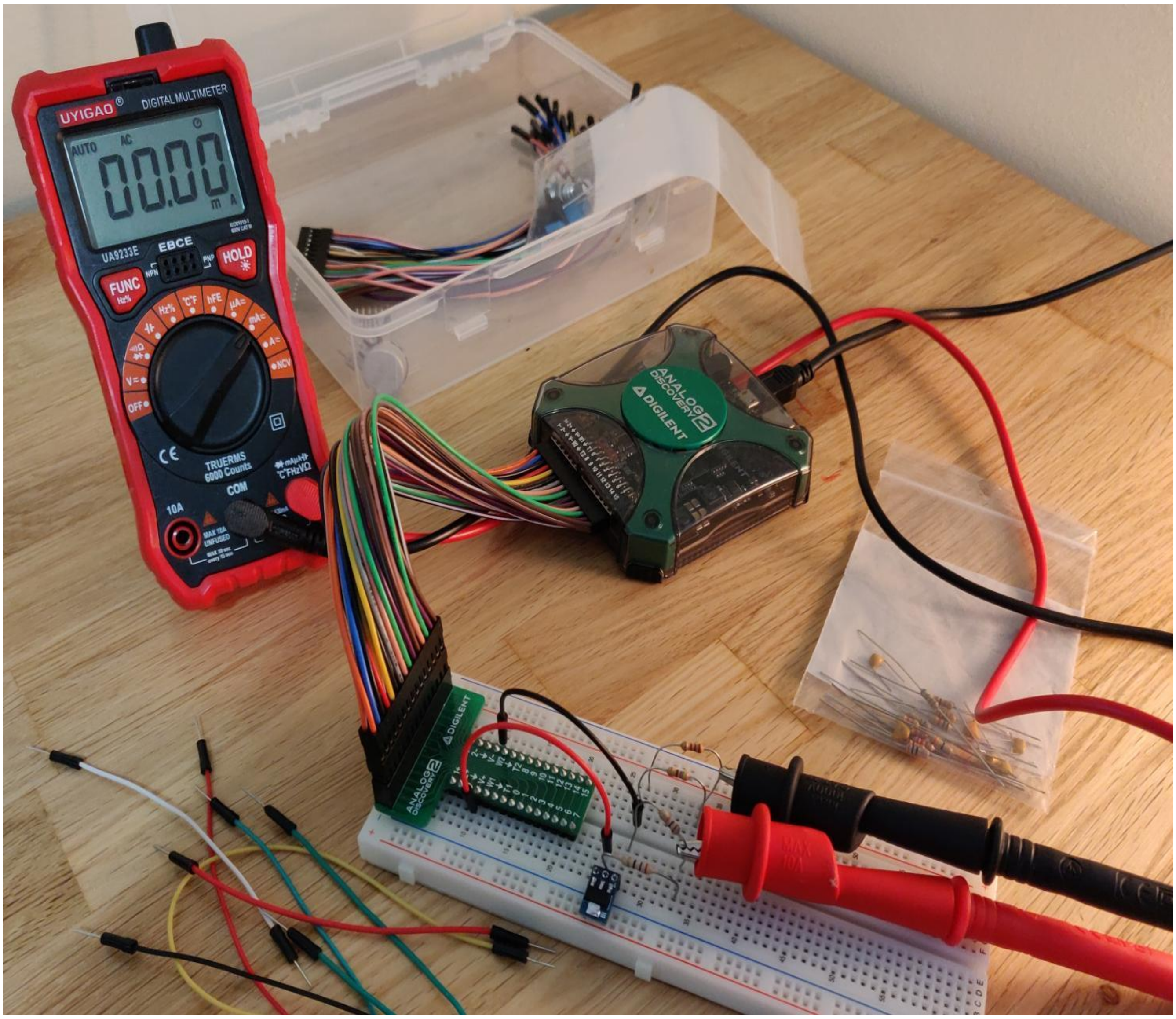
ECE202-Electrical Circuits-I
Electrical and Computer Engineering - University of Alberta



Lab 1 – Intro to DC Circuits

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1. Objectives

In this first lab session, you will become familiar with some of the common electrical tools and components used for circuits and use them to experimentally test and confirm the validity of concepts taught in the lectures. The objectives are as follows:

1. Introduce the following devices:
    - DC Voltage and DC Current Sources
    - Resistors and a Potentiometer
    - DC Voltmeter, DC Ammeter and an Ohmmeter
    - A Breadboard
2. Introduce the following concepts:
    - Ohm's Law
    - Power Dissipation of a Resistor
    - Kirchhoff's Laws - (KVL and KCL)
    - Series/Parallel Resistors
    - Voltage/Current Dividers
    - The Loading Effect - Voltmeter and Ammeter Loading

1.1 Instructions for ECE202 lab:

- Labs are typically completed in groups of two, so please try to pair up before coming to the lab. If you can't find a partner we will either pair you up in the lab or you may also be permitted to work by yourself. Only one lab report is required per group if you are working in a group, but please make sure to include the names, CCIDs, and student IDs of both students on the result sheet. Information regarding the due date of Lab 1 report submission is available on eClass lab schedule.

- Make sure you have either an electronic device with you where you can access this lab manual or print out the Lab 1 Manual before coming to your lab session.
- Lab 1 results sheet (available on lab eClass) to record your measurements during the lab session. **Everything in light blue on the results sheet is part of the post lab calculations.**

1.2 Equipment Required

- A Computer with Waveforms installed
- Analog Discovery 2
- Breadboard Breakout for the Analog Discovery 2 with a Ribbon Cable
- USB A to Micro-B cable
- Digital multimeter
- MB102 breadboard
- DC Current Source LM234Z (Data sheet of LM234Z)
- 1kΩ pot
- Jumper wires
- The following resistors (1/4 watt or 0.6 watt, 1% or 5%)
  - 10Ω
  - 3.6Ω
  - 100Ω
  - two 470Ω
  - 1kΩ
  - 4.7kΩ
  - two 10MΩ

1.3 Background

- Analog Discovery 2 QuickStart: YouTube Video Playlist
- The Basic of DC Circuit Theory
- Ohm's Law and Power
- Kirchhoff's Circuit Law
- Voltage Divider
- Current Divider

- Resistors
- Resistor Color Code
- Voltage Sources
- Current Sources
- Voltmeter Impact on Measured Circuit
- Ammeter Impact on Measured Circuit

(Please refer to the textbook to understand the above mentioned topics, website links provided here are just for reference.)

2. Procedures

2.1 Equipment Familiarization

2.1.1 Resistors

A resistor is a passive electrical component to create resistance in the flow of electric current. They can be found in almost all electrical networks and electronic circuits.

The unit of measure for resistance is Ohms (Ω) in the International System of Units (SI). The Ohm is the resistance of a conductor such that a constant current of one ampere in it produces a voltage of one volt between its ends.

Therefore the current is proportional to the voltage across the conductor's terminal ends. This ratio is represented by Ohm's law:

$$I = \frac{V}{R} \tag{1}$$

Where:

- I = the current through the conductor in amperes.
- V = the voltage across the conductor in volts.
- R = the resistance of the conductor in Ohms.

Resistors are used for many purposes. A few examples include to limit electric current, voltage division, heat generation, matching and loading circuits, control gain, and fix time constants. They are commercially available with resistance values over a range of more than nine orders of magnitude. Their size and power ratings vary greatly as they can be very large when used as electric brakes to dissipate kinetic energy from electric trains, or be smaller than a square millimeter for use in a smartphone.

More Information: [Wikipedia Resistor]

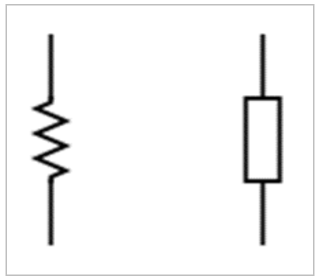
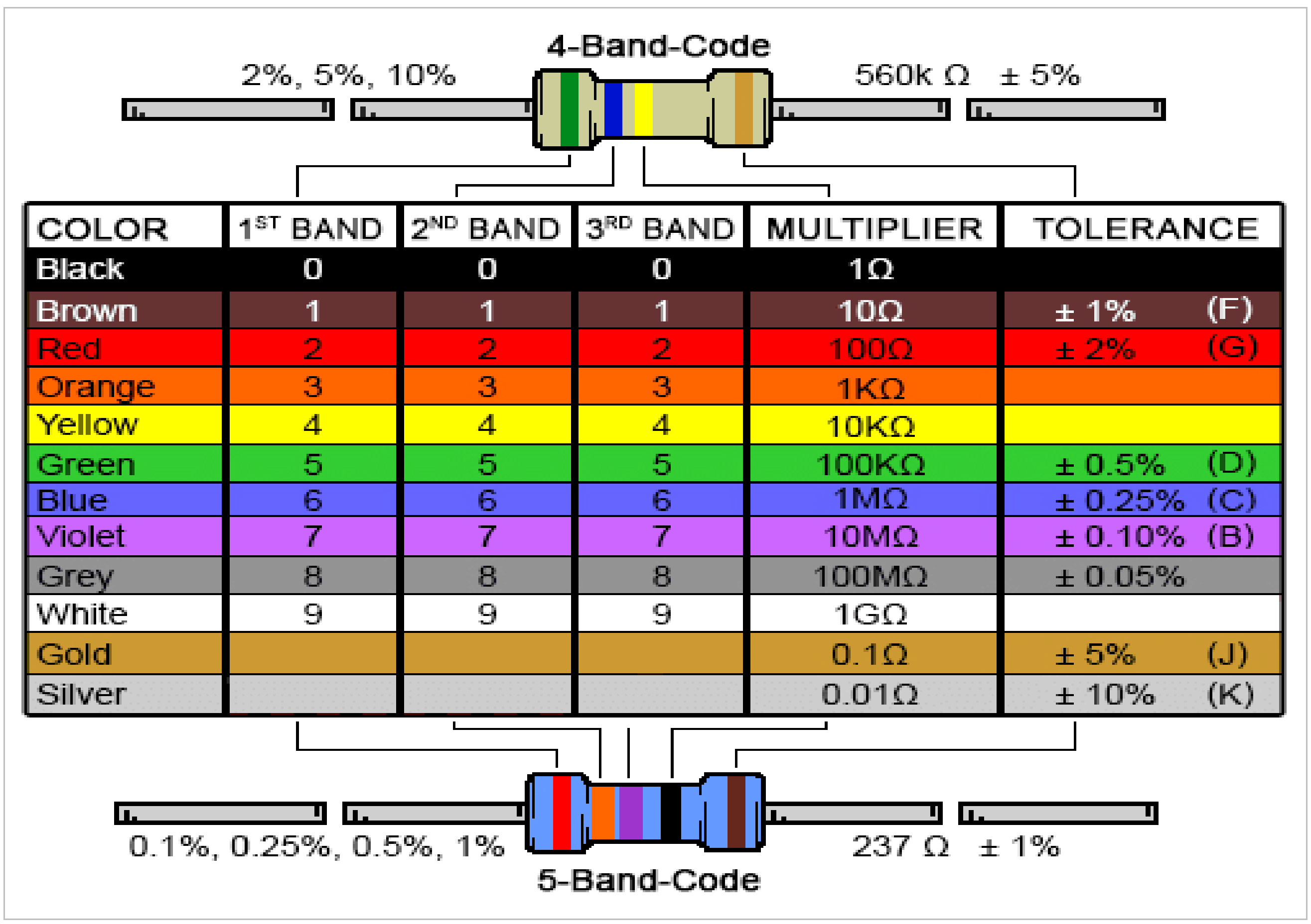


Figure 1: Fixed resistor schematic symbol (ANSI left, IEC right)



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Figure 2: Resistor color codes

Note:
The last band denotes the tolerance of the resistor which means that the actual resistance value can be slightly different then the rated one by that percentage over its operating temperature range.

2.1.2 Potentiometer

A potentiometer is a manually adjustable variable resistor with 3 terminals. The two outer terminals are connected to both ends of a resistive element, and the middle terminal connects to a sliding contact, called a wiper, moving over the resistive element. The resistive element can be seen as two resistors in series where the sum is the "potentiometer resistance rating", where the wiper position is the dividing point between the first resistor and the second resistor.

More Information: [Wikipedia Potentiometer]

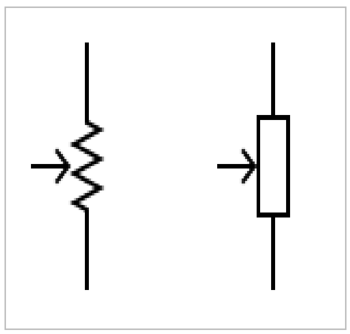


Figure 3: Potentiometer schematic symbol (ANSI left, IEC right)

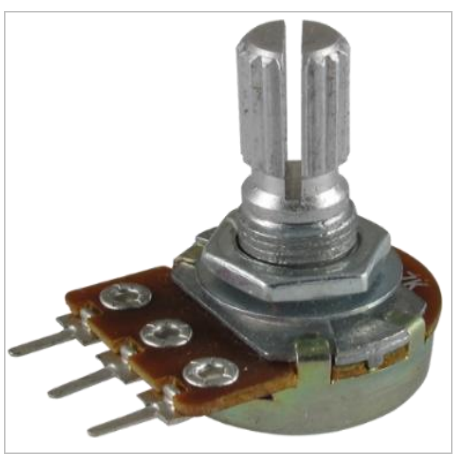


Figure 4: Potentiometer

2.1.3 Breadboard

A breadboard is a rectangular board with regular spaced holes for easily creating electrical connections between electronic components, a typical one is shown below. Due to the easy assembly of electrical connections these boards are mostly used to prototype circuits however they do have their limitations (i.e. higher frequency design). The connections aren't permanent and they can be removed and placed again and again.

