ELEC 3900
INTRODUCTION TO LABORATORY EQUIPMENT

Objectives:

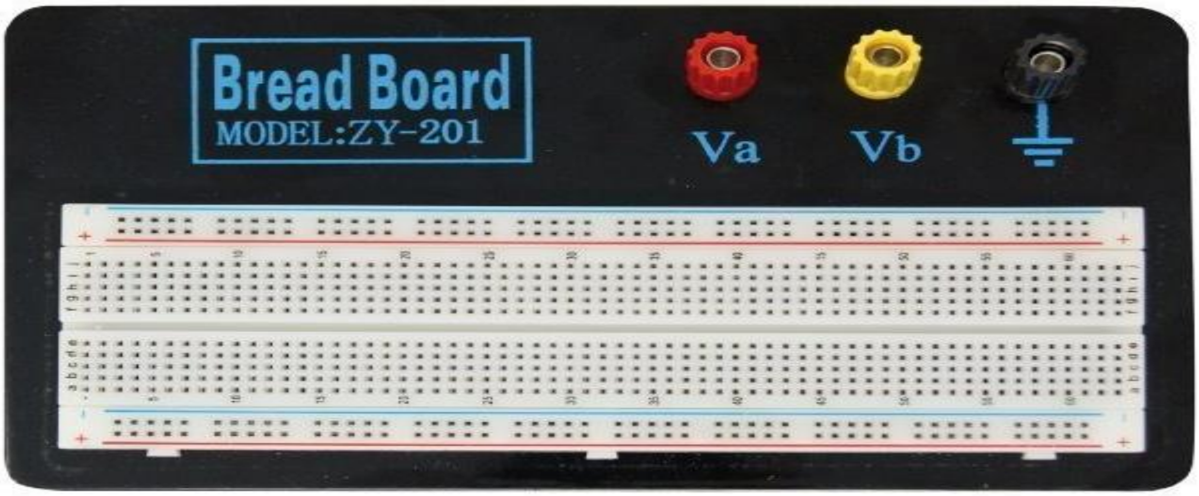
- Gain hands-on proficiency with the essential lab equipment to build, test, and troubleshoot electrical circuits and systems using the following:
  - Breadboards.
  - Digital Multimeters (DMM).
  - DC Power Supply.
  - Digital Storage Oscilloscopes.
  - Function Generator.
- Learn techniques to measure basic circuit properties such as resistance, voltage, and current.
- Learn how to determine whether components of an electronic system are behaving properly using the laboratory equipment.

Equipment Tutorials

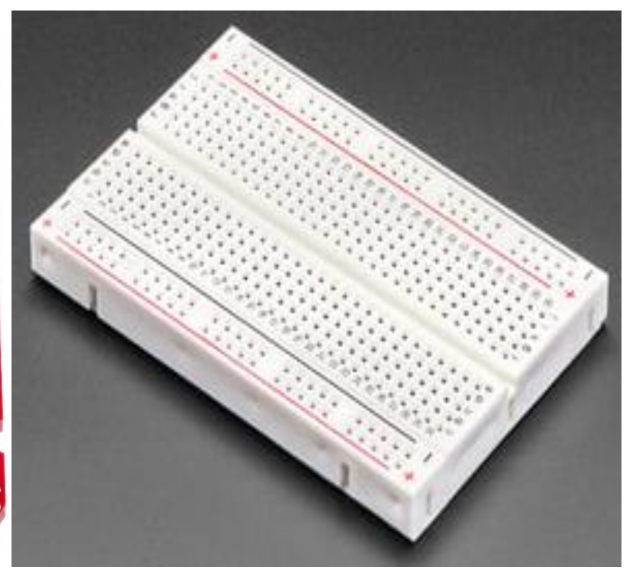
These tutorials will provide foundational instruction on the operation of essential laboratory instruments, specifically the digital multimeter (DMM), DC power supply, function generator, and oscilloscope.

BREADBOARD

We will build and test the designs of all our circuits on a breadboard shown below and verify that our design simulation is the same or close to our empirical results.



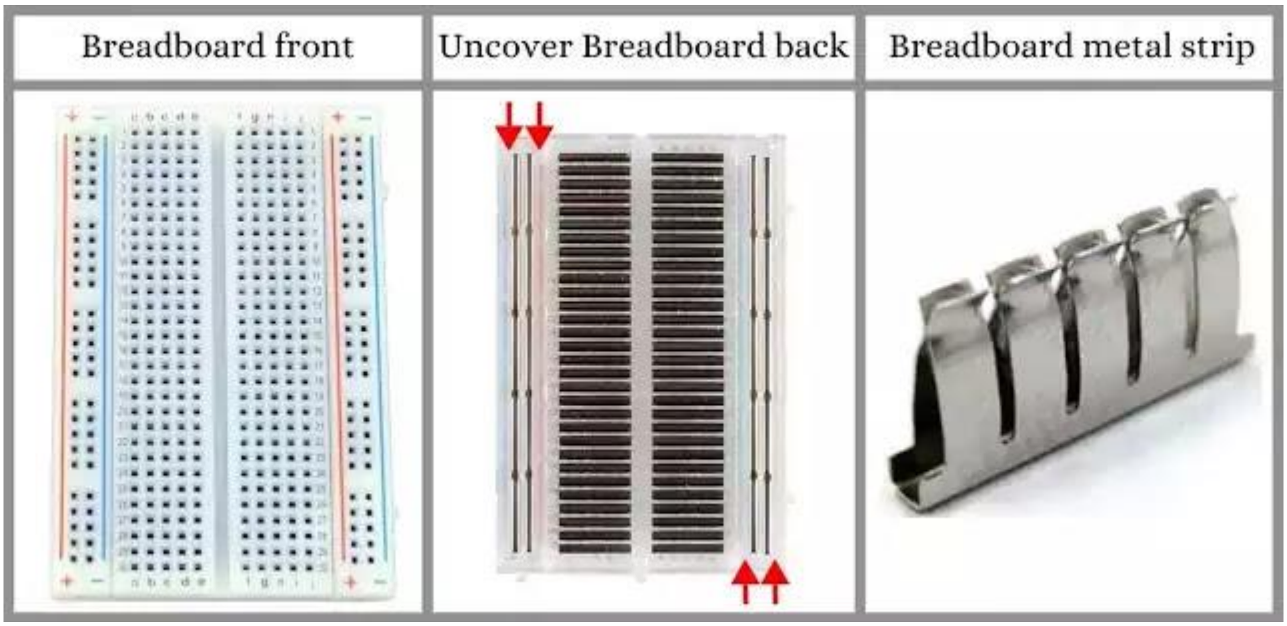
There are 2 types of breadboards: solderable and solderless.



Examples of Solderable and solderless breadboards

Solderable breadboards contain holes that you can utilize to connect electronic components onto the board. After connecting the necessary electronic components, you can then solder the components onto the board using a soldering iron.