The breadboard will be used to build the basic circuits used in these labs.

The vertical columns comprising of a pair of 5 interconnected holes are called terminals, while the 4 horizontal long rows are called power rails; these power rails are mostly used to connect the power supplies to the breadboard and are marked by red and blue lines in the image below and forming 4 separate groups of interconnected holes.

The reason it's called a breadboard dates back to when electronics components were much bigger and people would actually use wooden breadboards (boards used to cut bread) to connect electronic circuits. Fortunately, things have changed since then and only the name has been retained.

More Information: [Wikipedia Breadboard]

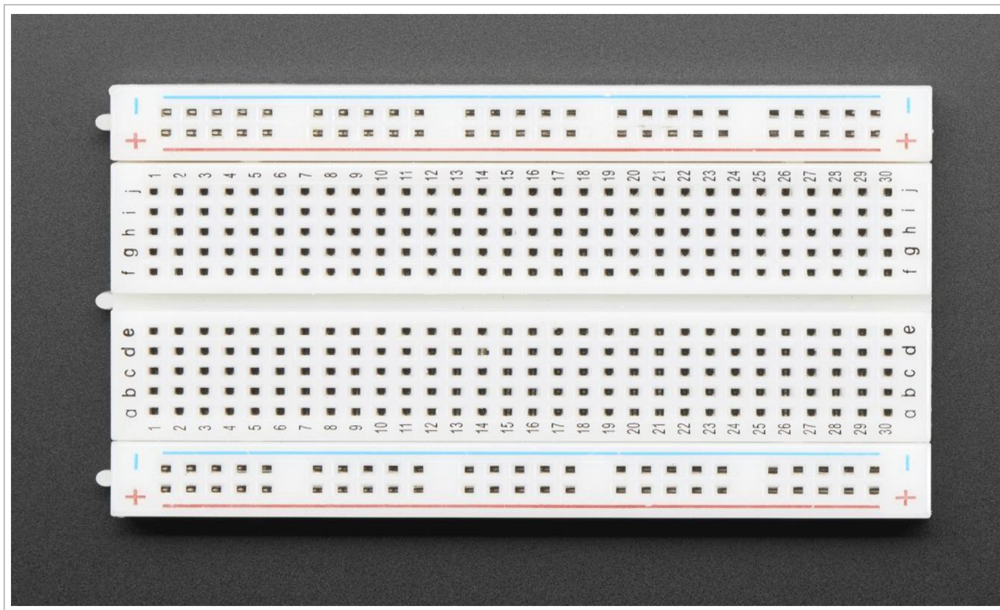


Figure 5: Anatomy of Breadboard

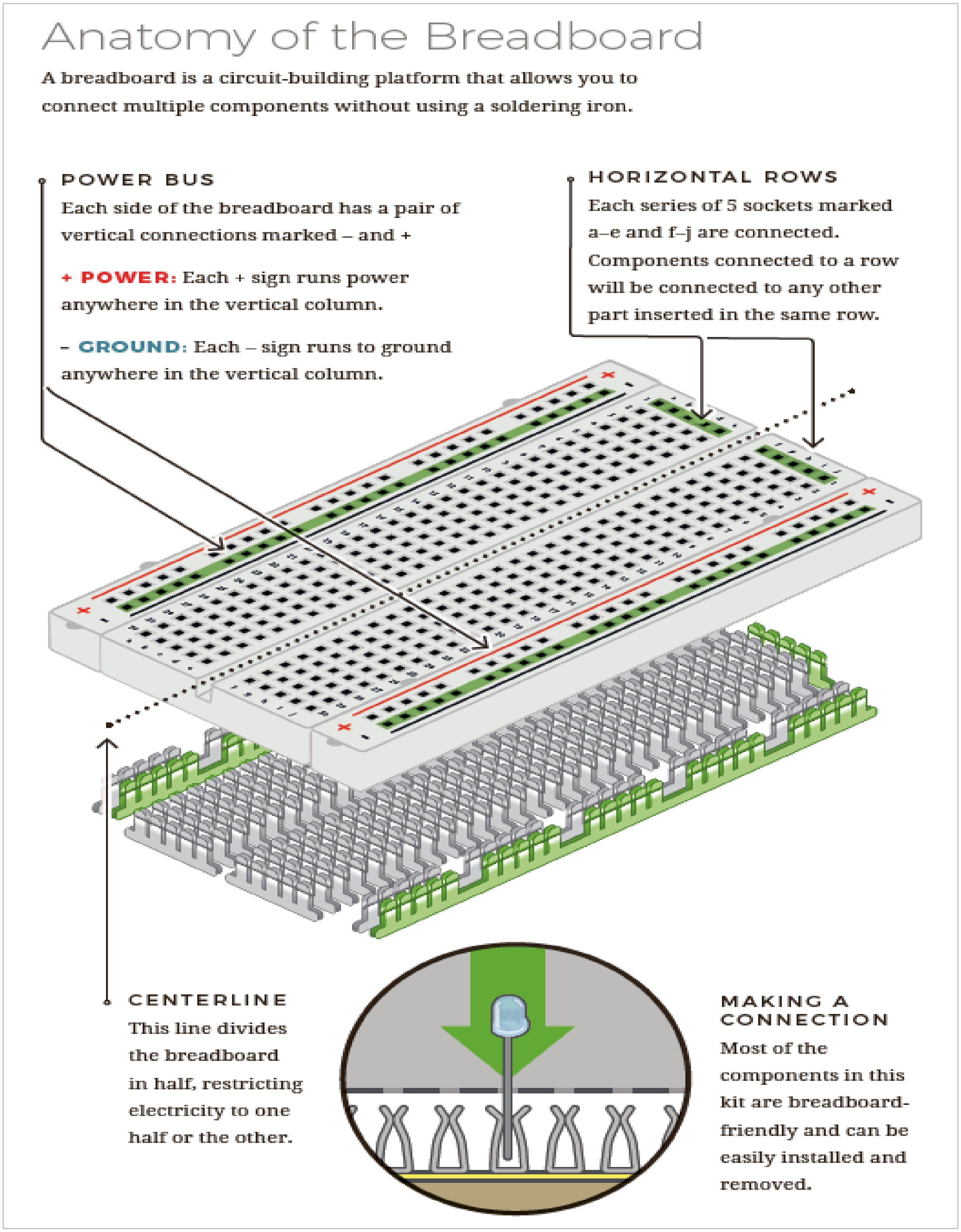


Figure 6: Typical Breadboard

If you haven't already. Please connect the metal plate to the back of the breadboard, this metal plate is there for 2 reasons: The first is to act as a backing for when you push components into the holes of the breadboard so they don't pierce the paper backing that is holding the metal contacts in place. The second is it acts as a shielding to prevent electrical noise from emitting or entering your circuits.

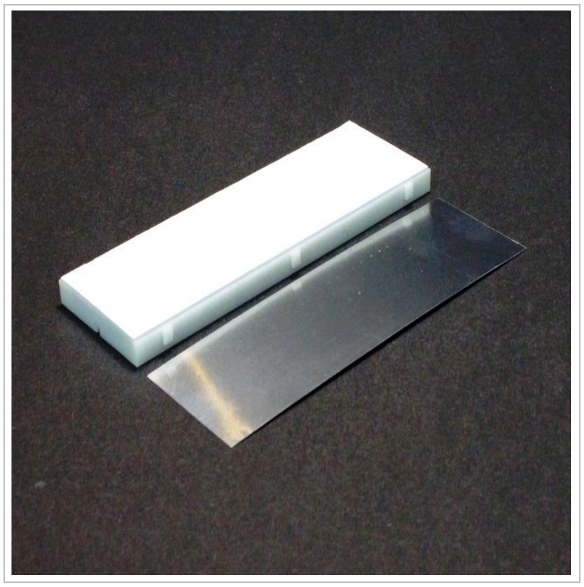


Figure 7: Breadboard without backing


Figure 8: Breadboard with backing

2.1.4 Analog Discovery 2

The Digilent Analog Discovery 2™, developed in conjunction with Analog Devices®, is a multi-function instrument that allows users to measure, visualize, generate, record, and control mixed signal analogue and digital circuits. The low-cost Analog Discovery 2 is small enough to fit in your pocket, but powerful enough to replace a stack of lab equipment, providing engineering students, hobbyists, and electronics enthusiasts the freedom to work with analogue and digital circuits in virtually any environment, in or out of the lab.

Intro to Analog Discovery 2

2.1.4.1 Software Installation

1. Install the required software Waveforms for your operating system. To install the waveform software on your PC, select the instructions listed below based on your computer's operating system.
    - Instructions for installing on Windows

- Instructions for installing on Mac
- Instructions for installing on Linux

Figure 9: Waveforms logo

Note: If you find any difficulties in installing waveform software, please click on this given link of Latest installer for all operating system page. This link directs you to Digilent page where you need to create a Digilent account. Once you do this it will direct you to download Waveform software page. So please download the software depends on your electronic device operating system.

2.1.4.2 Connections

2. Connect the Analog Discovery 2.
    a. Use the provided USB A to micro-B cable to connect your Analog Discovery 2 to the USB port on your computer.

Figure 10: Analog Discovery 2 connected to a computer

b. Connect the one end of the ribbon cable with the notch in the proper orientation to the Analog Discovery 2 as shown below. Then connect the other end of the ribbon cable to the [Breadboard Breakout]() using the supplied 15x2 header pins. Make sure that the orange wires of the ribbon cable end up on the same side as the breadboard breakout pin labeled 1+.

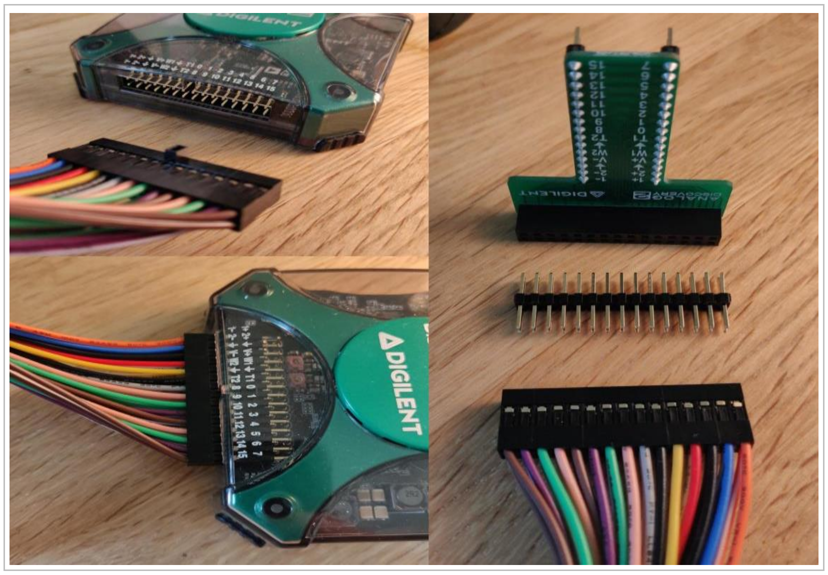


Figure 11: Connecting the breakout board to the Analog Discovery 2

c. Plug the breadboard breakout into the breadboard as shown.

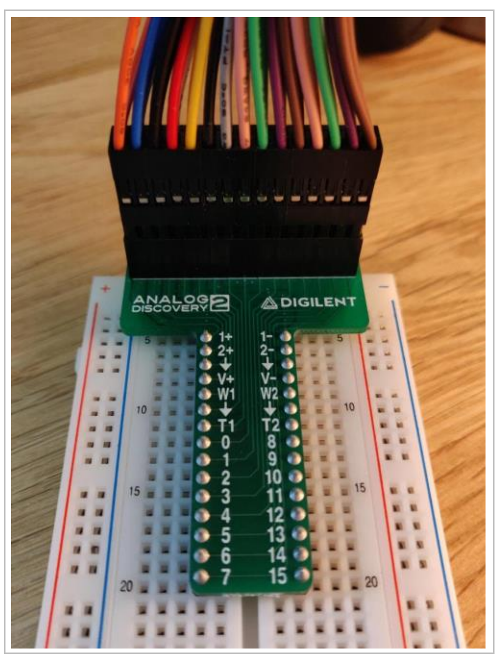


Figure 12: Breakout board connected to the breadboard

d. The connection of AD2, Breadboard breakout and ribbon cable looks as shown below.

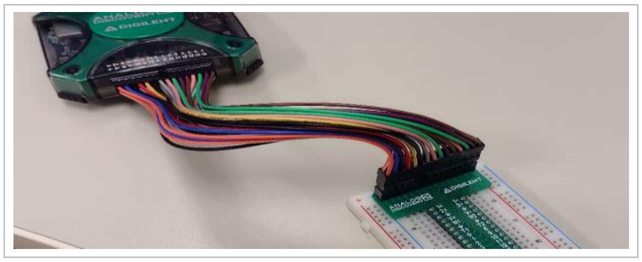


Figure 13: Connecting ribbon cable to breakout board and Analog discovery 2

2.1.4.3 DC Power supply

3. Use the DC Power Supply on the Analog Discovery 2.
   a. Start the 'Waveforms' software for the first time.

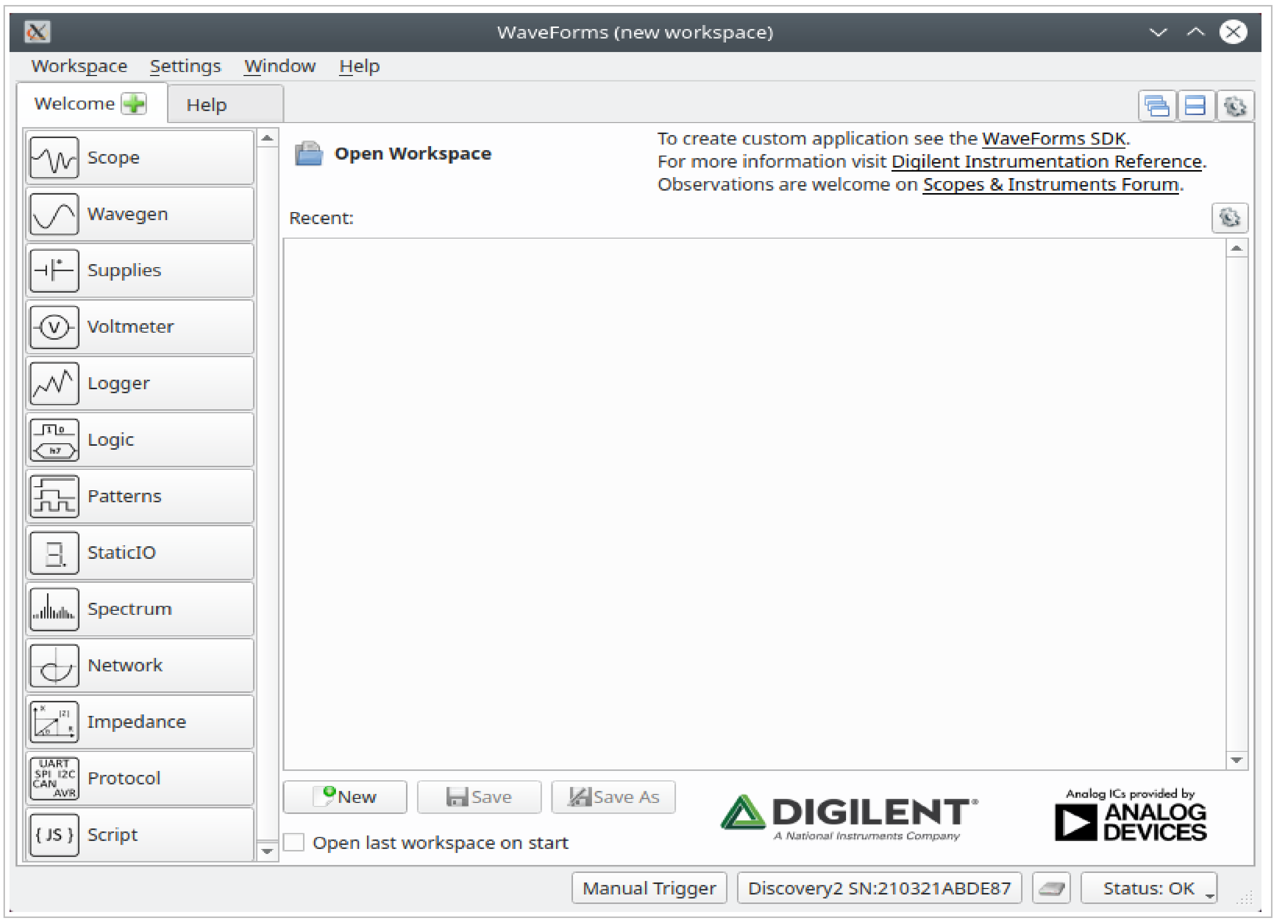


Figure 14: Waveforms start screen

   b. If everything is connected and installed correctly you should notice the device and serial number (SN:) in the bottom corner as well as the device status (OK).
   c. The first tab displayed should be the welcome screen. All of the available tools on the device are located along the left side of this tab. Click on the "Supplies" button and a new tab will open with the controls for the Supplies.

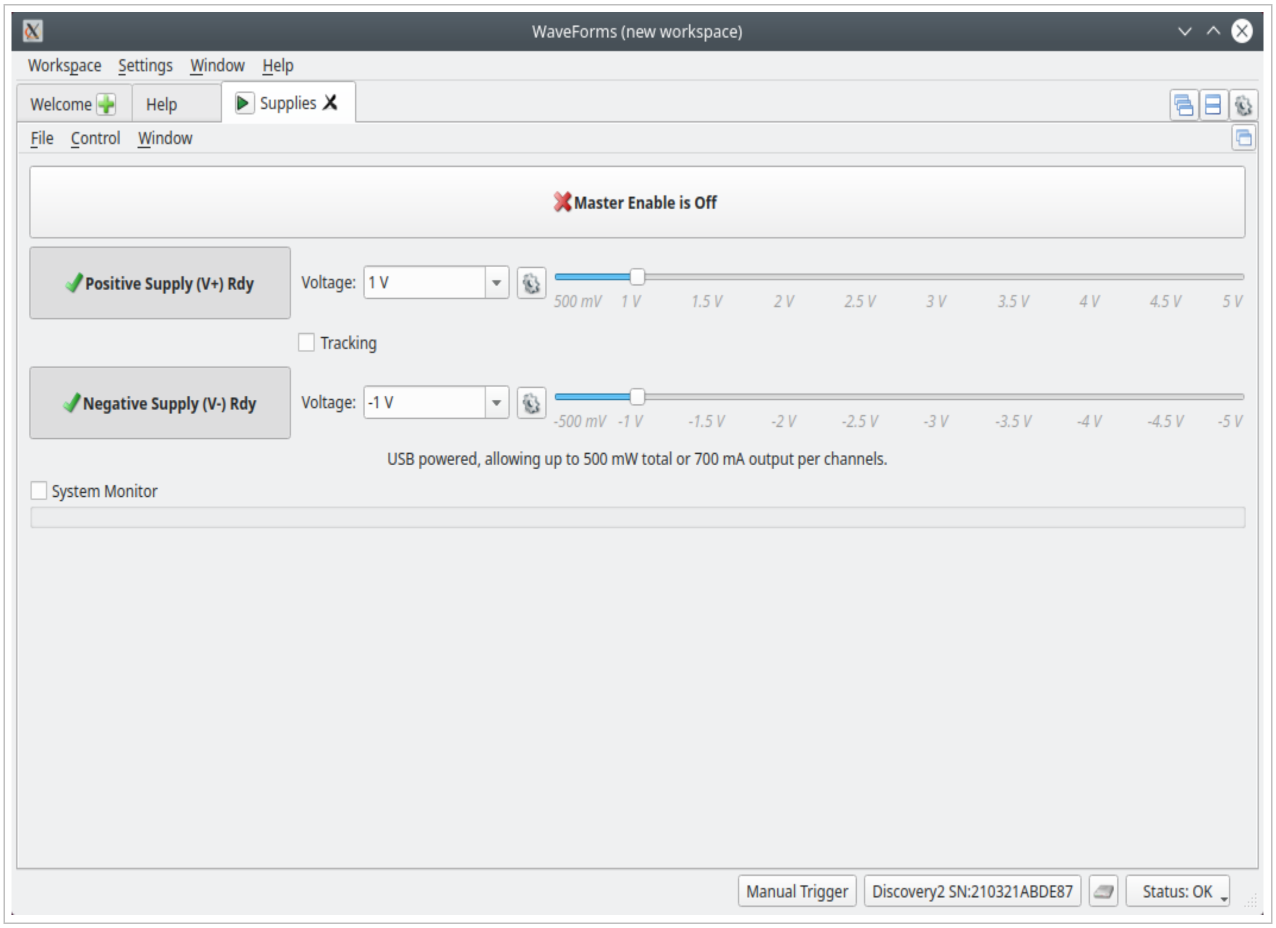


Figure 15: Waveforms DC power supply control screen

d. The Analog Discovery 2 is equipped with two DC power supplies: 1 positive supply and 1 negative supply.

- Both power supplies should currently be disabled as the "Master Enable is off".
- By clicking on the "Master Enable" both supplies will then output the corresponding voltage for that supply on its designated output pins: (V+ and Gnd/↓) and (V- and Gnd/↓) for the positive and negative supplies respectively.

Note:

On the Analog Discovery 2 they show the circuit ground or circuit common of the device with a down arrow (↓), it can also be abbreviated as Gnd. There are 4 of these on the Analog Discovery 2 and they are all a common ground node.

- Each supply has its own enable as well.
- To control the output voltage of the supply you can either use the drop down to select a voltage, type the number to 3 decimal places or use the slider. The positive V+ has a range from 500mv to 5.0V while the Negative V- is from -500mv to -5.0V

- There is also a “Tracking” checkbox, when this is enabled the positive and negative voltage will always have the same absolute value. In this mode you can use any of the controls to set both output voltages.

e. Go ahead and play with the Supplies controls to test them out to see how they function.

2.1.4.4 Voltmeter

4. Use the Voltmeter on the Analog Discovery 2 to measure the output of the voltage supply on the Analog Discovery 2

   a. Use 2 jumper wires to make the following connections on the breadboard.

   - V+ to 1+
   - Gnd/ ↓ to 1-

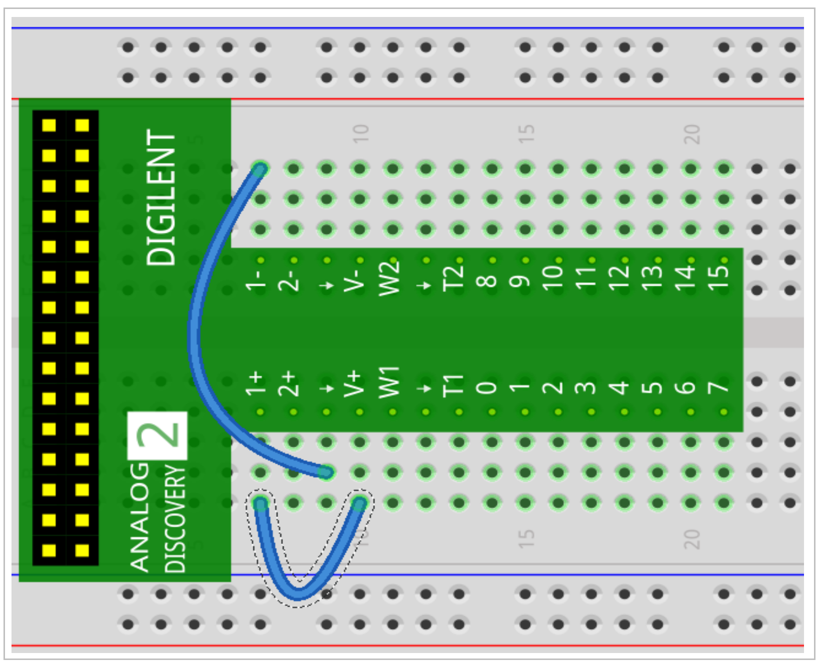


Figure 16: Breadboard connections to measure V+ on Channel 1

   b. From the Welcome screen start the “Voltmeter” tool to open the controls for the Voltmeter.

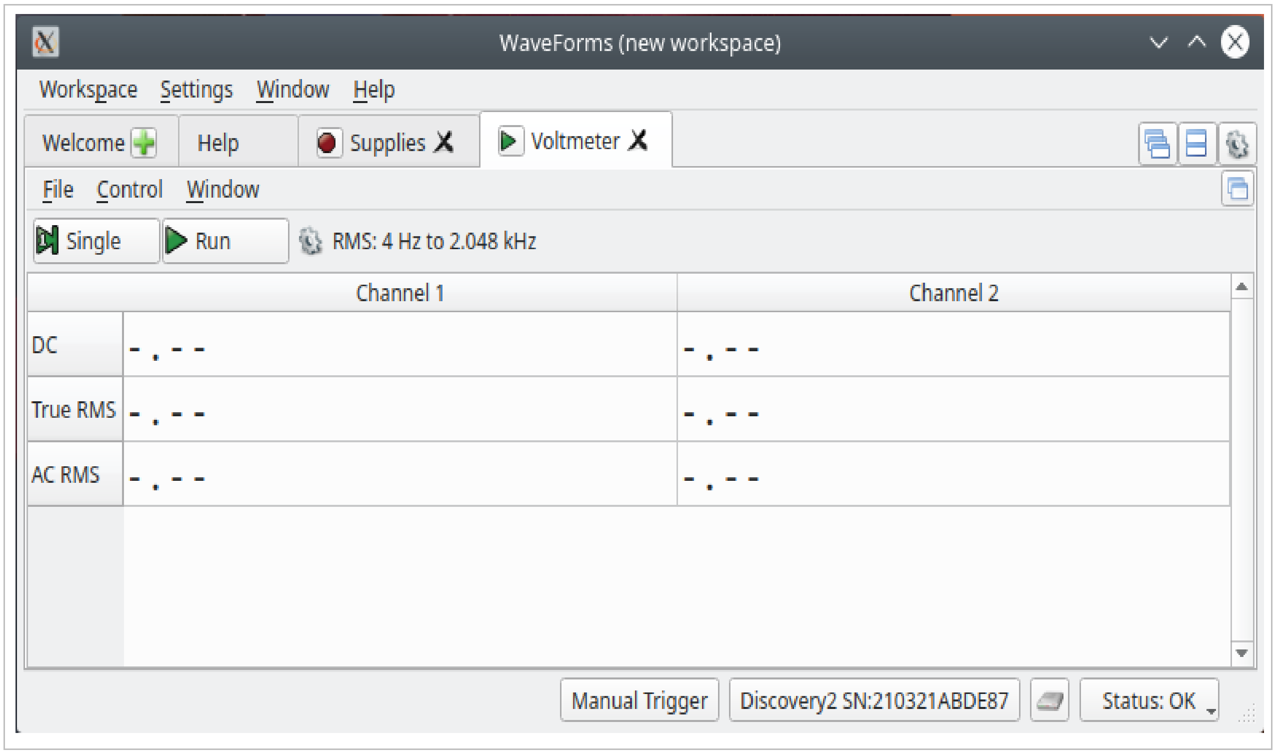


Figure 17: Waveforms voltmeter screen

c. The Analog Discovery 2 is equipped with 2 voltmeters: Channel 1 and Channel 2.