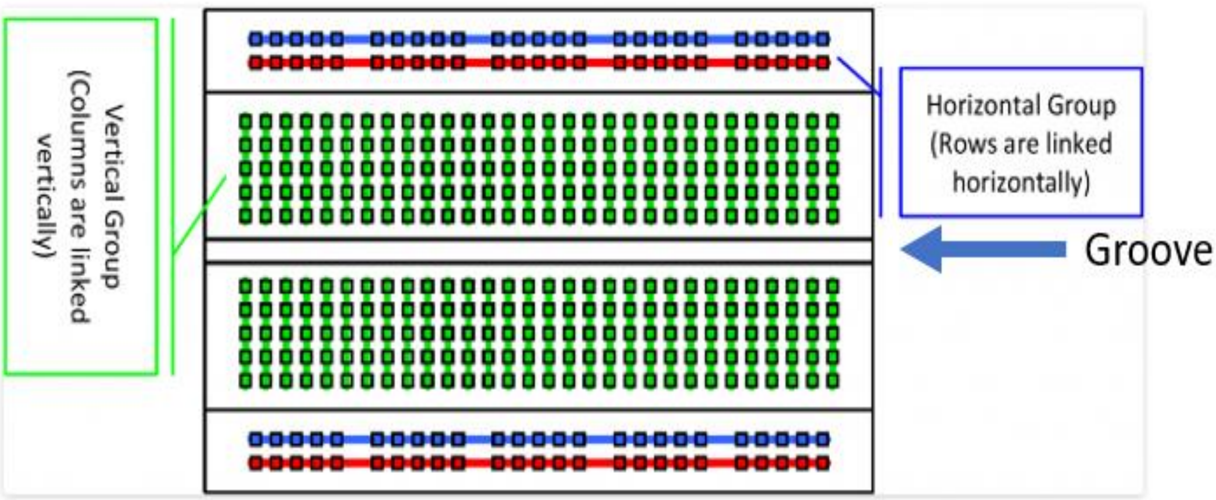
The solderless breadboard has strips of metal which run underneath a plastic grid board of holes/sockets, arranged as shown below, as yellow rectangles. Note that the top and bottom rows of holes are connected horizontally while the holes in the center sections are connected vertically.



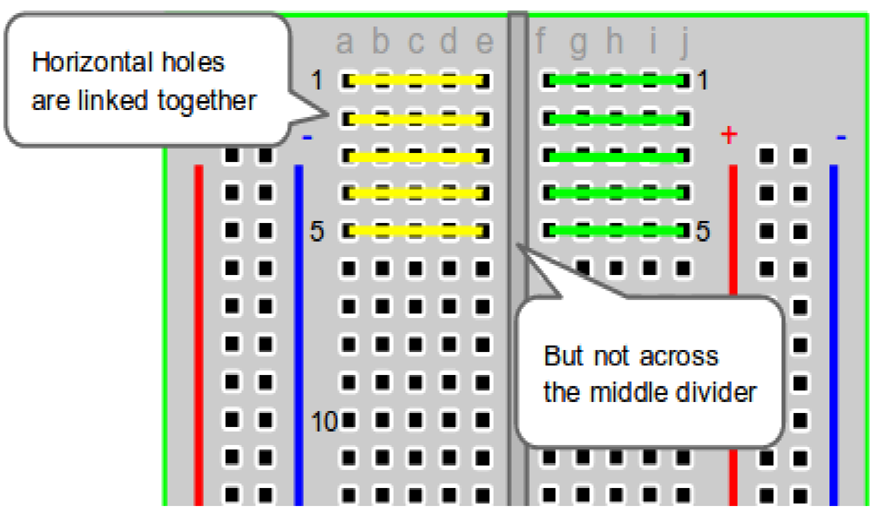
Inside view of each hole or socket

Many of the breadboards used in this class have binding posts for connecting power. Red is usually reserved for positive power source/supply, Green or Yellow for negative power source/supply, Black for Common/Ground. Note that even if the binding posts have power, that does not mean that the board is powered. One will have to bring power from the posts to the board by placing the jumper wires from the post to the breadboard.

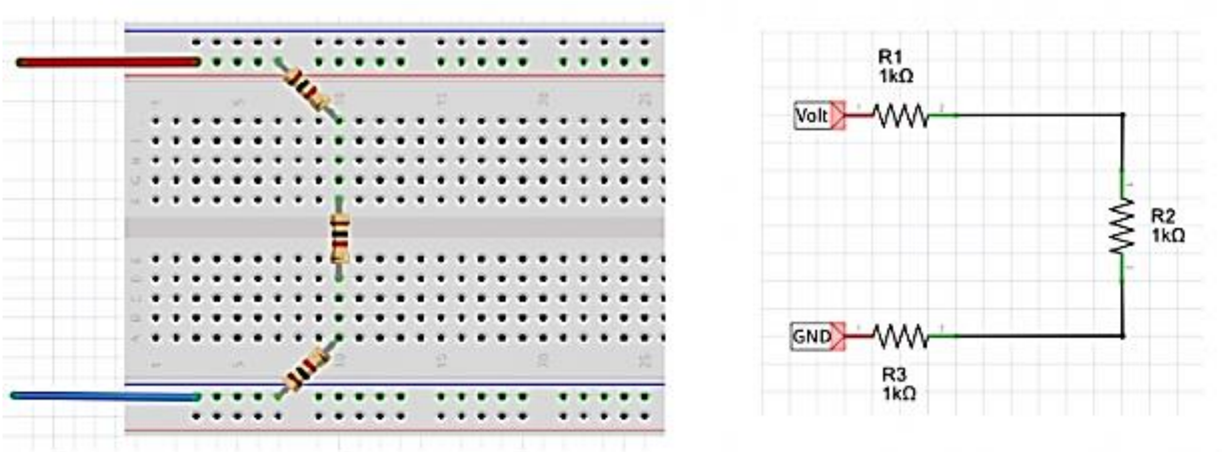
Now, let's view the board as rows, columns and grooves:

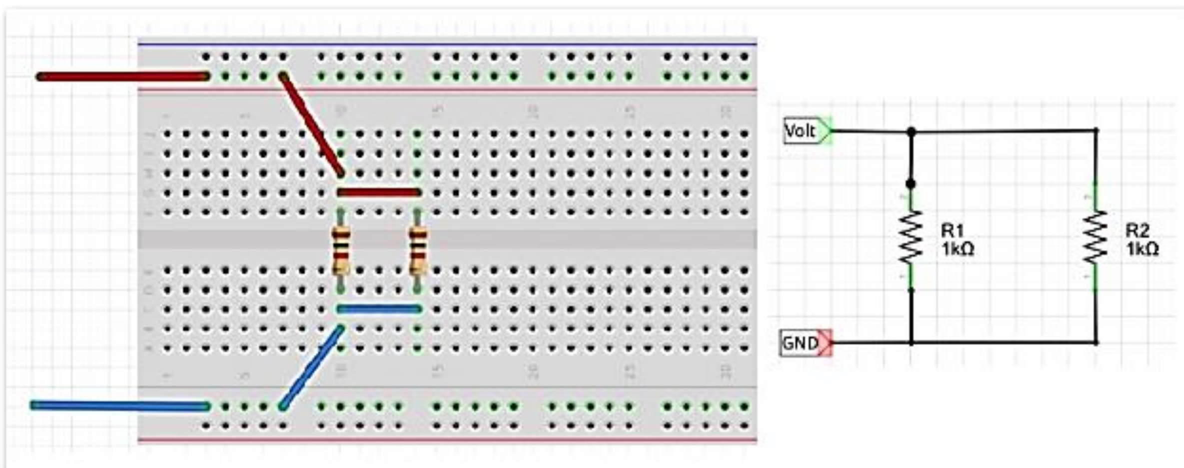


Note that:



Then we can see:



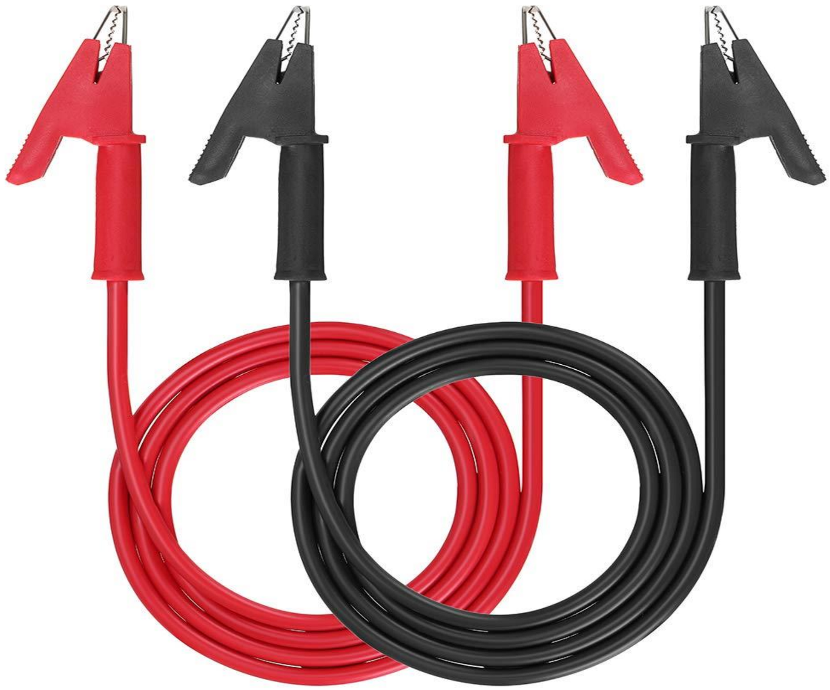


Finally, let us define jumper wires/cables and alligator clips and their importance to us in measurement. Never insert a probe directly into a socket. Put a jumper wire into the socket and use an alligator clip to create a measurement point.

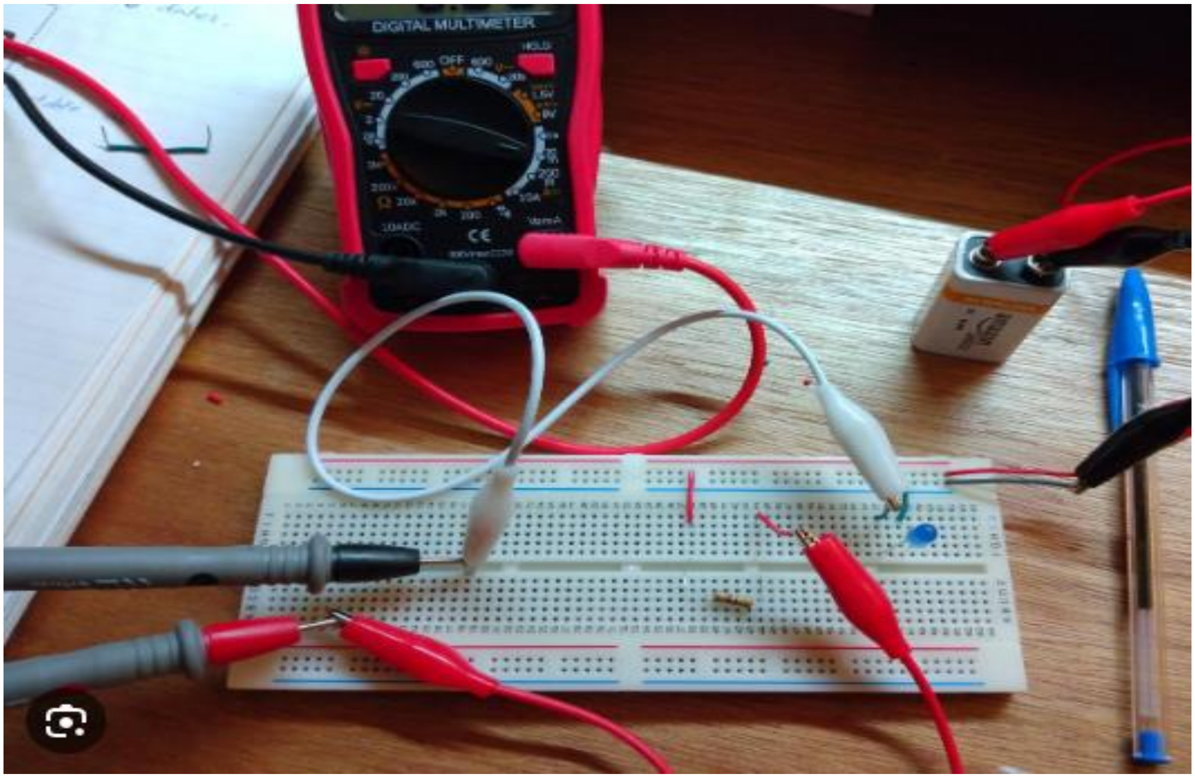
Jumper wire:

Types of Jumper wires which consist of Male to Male, Female to Female, Male to Female connectors.

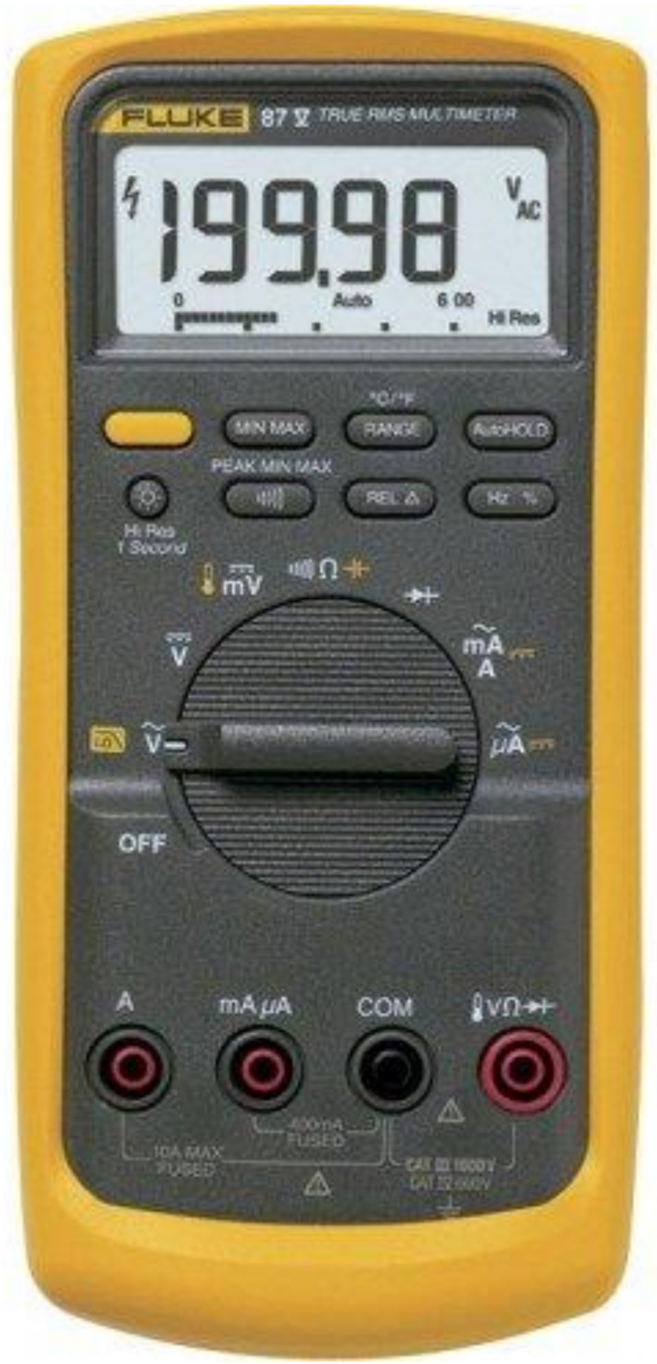
Alligator Clips:



When used together, we get such an implementation



DIGITAL MULTIMETERS (DMM)



Front panel view of the Fluke 87 DMM

The digital multimeter (DMM) is an indispensable instrument in any electrical engineering laboratory, serving as a fundamental tool for quantifying essential electrical parameters: voltage, current, and resistance. Its exceptional versatility makes it a cornerstone for circuit analysis, troubleshooting, and design verification.