- Both voltmeters should currently be disabled as they are not running.
- By clicking on the "Run" button both voltmeters will then display the corresponding voltage that is currently measuring on its input pins: (1+ and 1-) and (2+ and 2-) for Channel 1 and Channel 2 respectively. The measurements are updated at a certain refresh rate continuously.
- Hitting the same button again, now "Stop", will stop the acquisitions.
- There is also a "Single" acquisition button that will acquire a single measurement and then stop on its own.
- With each acquisition there are 3 values that are calculated: DC, True RMS, AC RMS. The reading we will use for this lab is the DC reading. You will learn what the difference between these readings are later in this course.

d. Using both the "Supplies" and "Voltmeter" controls, see if you can generate a voltage using the positive supply and measure it using channel 1 of the voltmeter. Try changing the voltage and measuring again. Play with all of the "Supplies" and "Voltmeter" controls until you are familiar with them.

Note:
You can enable or disable a tool from the tab by clicking on the green triangle to enable and the red square to disable.

2.1.5 Digital Multimeter (DMM)

A digital multimeter is a test tool used to measure electrical quantities, principally: voltage (volts), current (amps) and resistance (Ohms). It is a standard diagnostic tool for engineers in the electrical/electronic industries.

Digital multimeters long ago replaced needle-based analog meters due to their ability to measure with greater accuracy, reliability and increased impedance.

Digital multimeters combine the testing capabilities of single-task meters; i.e. the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (Ohms). Often, they include several additional specialized features or advanced options. Engineers with specific needs, therefore, can seek out a model targeted to meet their needs.

The face of a digital multimeter typically includes four components:

- Display: Where measurement readouts can be viewed.
- Buttons: For selecting various functions; the options vary by model.
- Dial (or rotary switch): For selecting primary measurement values (volts, amps, Ohms).
- Input jacks: Where test leads are inserted.

Figure 18: A typical digital multimeter (DMM)

2.1.5.1 Resistance Measurement

5. Prepare the digital multimeter (DMM) to measure a resistor.
   a. If you haven't installed the battery in your DMM, please do this first. You will need an appropriate screwdriver to remove the back cover to install the provided 9V battery.

Figure 19: Placing a battery in the DMM

   b. Connect a red banana lead to the Ω input on the bottom right of the device.
   c. Connect a black banana lead to the COM input on the bottom of the device.
   d. Turn the meter on by rotating the control select knob to Ω (ohmmeter).
   e. When nothing is connected between the red and black banana leads it should display OL indicating an open circuit or infinite resistance.
   f. When you connect (short) the red and black test leads ends together it should display approximately 000.0 indicating a short circuit or zero resistance

Figure 20: Measuring zero ohms when test leads are shorted

g. Connect the red and black alligator clips to the appropriate test lead as this will make it easier to measure the resistances in the next part.

Figure 21. Alligator clips connecting to the test leads

6. Use the resistor color code chart above to find the resistance values in the chart below. Write the color bands required for each resistor value and write the colors on the results page. Then use the digital multimeter to measure the actual resistance value of each resistor and record it on your results sheet. To measure the resistance connect the red and black alligator clips to either end of the resistor. These are the resistors that you will use throughout this first lab so keep them handy.

Measure Resistance					
R1	**R2**	**R3**	**R4**	**R5**	**R6**
10	100	470	1k	4.7k	10M

Table 1: Measure Resistance Value

Figure 22: Measuring a 470Ω Resistor

7. Measure resistors in series.

Measure Series Resistors		
RS1	**RS2**	**RS3**
100+470	1k+4.7k	10M+10M

Table 2: Measure series resistors

a. Use the breadboard to place the resistors in the table above in series as shown in the image below.

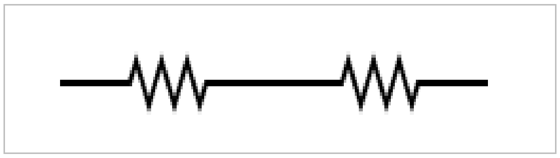


Figure 23: Resistors symbol connected in series

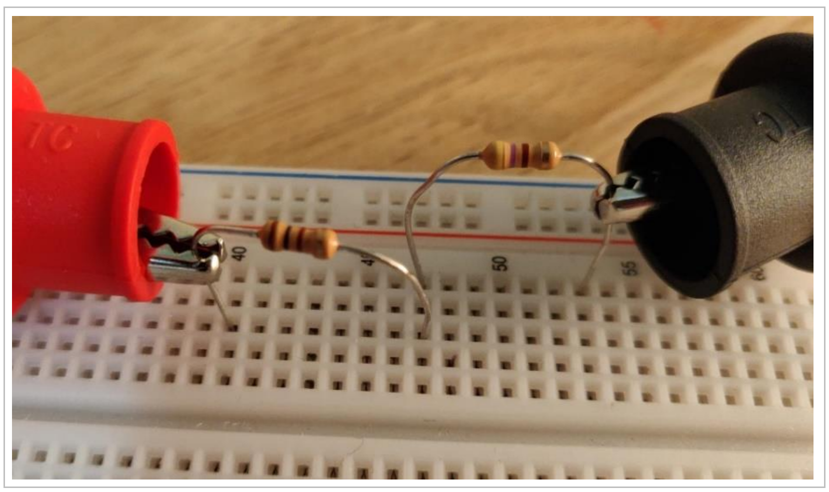


Figure 24: Series Resistors connected on a breadboard

b. Use the alligator clips on the leads of the resistors to measure the effective resistance of the two components in series and record your measurements on your result sheet.

8. Measure resistors in parallel.

Measure Parallel Resistors		
RP1	**RP2**	**RP3**
100 // 470	1k // 4.7k	10M // 10M

Table 3: Measure parallel resistors

a. Use the breadboard to place the resistors in the table above in parallel as shown in the image below.

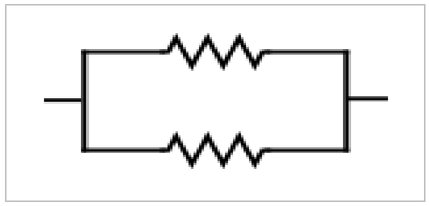


Figure 25: Resistors symbols connected in parallel

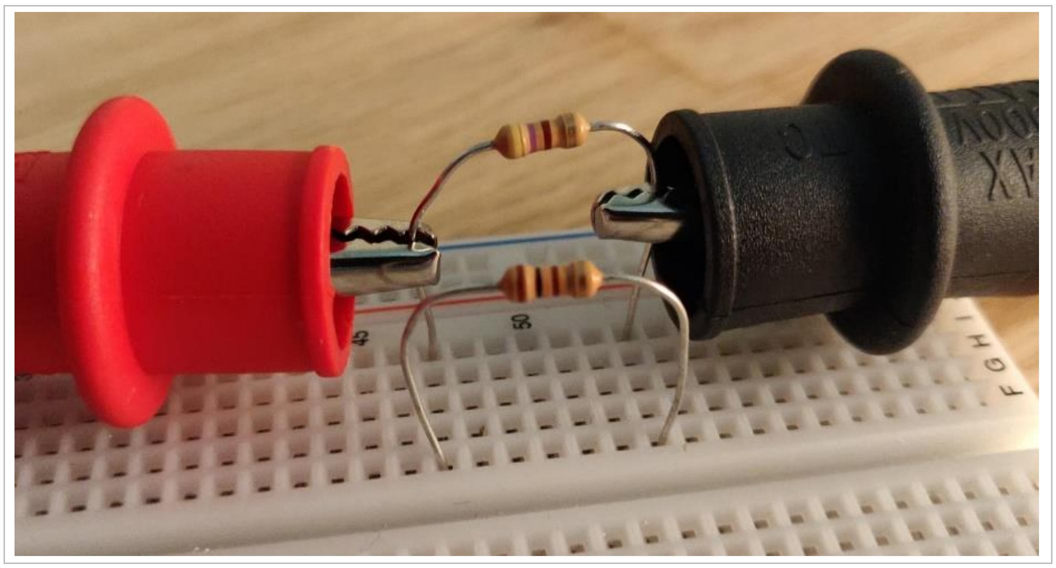


Figure 26: Parallel resistors connected on a breadboard

b. Use the alligator clips on the leads of the resistors to measure the effective resistance of the two components in parallel and record your measurements on your results sheet.

2.1.5.2 DC Voltage Measurement

Note:
An ideal voltmeter is an open circuit.

9. Use the digital multimeter (DMM) to measure a dc voltage.

   a. Prepare the DMM to measure a DC voltage.

      - Make sure the red banana lead is connected to the V input the bottom right of the device.
      - Make sure the black banana lead is connected to the COM input on the bottom of the device.

- Turn the meter on by rotating the control select knob to V (voltmeter).
- Press the function button (FUNC) until DC is selected at that top of the screen.

Figure 27: DC function indication on the DMM

b. Connect the DC voltmeter to the Analog Discovery 2 positive supply using either header pins or jumper wire:
   - Connect the red probe of the DMM to V+.
   - Connect the black probe of the DMM to Gnd (↓).

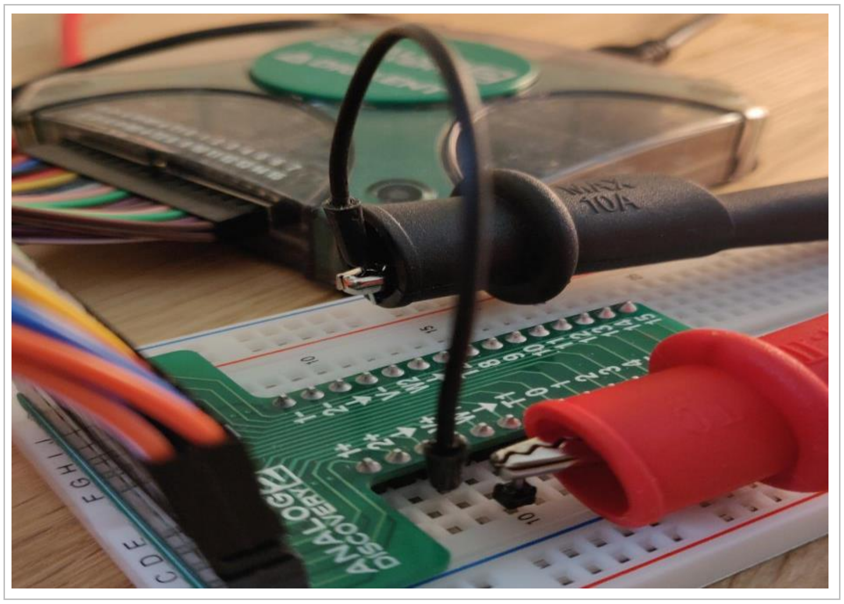


Figure 28: DC Voltmeter connected to the breadboard

c. Enable the positive supply in Waveforms, the output voltage should be displayed on the DMM. Now change the output voltage in Waveforms and make sure that your DMM is updated to correspond to this new setting.

d. Disable the voltage supply in Waveforms and the DMM should now read close to 0V.

e. Disconnect the DMM from the breadboard.

2.1.5.3 DC Current Measurement

Note:
An ideal ammeter is a short circuit.

10. This part just explains how to set up the DMM to measure a DC current. You won't actually measure a current here but you will use it in the next section.
    a. Prepare the DMM to measure a DC current.
        - Make sure the red banana lead is connected to the (mA) input at the bottom right of the device and the black to the COM input.

> **Note:**
> Most DMM's have multiple inputs for current so that different ranges of current can be measured accurately. This one has 2 separate inputs: One for larger currents that are less than 10 amps on the bottom left, and one on the bottom right for currents in the mA and µA ranges (internal fuse rated at 630 mA).
>
> 
>
>
> Figure 29: DMM current inputs (left = MAX 10A, Center = common, right = MAX 630mA)

- Turn the meter on by rotating the control select knob to mA (milliamps).
- Press the function button (FUNC) until DC is selected at that top of the screen

b. To measure a current with a multimeter you usually need to insert the meter in series with the device you wish to measure the current through as shown below.

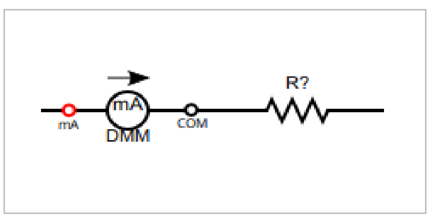


Figure 30: DMM current measurement connection (needs to be in series with component)

> **Note:**
> When altering a circuit, like when adding an ammeter, it is good practice to turn off any power applied to the circuit while the changes are being made.

2.2 Ohm's Law and Power

Ohm's Law

The current through a resistor in amps (A) is equal to the voltage across the resistor (V) divided by the resistance of the resistor R in Ohms (Ω):

$$I = \frac{V}{R} \tag{2}$$

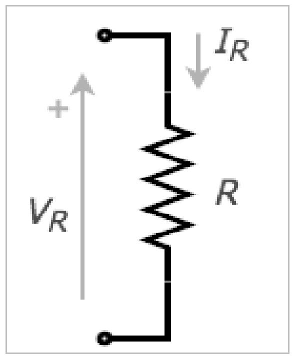


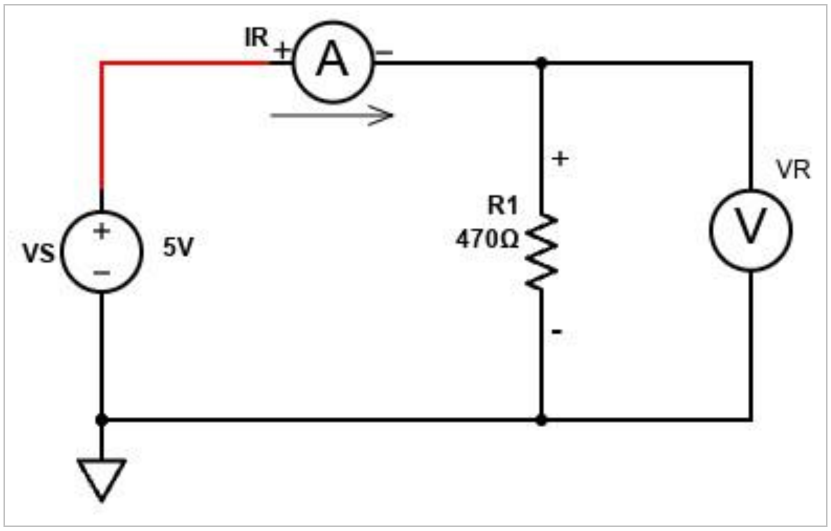
Figure 31: A Resistor (R) with its voltage and current polarity

Power Dissipated in Resistors

Any resistance in a circuit that has a current flowing through it dissipates power. This electrical power is converted into heat energy and this is why resistors have a power rating. This rating is the maximum power that can be dissipated from the resistor without it burning out. The rate at which the electrical energy is converted to heat is the power of dissipation.

$$P = I_R^2 \cdot R \tag{3}$$

11. Experiment with the concepts of both Ohm's Law and Power Dissipated in Resistors by connecting the circuit below and following the required procedures.



Circuit 1: Ohm's law circuit

a. Connect the circuit above using the following:

- Use the Positive DC Voltage Supply from the Analog Discovery 2 as **VS**. (V+ and Gnd/↓)
- Use the DMM as a milli-ammeter to measure **IR**. You might want to use alligator clips to connect the DMMs probes to the breadboard.
- Use the Voltmeter from the Analog Discovery 2 to measure **VR**. (1+ and 1-)

Tips: How to read schematic diagram of Ohm's law and connect the circuit

1. First of all start to connect the circuit form supply voltage.
2. Take a jumper wire and connect the one end of the jumper wire to the V+ on the breadboard breakout.
3. The other end of the jumper wire should go to the +Ve (red- mA) probe of the milliammeter (DMM). Use an alligator clip to secure the jumper wire in place.
4. Use another jumper wire to connect to the -Ve (black-COM) probe of the milliammeter (DMM) using an alligator clip. The other end of this jumper wire goes to one end of the 470Ωvresistor.
5. Take one more jumper wire and connect it between the remaining end of the 470Ω resistor and the Gnd (↓) on the breadboard.
6. To measure VR, use Channel 1 (+1 and -1) on the breadboard breakout. (You can use either channel 1 or 2 to measure VR.)
7. Attach a jumper wire to one end of the resistor and to +1 (channel 1) on the other end. Now connect a second jumper wire between -1 (channel 1) and the resistor's other end.
8. Your circuit is now complete.

> **Note:**
> - To measure voltage, connect two terminals of voltmeter across the component.
> - To measure current, the DMM, which we are using as a milliammeter, must be connected in series with the circuit.

- At first use a 470Ω resistor for **R1** and then change this resistor when required to either the 1.0kΩ or the 4.7kΩ.

b. It should look something like this when completed.

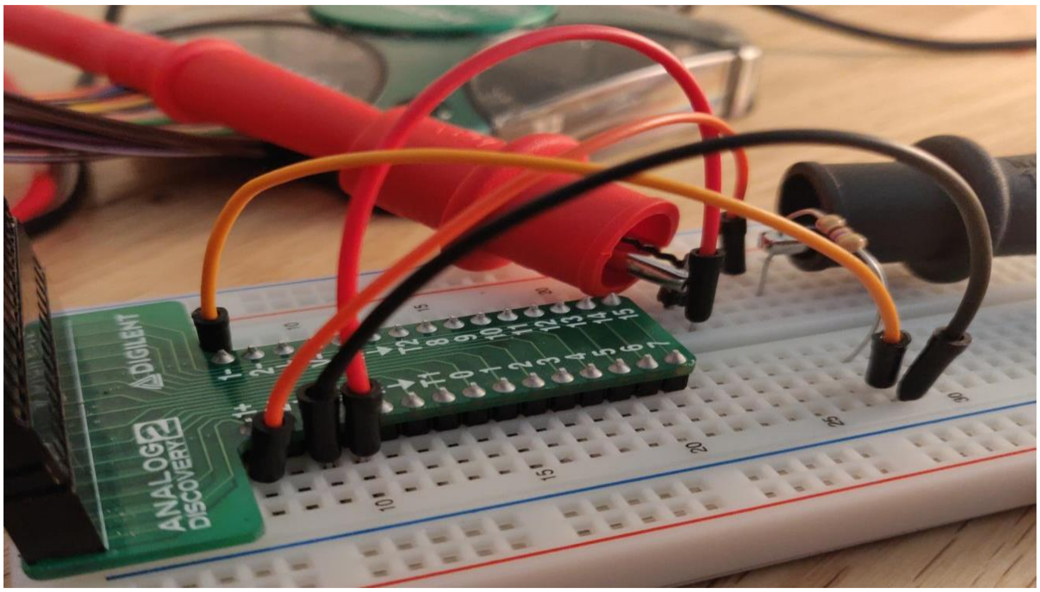


Figure 32: Ohm's law circuit shown on board

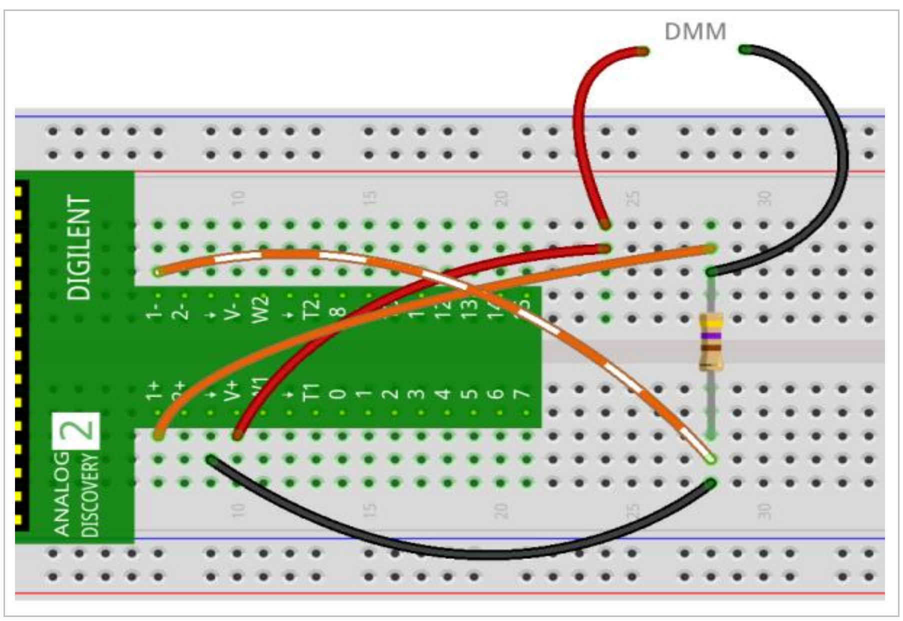


Figure 33: Ohm's law circuit (same as breadboard)

> **Note:**
>
> Please connect the circuit by understating the circuit diagram. Please don't blindly follow the breadboard images to connect your circuit. As from lab 2 there will be no bread board pictures available in the lab manual.

c. Turn on the Analog Discovery 2 positive voltage source and adjust it to 5V.

d. Measure and record on your results sheet the current through and the voltage across the resistor with the following voltages applied. (5V, 3.5V, 1V, 0V, -2.5V, -5V)

- For 0V simply disable the voltage supply.
- For the negative voltages move the one end of the jumper wire that connects to the V+ output of the Analog Discovery 2 to the V- output and use the negative supply controls in Waveforms to adjust the voltage

> **Note:**
> Both the voltage and current should be positive when you apply a positive voltage and both should be negative when you supply a negative voltage. If this is not the case you need to interchange the leads either on the DMM or the voltmeter so the correct sign is displayed.

e. Try replacing the resistor with first a 1.0kΩ and then a 4.7kΩ and repeat the same measurements as above for each resistor making sure to record your results.

f. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage sources and disconnect the circuit.

2.3 Voltage Divider

Kirchhoff's Voltage Law

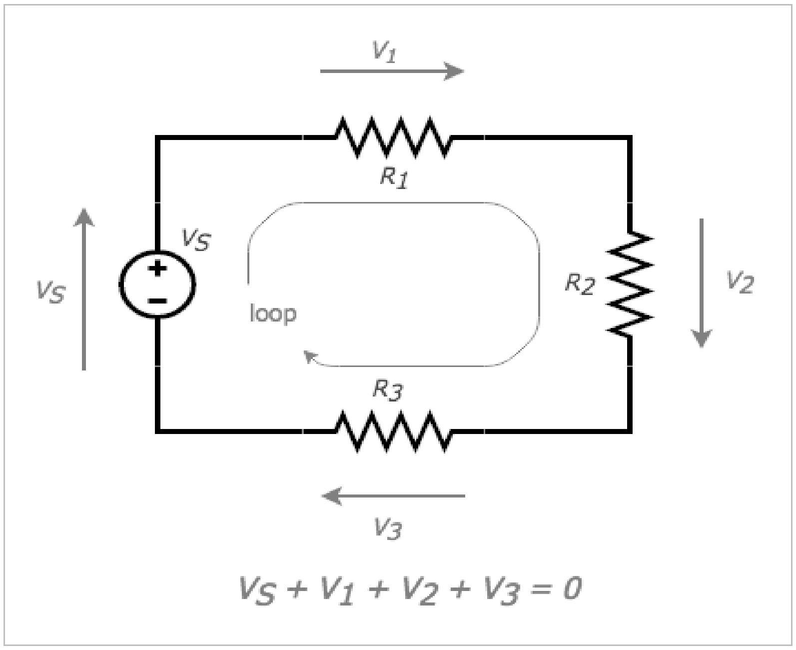


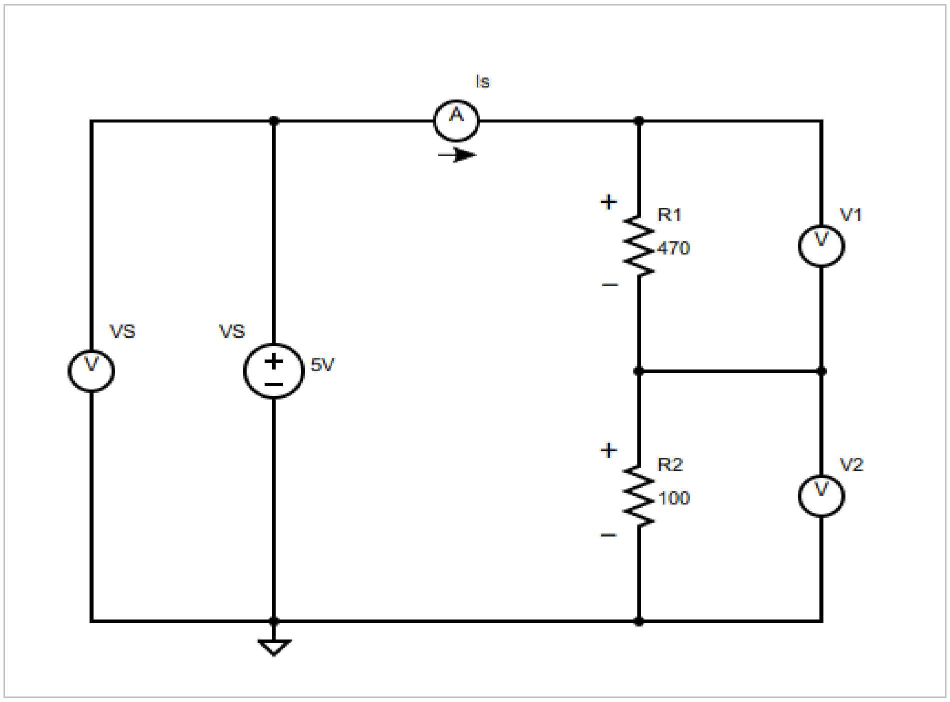
Figure 34: Kirchhoff's voltage law (KVL)

Kirchhoff's Voltage Law (KVL) is one of his fundamental laws we can use for circuit analysis. His voltage Law states that for a closed loop series path the algebraic sum of all the voltages around any closed loop in a circuit is equal to zero. This is because a circuit loop is a closed conducting path so no energy is lost.

In other words the algebraic sum of ALL the potential differences around the loop must be equal to zero as: **ΣV=0**. Note here that the term "algebraic sum" means to take into account the polarities and signs of the sources and voltage drops around the loop.

This idea by Kirchhoff is commonly known as the Conservation of Energy, as moving around a closed loop, or circuit, you will end up back to where you started in the circuit and therefore back to the same initial potential with no loss of voltage around the loop. Hence any voltage drops around the loop must be equal to any voltage sources met along the way.