Multimeters are broadly categorized into two types: digital multimeters (DMMs), which provide readings as numerical displays, and analog multimeters (AMMs), which utilize a needle on a calibrated scale. While AMMs offer a continuous visual representation of a changing value, DMMs are generally preferred in modern labs due to their higher precision, clearer readings, and often, additional functionalities.

Connection to the circuit under test is achieved via two test leads, commonly referred to as probes. These leads typically feature a male banana plug connector at one end, designed to interface securely with the meter's input jacks. The opposing end of the lead may terminate in various styles, such as an alligator clip for secure, temporary connections, or a pointed metal tip for precise contact with circuit nodes.

Standard practice dictates that the test leads are color-coded: one red and one black. Adhering to established conventions, the black lead is typically connected to the meter's negative (or common/reference) input jack, while the red lead is connected to the positive input jack. Although the DMM's internal circuitry is polarity-agnostic concerning the lead colors, consistent adherence to this color-coding convention is crucial for efficient and error-free operation, particularly when interpreting measurements and maintaining a clear understanding of circuit polarity. The measured value is then directly displayed as a digital readout on the DMM's liquid crystal display (LCD) or light-emitting diode (LED) screen.

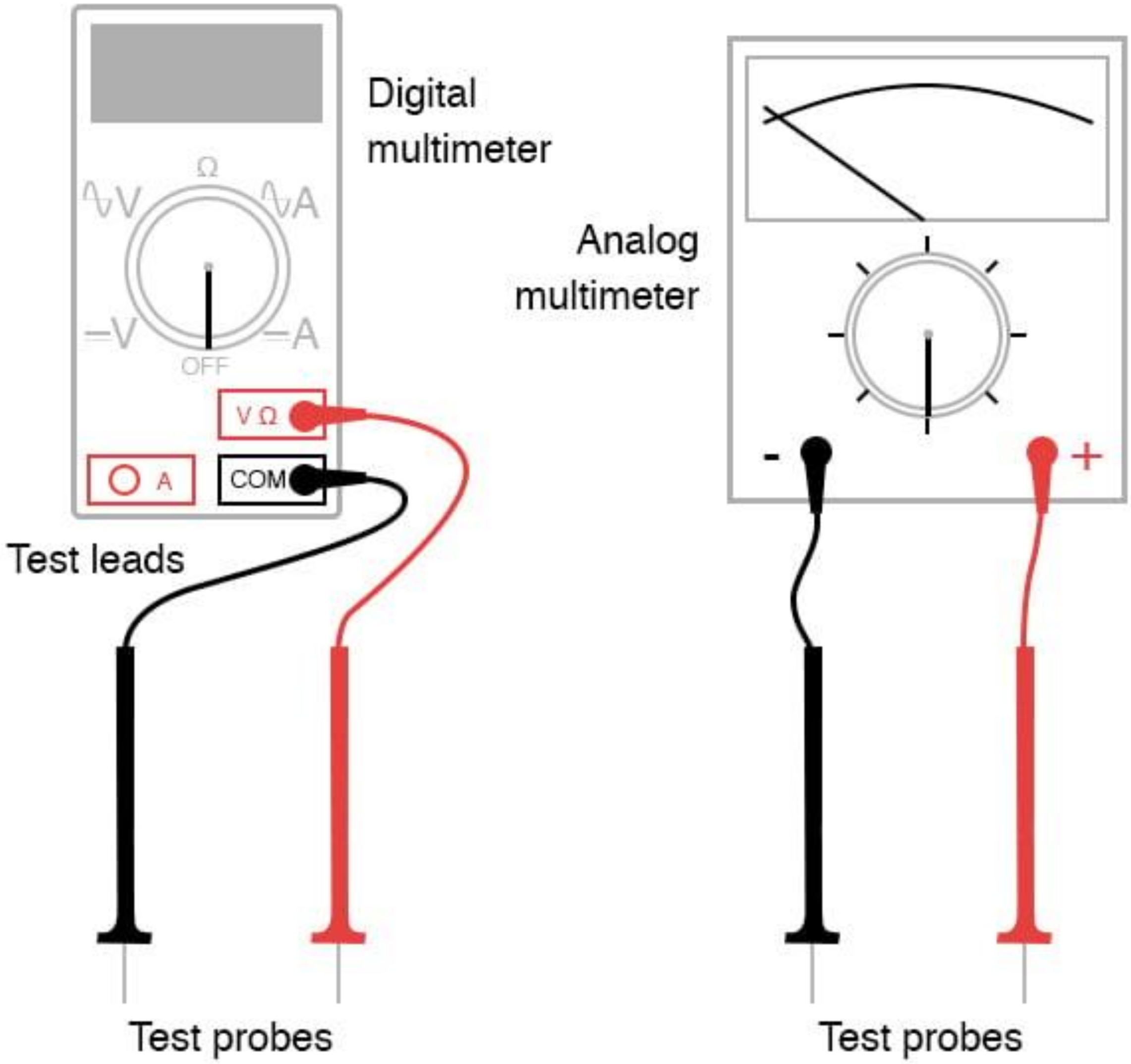
In the case of an Elenco multimeter, you can measure inductance and capacitance plus these same features. There are also a couple of additional features that will also be useful to know when using the DMM: connection continuity (open) and isolation of a circuit (short).

When a PCB undergoes Electrical Test, the main goal is to determine if there are any “opens” or “shorts” in the design circuitry. Opens are defined as breaks in any given “net” or “circuit,” while Shorts are defined as any non-desired connections between atypical or individual “nets” or “circuits.

Continuity testing and isolation of a circuit using a DMM is the act of testing the resistance between two points. If there is very low resistance (less than a few Ωs), the two points are connected electrically, and a tone is emitted. If there is more than a few Ωs of resistance, then the circuit is open, and no tone is emitted. This test helps ensure that connections are made correctly between two points. This test also helps us detect if two points are connected that should not be. Look for these symbols on DMM:

V	Volts
A	Amperes
mA	milliamps
Ω	Ohms
~	AC
⎓	DC
─▶─	Diode test
•)))	Continuity test
Hz	Hertz
─|(─	Capacitance

Symbols on the DMM for the parameter under test.



If you have never used a DMM, read the Spark Fun tutorial "How to use a multimeter" (https://learn.sparkfun.com/tutorials/how-to-use-a-multimeter/all) or watch the video, https://www.youtube.com/watch?v=ts0EVc9vXcs

DC POWER SUPPLY

Each workstation is equipped with two Agilent E3630A 35W Triple Output, 6V, 2.5A & $\pm$ 20V, 0.5A DC power supplies. The power supply is used to produce a variable DC output voltage between ± 20V & +6V.

Front Panel View of the Agilent power supply workstation

The power supply can produce three different outputs.

Output 1: 0 to +6 V, 0 to 2.5 A → Specifically used for Digital Logic circuits

Output 2: 0 to +20 V, 0 to 0.5 A

Output 3: 0 to -20 V, 0 to 0.5 A

Which of these output ranges you use depends on how you connect the power supply to your circuit. The three Meter selector buttons: +6V, +20V, -20V allow you to select which of the three ranges will be displayed on the digit meters shown on the front of the power supply. It is important to note that you should not depend on the digital displays for important data. Use them only as a gauge and measure the output of the meter with the DMM to be more accurate.

The “voltage adjust dials” on the upper right of the power supply adjust the output voltage for their specific ranges. If you want to use the 6V scale of the supply, connect your power between the +6V and common (com) connection points. If you desire to use the 20V scale, connect your output between the +20V and com connections. For the –20V scale, use the -20V and com connections.

This is a floating power supply. That means that the output of the power supply is not directly connected to earth ground inside the power supply. That is the reason for the extra earth ground connection on the supply. If you wish for the output of the supply to be connected to earth ground, simply connect a wire between the earth ground connection point and the com point on the supply.

You should note that the three scales operate independently of one another, and you may use all three outputs simultaneously even though you will only be able to see one of them on the digital meters on the supply.

For the sake of completeness, the tracking dial allows you to adjust the ratio between the +20V and –20V scales. You would use this if you needed to simultaneously have +12V and –18V supplies for instance. Leave the tracking ratio knob at Fixed.

Note: The output of the power supply is between the +6V, +20V, -20V and COM connections and NOT the +6V, +20V, -20V and earth ground points!

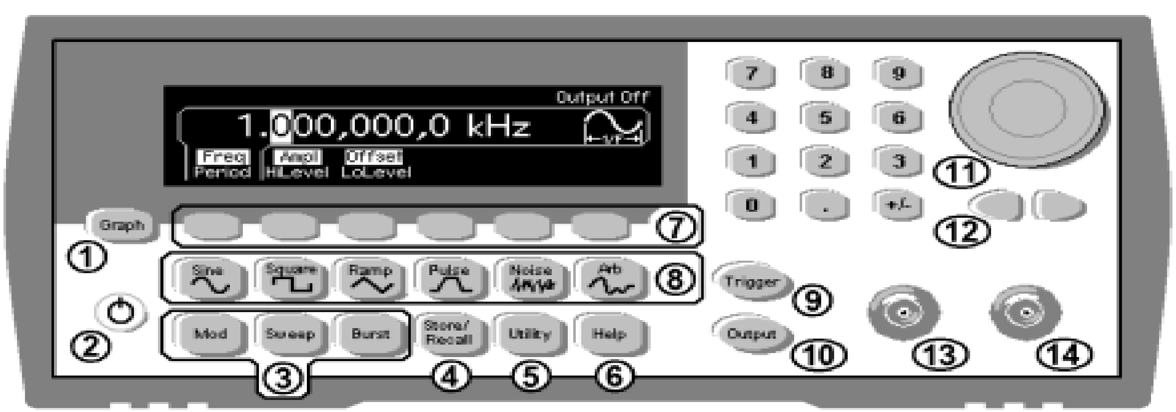
You will recall from a previous class that operational amplifiers have two supply rails because the need to swing bipolar – output voltages that go either positive or negative in response to the normal range of input signals without the dual supplies, the output signal would clip at the ground potential.

To work with the power supply on the workbench, use the following banana probes ONLY. You will find them in the cupboard near the front whiteboard near the instructor's table.

FUNCTION GENERATOR

Front Panel View of the Function Generator

A function generator is a piece of electronic test instrument used to generate and deliver standard waveforms, typically sine and square waves, to a device under test. It can be used to test a design or confirm that a piece of electronic equipment is working as intended.



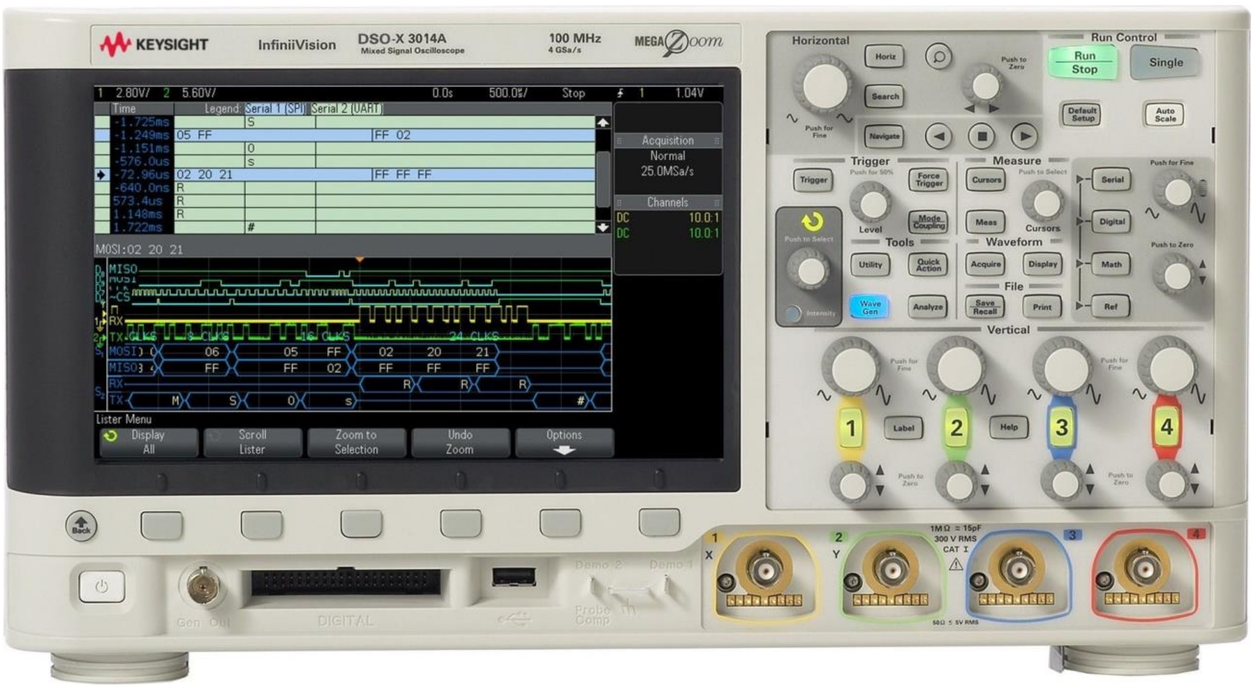
1 Graph Mode/Local Key
2 On/Off Switch
3 Modulation/Sweep/Burst Keys
4 State Storage Menu Key
5 Utility Menu Key
6 Help Menu Key
7 Menu Operation Softkeys
8 Waveform Selection Keys
9 Manual Trigger Key (*used for Sweep and Burst only*)
10 Output Enable/Disable Key
11 Knob
12 Cursor Keys
13 Sync Connector
14 Output Connector

To connect to this device, use the BNC cables ONLY from the cupboard near the front whiteboard shown below:

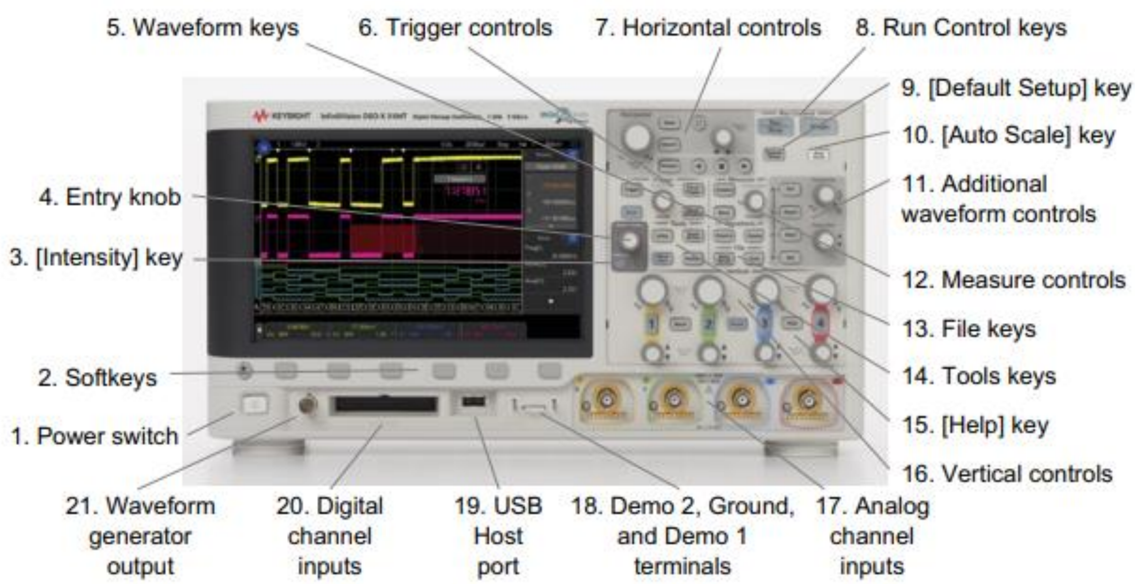
For more information, consider the link below:

https://www.keysight.com/us/en/assets/7018-01868/data-sheets/5989-8926.pdf

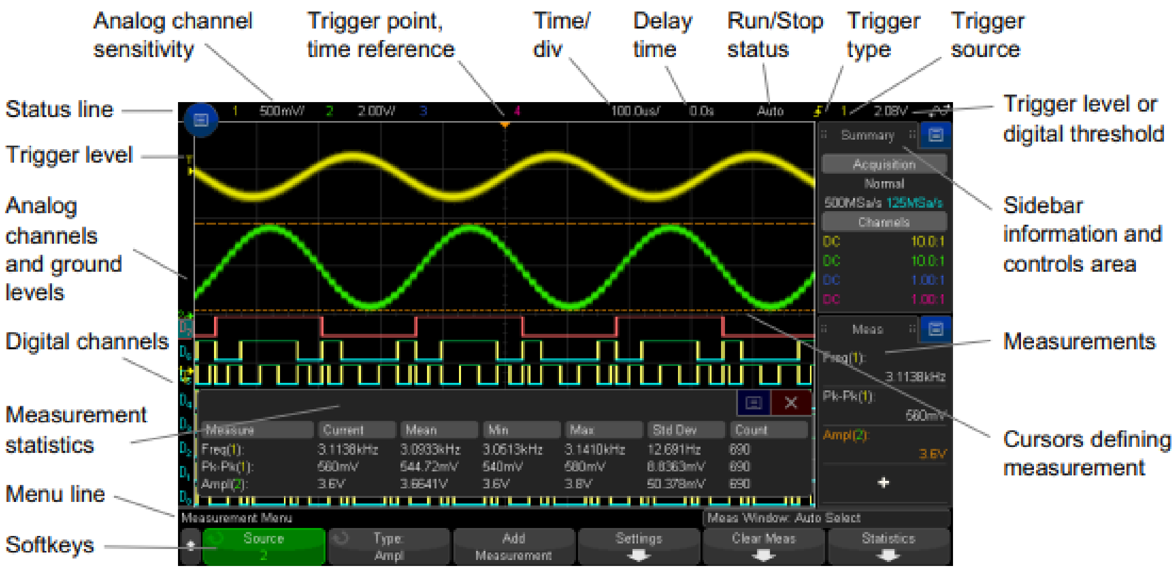
DIGITAL STORAGE OSCILLOSCOPE



Front Panel View of the Digital Storage Oscilloscope



When connecting to the Oscilloscope, use ONLY the cables shown below. These cables can be located near the cupboards where the lab components are available



Interpretation of the Oscilloscope Display

For more information or specific information consider this link:

https://www.keysight.com/us/en/assets/7018-02734/data-sheets/5990-6619.pdf

SOFTWARE TUTORIALS

In this course, we will be using Altium Designer, KiCAD and Cadence “Capture CIS” PSpice.

Cadence Capture CIS

INITIAL STEPS TO RUN ORCAD CAPTURE CIS:

1. Select Start → “**CADENCE Release_version_number**”.
2. Select “**Capture CIS**” icon from the drop-down menu.
3. Once the window opens for “**Capture CIS**”, Select “**FILE**” → “**NEW PROJECT**”.
4. Assign the project the following files name “STUDENT_NAME_Project_Name”.
5. A “**New Project**” windows opens. Select “**Analog or Mixed A/D**” button and Select “**OK**”.
6. Another window “**Create PSpice Project**” opens on the screen. Select the option “**Create a blank project**” on this window.
7. Congratulations!!! You are now ready to make the schematic/PSpice simulation for your required experiment.

PART 1

HARDWARE LABORATORY PROCEDURES

Things to remember when measuring voltage, current and resistance

1. Voltage is measured in parallel.
2. Current is measured in series.
3. Resistance is measured in parallel.
4. Resistance is measured with the power off.
5. Select the correct function on the DMM (Voltage, Current, or Resistance).
6. Be aware if you are measuring an elements resistance or a circuits equivalent resistance.

Measuring Voltage, Current, Resistance:

Voltage is measured in parallel. That means you connect the DMM in parallel with the voltage you would like to measure.

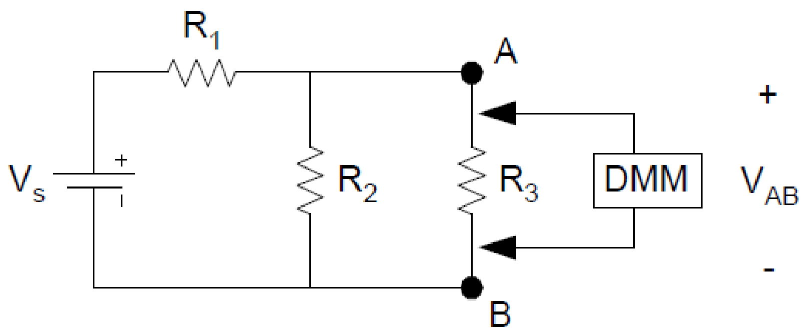


Fig. 1: Measuring Voltage with DMM

In Fig. 1, the DMM is connected to measure the voltage across the resistor R_3. This is labeled as V_{AB} in the Figure. When two subscripts are used to identify voltage, the first subscript is at the more positive potential. So V_{AB} is the voltage at point A relative to point B. If a voltage has only one subscript, it is the voltage at that point relative to ground. When measuring voltage with a DMM, be sure that the probes are connected between the voltage measurement terminals and the proper setting for either AC or DC measurement has been selected. The voltage terminals on any meter will usually be labeled.

Current is measured by placing the meter in series with the current being measured. This is shown in Figure 2.

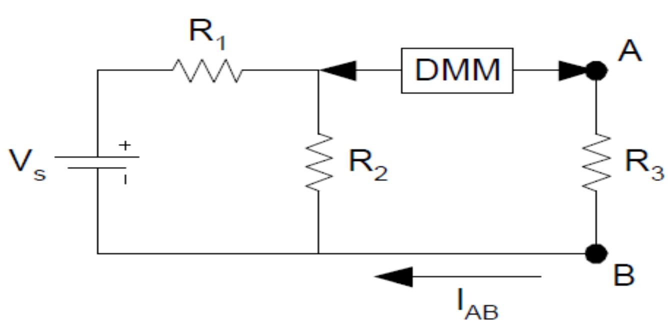


Fig. 2: Measuring Current with DMM

Fig. 2 shows the DMM connected to measure the current flowing through the resistor R_3. This is labeled as I_{AB}. Current labels are always from the tip to the tail as shown in the Figure. When measuring current, you must break a connection in the circuit and insert the meter in series where the break was made. Changing circuit connections like this should always be done when the power is turned off. On our DMM, current is measured between the bottom two connections, and we can measure up to 10A.