12. Experiment with Kirchhoff's Voltage Law by connecting the circuit below and following the required procedures.



Circuit 2: Voltage divider circuit

a. Connect the circuit above using the following:
   - Use the positive DC voltage supply from the Analog Discovery 2 as **VS**. (V+ and Gnd/↓)
   - Use voltmeter channels 1 and 2 from the Analog Discovery 2 to measure VS and V1 respectively. Use channel 1 to measure V2 as well, you will need to move the channel 1 wires back and forth when required depending on which measurement is needed.
   - Use the DMM as a milli-ammeter to measure IS. You might want to use header pins to connect the DMM probes to the breadboard.
   - Use a 470Ω resistor for R1.
   - At first, use a 100Ω resistor for R2 and change this resistor when required to either a 470Ω, 1.0kΩ or 4.7kΩ.

b. It should look something like this when completed.

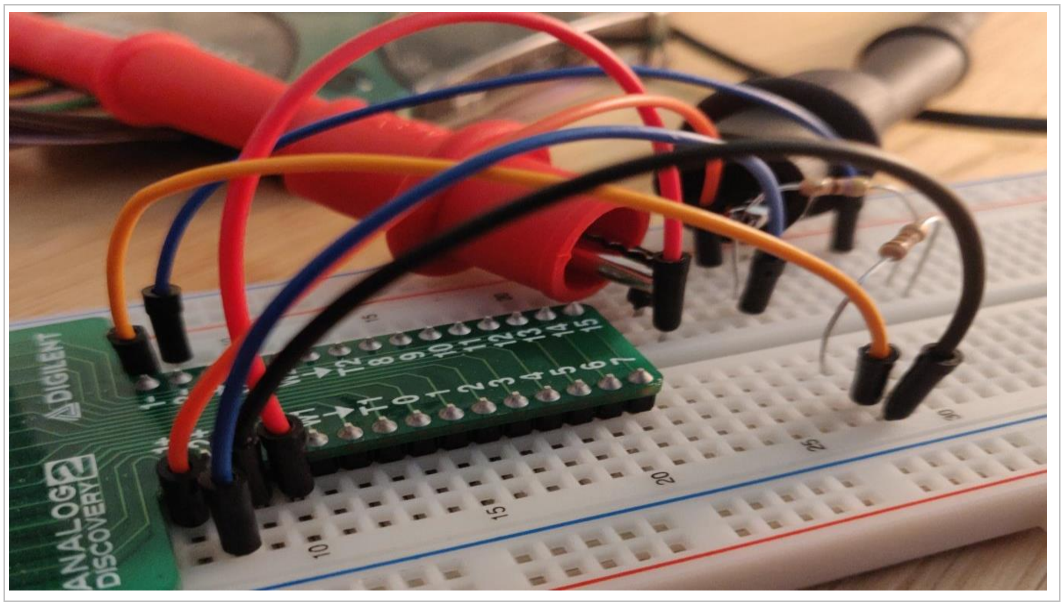


Figure 35: Voltage divider circuit shown on breadboard

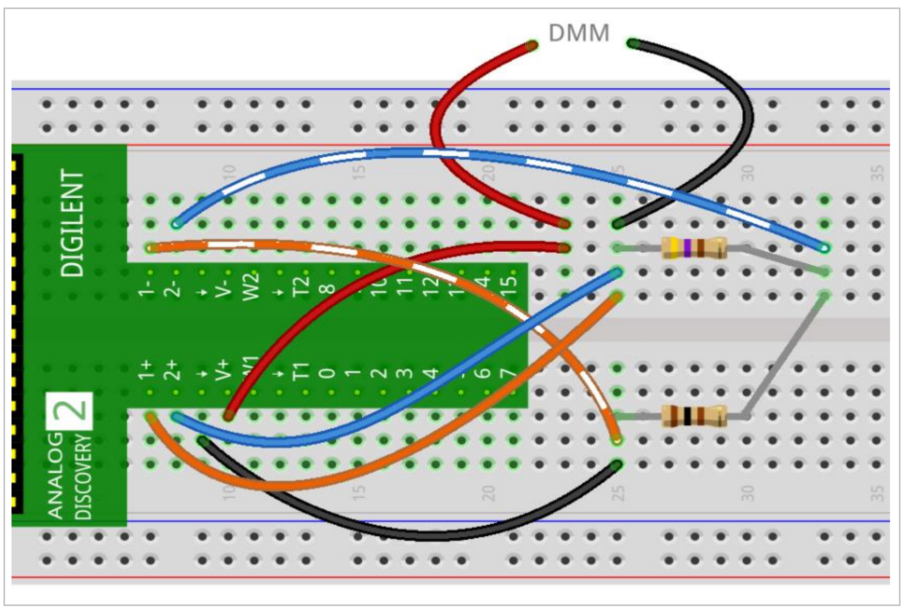


Figure 36: Voltage divider circuit (same as breadboard)

c. Turn on the Analog Discovery 2 positive voltage source and adjust it to 5V.

d. Measure and record the current through (IS) and the 3 voltages: the source voltage (VS), across resistor R1 (V1) and across resistor R2 (V2).

e. Replace the resistor (R2), first with a 470Ω resistor followed by a 1kΩ & 4.7kΩ resistor and repeat the same measurements as above making sure to record your results.

f. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage sources and disconnect the circuit.

2.4 Current Divider

Kirchhoff's Current Law

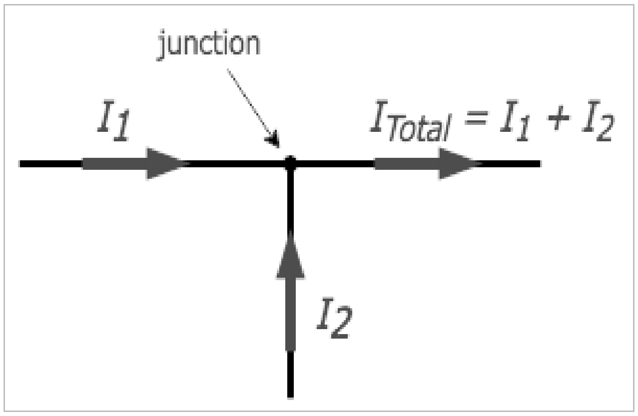


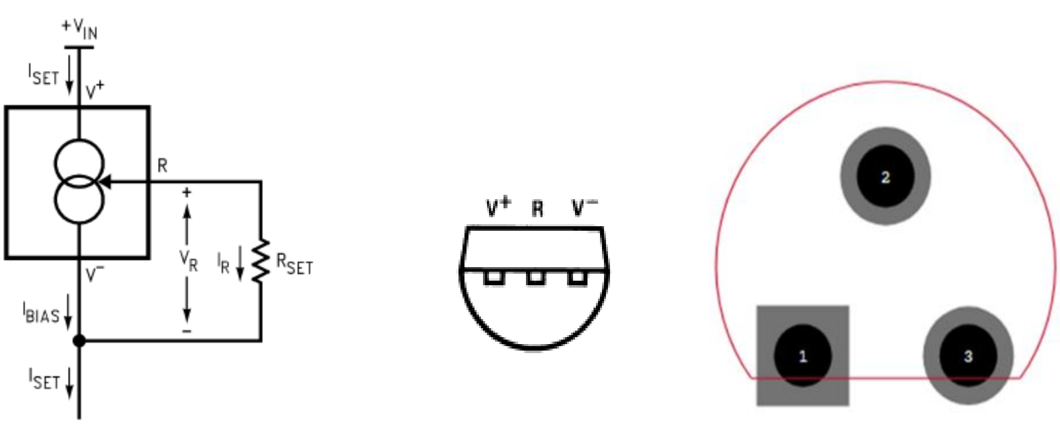
Figure 37: Kirchhoff's current law

Kirchhoff's Current Law (KCL) is another one of the fundamental laws used for circuit analysis. His current law states that for a parallel path the total current entering a circuit's junction is exactly equal to the total current leaving the same junction. This is because it has no other place to go as no charge is lost.

In other words the algebraic sum of ALL the currents entering and leaving a junction must be equal to zero as: $\mathbf{\Sigma I_{IN} = \Sigma I_{OUT}}$.

This idea by Kirchhoff is commonly known as the Conservation of Charge, as the current is conserved around the junction with no loss of current.

13. Test the current source by connecting the circuit below and following the required procedure.



$I_{SET} = 67.7mV/R_{SET}$ (@25˚C)

Figure 38:LM234Z (Left: as a basic current source, Middle: bottom view, Right: foot print)

a. Configure the LM234Z on the breadboard as a 5mA current source using the following:

- The LM234Z current source. (To get more information please go through datasheet given in section 1.2)

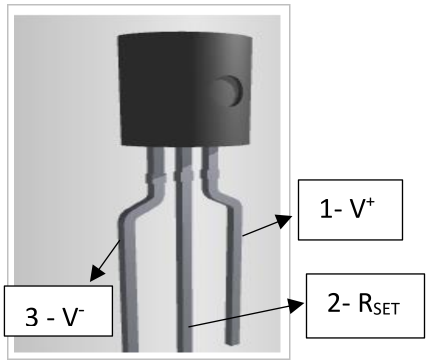


Figure 39: LM234Z current source 3D model

- Connect terminal 1 (V^+) of LM234Z to V+ of the Analog Discovery 2.
- Connect a 13.6 Ω (10 Ω +3.6 Ω) resistor as R_{SET} at the middle terminal of the LM234Z. (To get a 13.6Ω resistor, you need to connect 10Ω and 3.6Ω resistors in series as shown in figure 40.)
- As indicated in figure 40, the other end of the 13.6 Ω (10 Ω +3.6 Ω) resistor (R_{SET}) and terminal 3(V^-) must be connected together with the use of the jumper wires.
- Connect the red probe of the DMM configured as a milli-ammeter to the I_{SET} point in the diagram above. Connect the black probe of the DMM to the V- of the analog discovery2.

b. Your circuit should look something like this when completed. Make sure to connect the current source as shown in figure 40. If you connect it incorrectly, it gives you wrong current value.

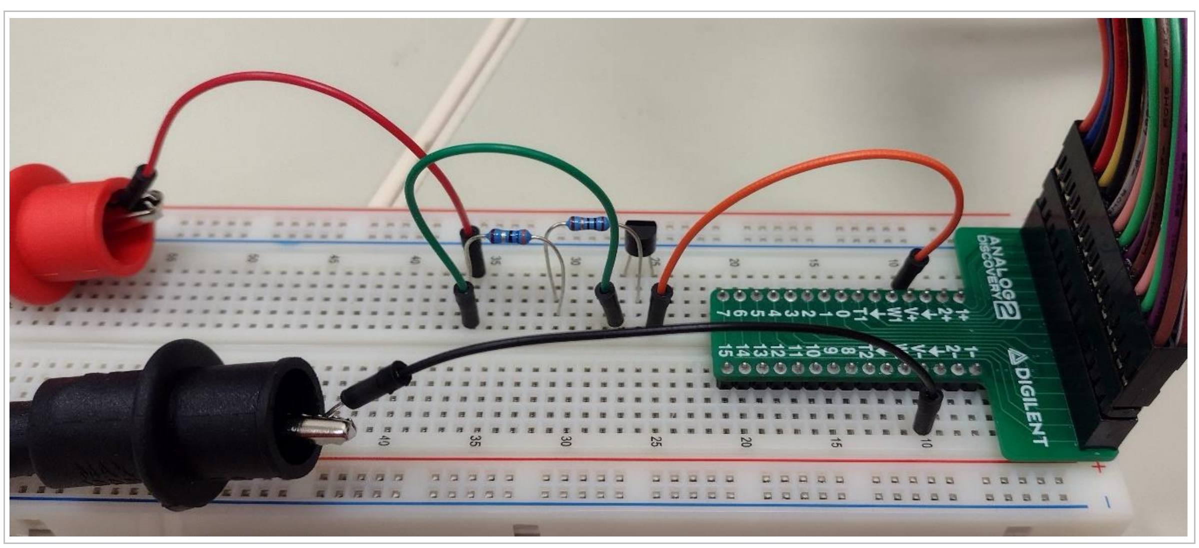
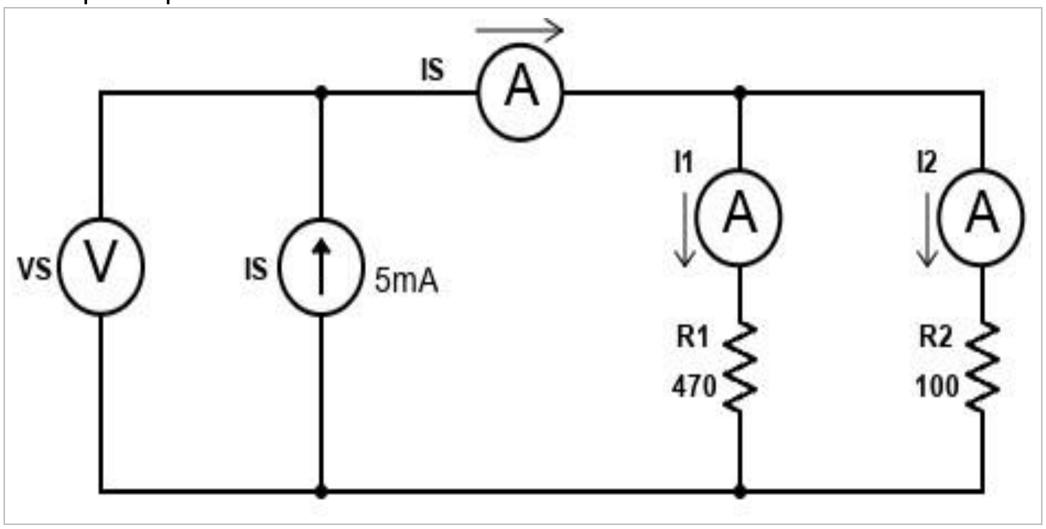


Figure 40: Current source circuit shown on breadboard

c. Turn on both the positive and negative voltage supplies of +5V and -5V on the Analog Discovery 2 and you should get an approximate reading of 5mA on the DMM.

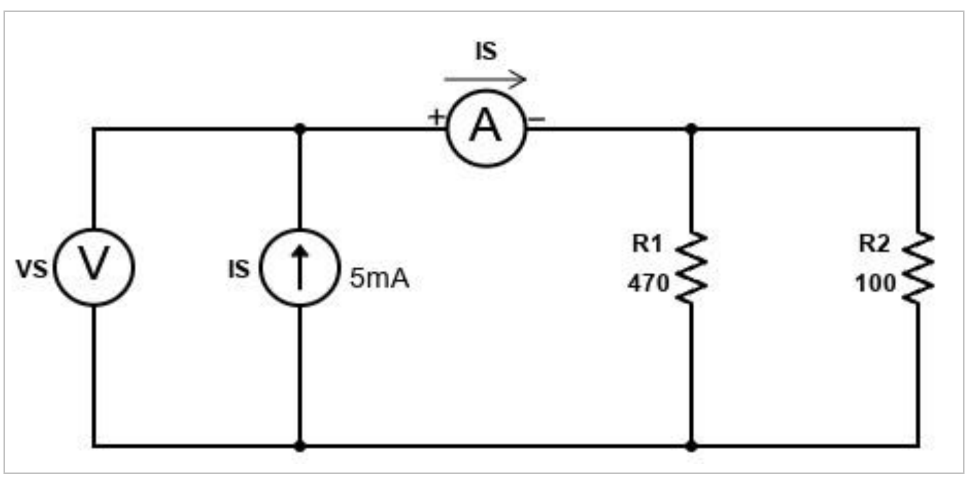
14. Experiment with Kirchhoff's Current Law by connecting the circuit below and following the required procedures.



Circuit 3: Current divider circuit

a. Connect the circuit above using the following:

- Use the 5mA current source you connected in the previous step.
- Use the voltmeter channel 1 on the Analog Discovery 2 to measure **VS**.
- In order to measure **IS** connect the circuit as shown below (Circuit 3a). Use the DMM as a milli-ammeter to measure **IS**.



Circuit 3a. Current divider circuit measuring **IS**

- Use a 470Ω resistor for **R1**.
- At first use a 100Ω resistor for **R2** and change this resistor when required to either a 470Ω, 1.0kΩ or 4.7kΩ.

b. It should look something like this when completed.

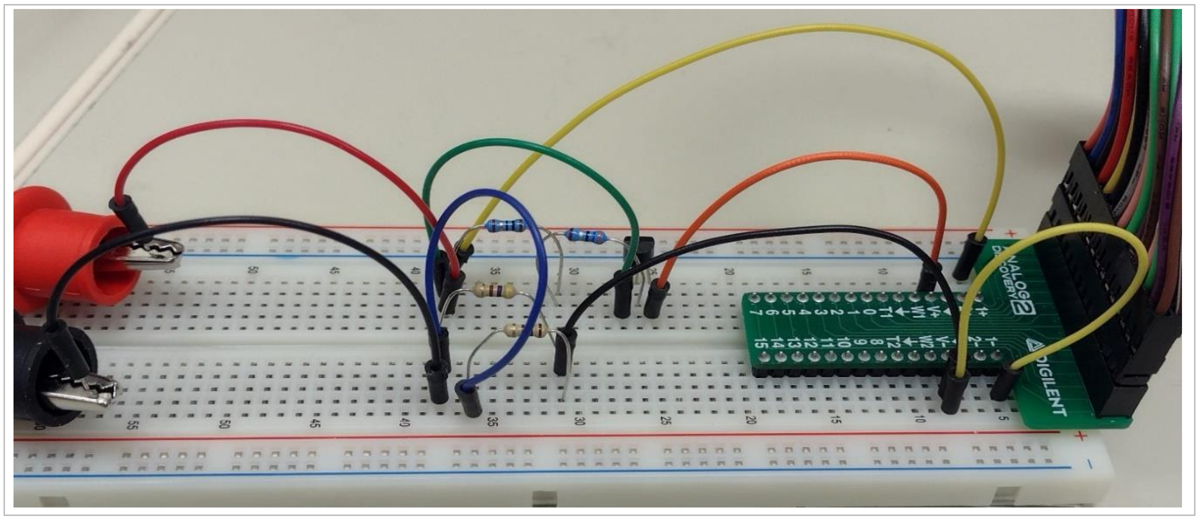
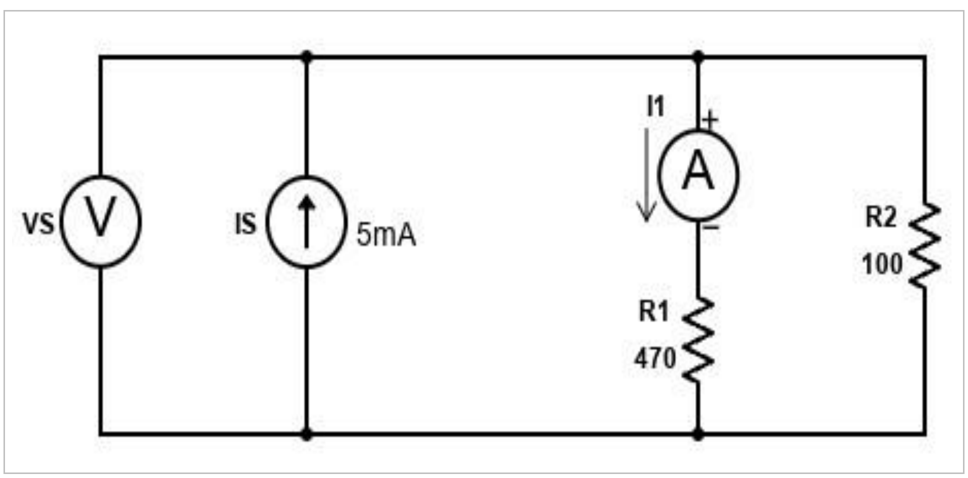


Figure 41: Current divider circuit shown on breadboard (measuring **IS**)

c. Turn on both the positive and negative voltage supplies on the Analog Discovery 2 to 5.0V and -5.0V & you should get an approximate reading of 5mA on the DMM for **IS**.

d. Measure and Record both the IS value from the DMM and the VS reading from Waveforms. To obtain the IS and VS measurements for the other values of resistor (R2) first replace a 100Ω resistor with a 470Ω followed by a 1kΩ and 4.7kΩ and repeat these measurements and record your results.

e. To obtain a measurement for **I1** you will need to reconfigure your circuit as shown in Circuit 3b. Use the DMM as a milliammeter to measure **I1.**



Circuit 3b. Current divider circuit measuring **I1**

f. It should look something like this when completed.

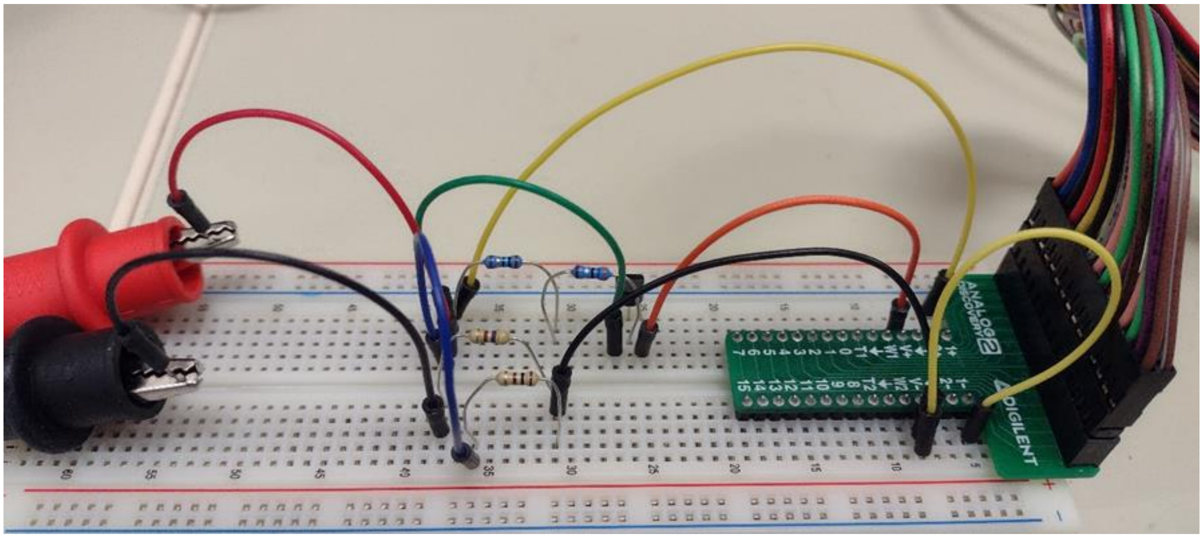
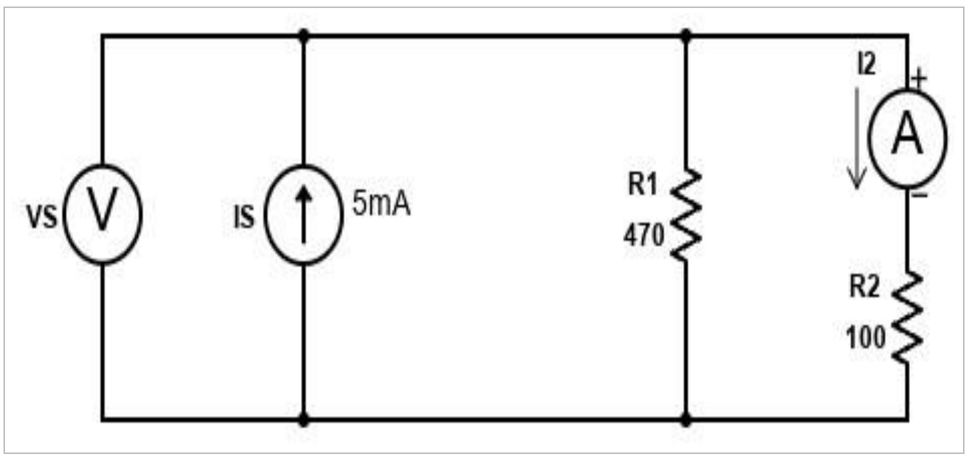


Figure 42: Current divider circuit shown on breadboard (measuring **I1**)

g. Measurement and record the values for I1 for each of the 4 resistors (100Ω, 470Ω, 1.0kΩ, 4.7kΩ) taking their turn as R2.

g. To obtain a measurement for **I2** you will need to reconfigure your circuit as shown in the Circuit 3c. Use the DMM as a milliammeter to measure **I2**.



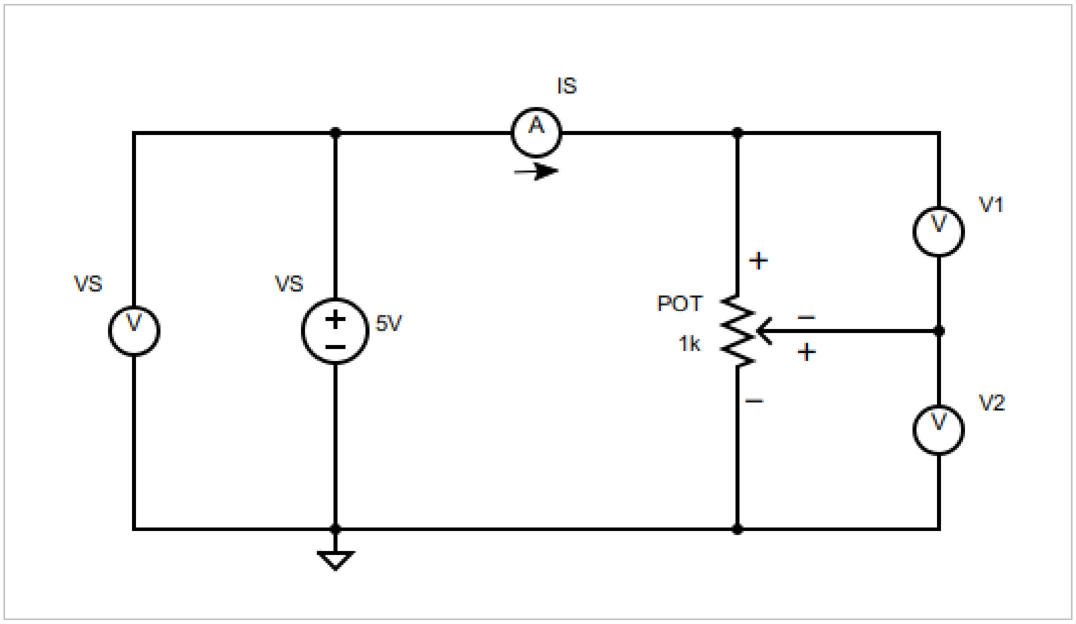
Circuit 3c. Current divider circuit measuring **I2**

h. Now measure and record the values for I2 for each of the 4 resistors (100Ω, 470Ω, 1.0kΩ, 4.7kΩ) taking their turn as R2.

i. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage sources and disconnect the circuit.

2.5 Potentiometer Divider

15. Experiment with a Potentiometer by connecting the circuit below and following the required procedures.



Circuit 4: Potentiometer divider circuit

a. Connect the circuit above using the following:
   - Use the Analog Discovery 2 positive voltage source as **VS**.
   - Use both Analog Discovery 2 voltmeters to measure the voltage across each part of the potentiometer: **V1** and **V2**.
   - Use the DMM as an ammeter to measure **IS**.
   - Use the 1.0kΩ potentiometer.
b. The circuit should look something like this when completed.