The voltage and current measurement connections on the DMM share a common point. This is the ground connection for voltage measurement and the tail of the arrow for current measurement. When measuring current, be sure that the current button has been selected for either AC or DC current measurement.

Resistance is measured similar to voltage and through the same terminals on the meter. It is measured in parallel. Resistance cannot be measured with a DMM when power is connected to the circuit. So, to measure equivalent resistance between two points, turn off the power supply and replace it with a short circuit. This is shown in Figure 3.

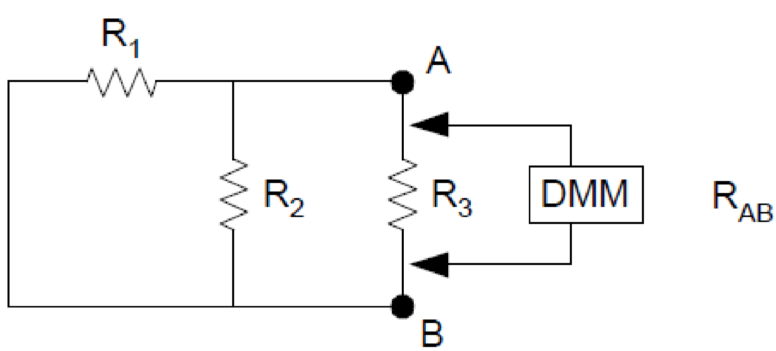


Fig. 3: Measuring Equivalent Resistance with DMM

In Fig. 3, the DMM is connected in parallel with resistor R_3. Since there are other resistors connected to the same points (A and B), the DMM will measure the total resistance between the points, A and B. If it is desired to measure only the resistance of R_3, then R_3 must be removed or at least separated from the circuit. This is shown in Fig. 4.

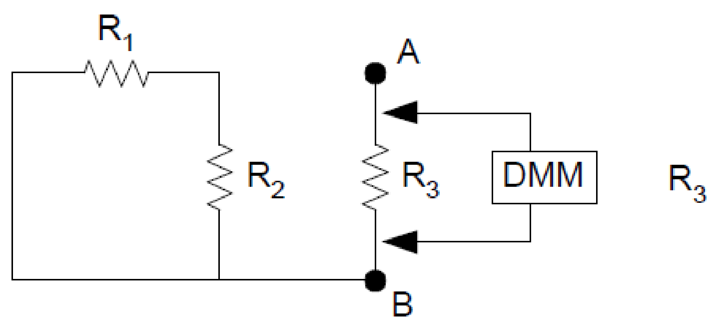


Fig. 4: Measuring Resistance of a Resistor

The resistance being measured in Fig. 4 is the resistance of R_3 since R_1 and R_2 have been removed from the circuit. When measuring resistance, be sure the resistance button has been pressed on the DMM. Also note that resistance does not have a polarity associated with it so $R_{AB} = R_{BA}$.

Task 1: Resistance Measurement *(10 points)*

In this exercise, you will utilize the **Digital Multimeter (DMM)** to precisely measure the resistance of various resistors. While resistors are typically marked with color bands indicating their nominal resistance value and tolerance, these markings provide an approximate value. It is crucial to understand that the **tolerance band** specifies the permissible deviation from this nominal value. For instance, a 10 kΩ resistor with a ±5% tolerance could legitimately exhibit resistance anywhere between 9,500Ω and 10,500Ω. This inherent variability means that two resistors with identical color codes could potentially have measured values differing by as much as 10% of the nominal value. Therefore, accurate measurement with a DMM is essential for precise circuit design and analysis.

Procedure:

1. **Resistor Acquisition:** Obtain five different resistors of varying values from the laboratory supply.
2. **Initial Data Recording:** For each resistor, carefully record its **nominal resistance value** (from the color code or labeling) and its **tolerance percentage** in a designated data table.
3. **Ohmmeter and Probe Verification:** Before proceeding with resistor measurements, verify the functionality and accuracy of your DMM's ohmmeter setting and test probes.

- Set the DMM to the resistance measurement mode.
- Touch the tips of the two test probes together. A functional DMM and probes should display a reading close to 0Ω, typically around 0.5Ω to 1Ω, representing the inherent resistance of the probes and internal connections. This confirms proper operation.

4. **Individual Resistor Measurement:**

- For each of the five resistors, carefully connect the DMM probes across its terminals. Ensure that the resistor is **not connected to any circuit or power source** during measurement to prevent erroneous readings or damage to the DMM.
- Select an appropriate resistance range on the DMM. If your DMM has auto-ranging, it will automatically select the best range.
- Measure the resistance of each resistor to the nearest Ohm.
- Record the measured resistance value for each resistor in table 1 below.

TABLE 1

Color Code (First band, Second band, Multiplier, Tolerance Band)	Nominal (Labelled) Value (in ohms)	Measured Value (in ohms)	Tolerance (in %)	Percent Difference between Nominal and Measured

Task 2: Power Supply Output Verification *(10 points)*

It is a fundamental principle of **good engineering practice** to always return all power supply voltage adjustments to their minimum (zero) setting upon completion of work. This critical step prevents inadvertent application of excessive voltage to sensitive circuit components or measurement equipment, thereby mitigating the risk of accidental damage.

Procedure:

1. **DMM Configuration:** Set the function switch on your Digital Multimeter (DMM) to measure **DC Voltage (VDC)**. Ensure the DMM leads are connected to the appropriate voltage measurement jacks (typically "V Ω mA" and "COM").

2. **+20V Output Measurement:**

   - Turn on the DC power supply.
   - Slowly turn the voltage adjustment knob for the **+20V output** (or similar primary positive output) to its maximum setting.
   - Carefully connect the DMM probes to the +20V output terminals, ensuring **correct polarity** (red lead to positive terminal, black lead to common/ground terminal).
   - Measure and record the **maximum output voltage** in Table 2.
   - Slowly turn the voltage adjustment knob for the +20V output all the way down to its minimum setting.
   - Measure and record the **minimum output voltage** from the +20V output in Table 2.

3. **+6V Output Measurement:**

   - Repeat the steps outlined in point 2 for the **+6V output** (or similar lower positive voltage output) of the power supply.
   - Measure and record both the maximum and minimum output voltages for this rail in Table 2.

4. **-20V Output Measurement:**

   - Repeat the steps outlined in point 2 for the **-20V output** (or similar negative voltage output) of the power supply.

- **Important:** When measuring the negative output, ensure the DMM's black lead is connected to the negative terminal and the red lead to the common/ground terminal. Your DMM should display a negative voltage reading.
- Measure and record both the maximum and minimum output voltages for this rail in Table 2.