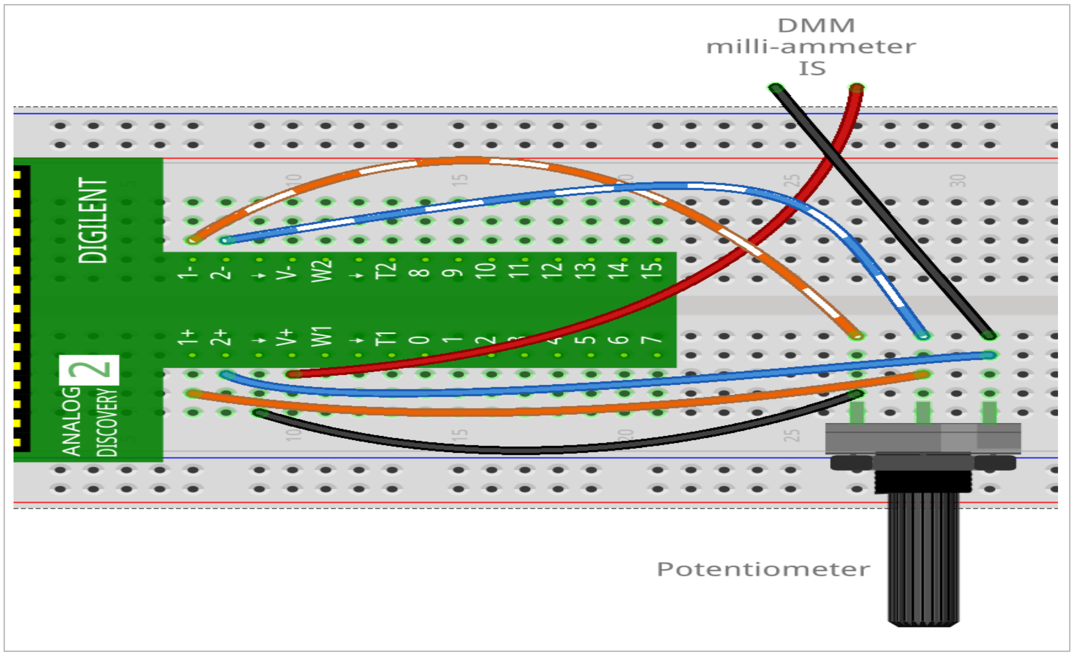


Figure 43: Potentiometer divider circuit

c. Turn on the Analog Discovery 2 voltage source and adjust it to 5V.

d. Turn the potentiometer knob until you obtain the V1 setpoints of (0V, 1V, 2V, 2.5V, 4V, 5V) making sure to measure and record the values of V1, V2, and I1 at each point.

e. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage sources and disconnect the circuit.

2.6 Loading Effect

Loading Effect

The loading effect is to what degree a measurement device impacts the electrical properties of the circuit under test (i.e. voltage, current, resistance). Ideally the piece of equipment will have a negligible effect on the circuit and therefore give you the correct readings. However, under certain conditions the measurement device can have a significant effect and alter the normal operation of the circuit and therefore give your readings an unexpected result if not accounted for.

2.6.1 Voltmeter Loading

Voltmeter Loading

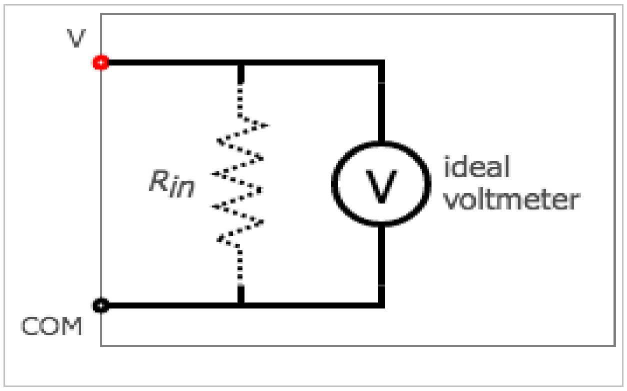


Figure 44: Non-ideal voltmeter

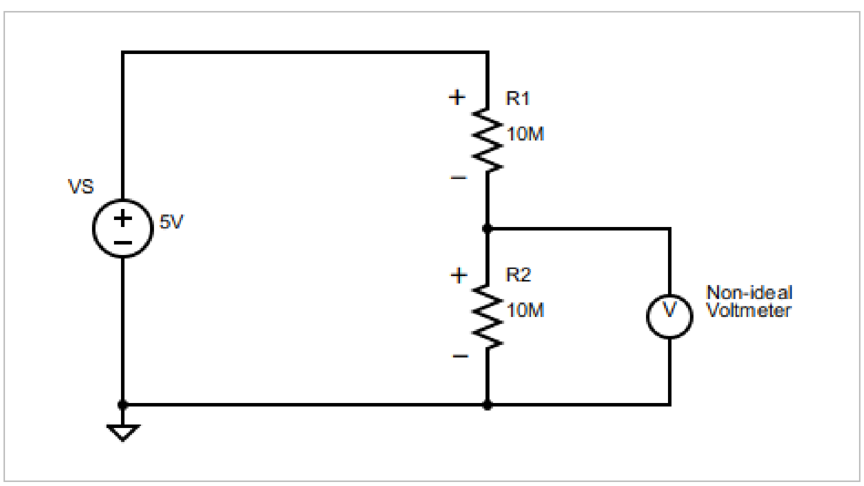
An ideal voltmeter imposes no load on the circuit being measured so as to not disturb the circuit. In practice, voltmeters draw some current and hence some small amount of load to the circuit affecting results.

So in an ideal voltmeter, the resistance of the meter is infinite.

In practice, voltmeters originally had resistance of several thousand Ohms, 30KΩ or 100KΩ was common. The resulting power used was required to deflect a moving needle galvanometer type meter.

Later electronic meters with input amplifiers such as vacuum tube and transistorized volt meters drew much less current with very high impedance and active amplifiers to drive the meter movements; today's digital multimeters typically have 10MΩ input impedance.

16. Experiment with Voltmeter Loading Circuit by connecting the circuit below and following the required procedures.



Circuit 5: Voltmeter loading Circuit

a. Connect the circuit above using the following:
   - Use the Analog Discovery 2 as the voltage source **VS**
   - Use the DMM as the **Non-Ideal Voltmeter** to measure the voltage across R2.
   - Use two 10MΩ resistors in series as **R1** and **R2**.

b. Turn on the Analog Discovery 2 voltage source and adjust it to 5V.

c. With the Non-ideal Voltmeter across (R2) measure and record the voltage.

d. Move the Non-ideal Voltmeter to measure the voltage across (R1) and record the voltage again.

e. Now move the Non-Ideal Voltmeter to measure the voltage across (VS) and record the voltage reading once again.

f. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage source and disconnect the circuit.

2.6.2 Ammeter Loading

Ammeter Loading

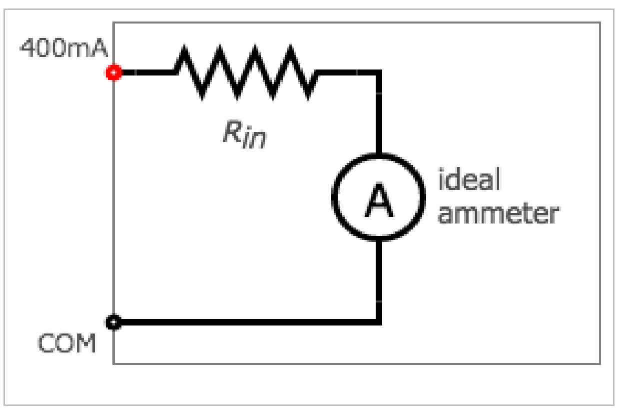
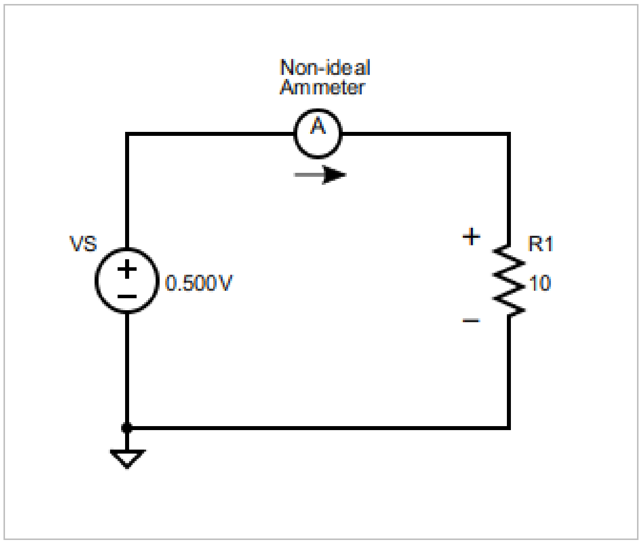


Figure 45: Non-ideal ammeter

Just like voltmeters, ammeters tend to influence the amount of current in the circuits they're connected to. However, unlike the ideal voltmeter, the ideal ammeter has zero internal resistance, so as to drop as little voltage as possible as electrons flow through it. Note that this ideal resistance value is exactly opposite as that of a voltmeter. With voltmeters, we want as little current to be drawn as possible from the circuit under test. With ammeters, we want as little voltage to be dropped as possible while conducting current.

17. Experiment with the Ammeter Loading Circuit by connecting the circuit below and following the required procedures.



Circuit 6: Ammeter loading circuit

a. Connect the circuit above using the following.
   - Use the Analog Discovery 2 voltage source as **VS**.
   - Use the DMM as a **Non-Ideal Ammeter** to measure the current through R1.
   - Use the 10Ω resistor for **R1**.
   - Use the Analog Discovery 2 voltmeter to measure the voltage across the Non-Ideal Ammeter.
b. Turn on the Analog Discovery 2 positive voltage source and adjust it to 0.500V.
c. Measure and record the reading on the Non-Ideal Ammeter as well as the voltage across the Non-Ideal Ammeter.
d. Adjust the Analog Discovery 2 voltage source first to 1.5V and then to 2.5V measuring and recording the current and voltage reading as in the last step.
e. Once all of the required measurements are obtained and checked, turn off the Analog Discovery 2 voltage source and disconnect the circuit.

2.7 Cleanup

Congratulations, you have completed the experimental part of the laboratory. Verify your results with a lab instructor or TA before cleaning up. If you are not continuing to work with the equipment please disconnect everything and put it away to prevent it from getting damaged.

3 Post Lab

The following is what you are expected to complete & submit for grading of Lab 1 before the deadline.

1. The Lab 1 - Results sheet is provided on lab eClass page. This sheet should include the following.
    - Your name, student ID and CCID.
    - All of the required measurements from the lab procedures.
    - Answer the questions available on a Lab 1 result sheet.
    - All of the required calculations as discussed below.
    - The required plots as discussed below.
2. The **Lab1 - Result Sheet** needs to be submitted to the Submit **(Lab 1 - Results)** link on eClass as a **PDF** document. Only one lab report is required to be submitted per group. Information regarding the due date of Lab 1 report submission is available on eClass lab schedule.
3. Complete the online **Quiz (Lab 1 - Post Lab)** on eClass individually, which will be due usually on same day as a lab result sheet. Detailed Information regarding the due date of Lab 1 Quiz is available on eClass lab schedule.

3.1 Calculations

For these calculation you only need to provide the answers in the space provided on your results sheet, you do not need to show your work other than requested on the result sheet.

i. For Ohm's Law and Power calculate the resistance from your voltage and current measurements for each resistor at each voltage supplied.

ii. For Ohm's Law and Power calculate the power dissipated in each resistor from your voltage and current measurements for each resistor at each voltage supplied.

iii. For the Voltage Divider calculate the power dissipated in each resistor and the total power supplied by the power source.

iv. For the Current Divider calculate the power dissipated in each resistor and the total power supplied by the power source.

v. For the Potentiometer Divider add the 2 voltages you measured for V1 and V2 to show that it equals the supply voltage you used for this circuit.

vi. For Voltmeter Loading add the 2 measurements you obtained to see if they add to supply voltage you used for this test.

vii. For Ammeter Loading use the current you measured through the milli-ammeter and the voltage you measured across the milliammeter to determine the non-ideal resistance of the milliammeter.

3.2 Plots

To create your plots you can use whichever software you would like (Excel, Matlab, etc), export your plot as an image and import it into your Lab 1 - Results sheet in the appropriate place.

Your plots should include:

- A Plot title
- Label your axes and show what unit of measure is used.
- Include a marking for your datapoints.
- Include a line between your datapoints in the same series.
- Include a legend.
- Make sure your scales are appropriate and visible.

1. **Resistor I-V Characteristic Plot**: For your Ohm's Law and Power results, plot the current vs. voltage, with each resistor value as a separate series.
2. **Resistor P-V Characteristic Plot**: For your Ohm's Law and Power results, plot the power vs. voltage, with each resistor value as a separate series.
3. **Voltage Divider (R1 = 470Ω) - Voltage Plot**: For your Voltage Divider results, plot a series for each voltage: source voltage, R1 voltage and R2 voltage versus the resistance value of R2.
4. **Voltage Divider (R1 = 470Ω) - Power Plot**: For your Voltage Divider results, plot a series for each power: the source power, the R1 power dissipated and the R2 power dissipated versus the resistance value of R2.
5. **Current Divider (R1 = 470Ω) - Current Plot**: For your Current Divider results plot a series for each current: source current, R1 current and R2 current versus the resistance value of R2.
6. **Current Divider (R1 = 470Ω) - Power Plot**: For your Current Divider results plot a series for each power: the source power, the R1 power dissipated and the R2 power dissipated versus the resistance value of R2.