Power Supply Selection	**Maximum Output Voltage (V)**	**Minimum Output Voltage (V)**
+6 V		
+20 V		
-20 V		

PART 2

SOFTWARE LABORATORY PROCEDURES

Test to see what you have learned about PSpice:

1. Find the following components from the library and identify the category they fall in like OP-AMP, transistor, diode, etc. ***(10 points)***

a. 2N222

b. AD741

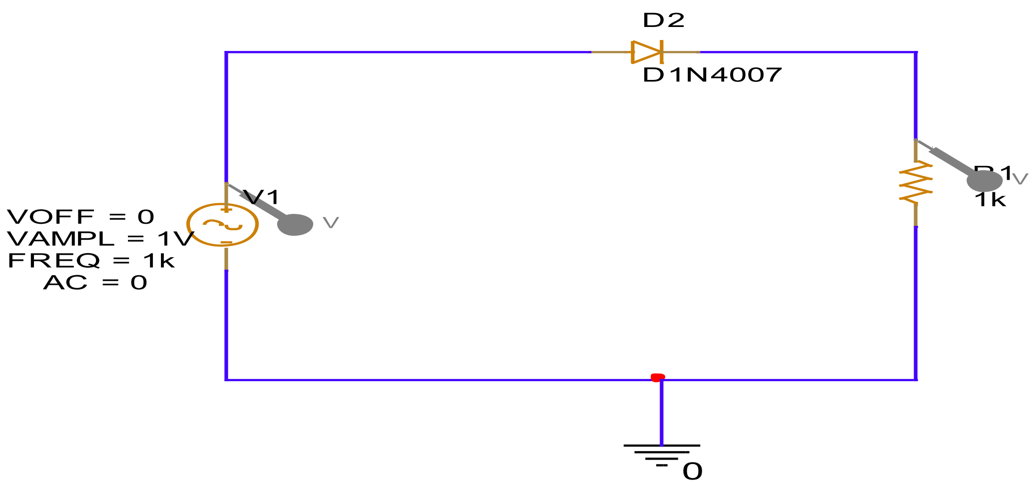
c. D1N4153

2. Given below is a circuit of a rectifier. The values of the components in the circuit are as follows: ***(10 points)***

Diode: D1N4007

Resistor: 1K ohms

Input source: 1Vp-p, 1KHz Sinewave (Select the appropriate input source)

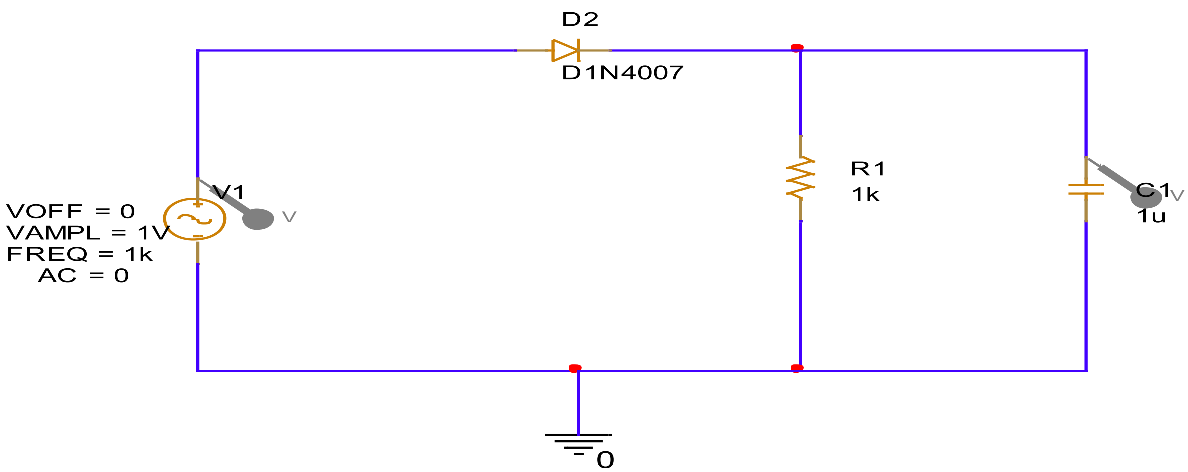


Once the circuit is generated, perform the following steps:

1. Use the voltage probes from the parts and add them to the input voltage source and the resistor respectively as shown in the circuit above.
2. Select "New Simulation Profile" icon and create this simulation profile.
3. A windows of simulation setting will be shown. Select the analysis type as "Time domain (Transient)"

4. Input the "run to time" value as 5ms.
5. Input "maximum step size" as 0.1 or 0.001. Select "Apply" and "OK"
6. A waveform simulation window will appear. Observe the waveform and take a snapshot of this output waveform.
7. To increase the width of the waveform, select the required waveform, right click using the mouse and select the "Trace Property" option from the menu.
8. Increase the width of both the waveforms as per your need. Take a snapshot of this output waveform.

3. Now add a small capacitor of 1uF across the resistor as shown below: ***(10 points)***



Perform steps 1 to 8 from question 2 again for this circuit.

Once you have performed Q.2 and 3, generate a PDF of the observations you have done along with the waveforms for the respective circuit.

4. Identify the type of circuit for the task given, explain the electrical phenomena observed upon adding the capacitor, and describe its critical applications in electronics. ***(10 points)***

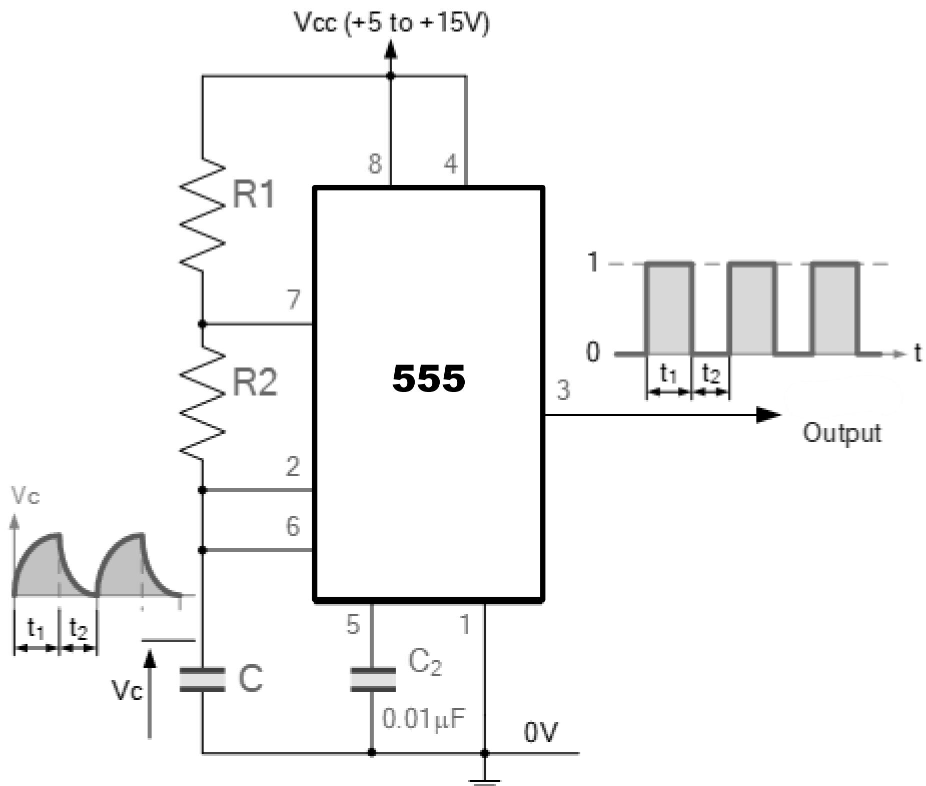
PART 3

CIRCUIT PROTOTYPING PROCEDURES

1. Implementing and Verifying a Square Wave Generator:

This lab task focuses on the practical implementation and verification of a circuit under test (CUT) using a breadboard. We will construct a square wave generator circuit utilizing the NE555 timer integrated circuit (IC). The generated square wave output will be simultaneously observed and analyzed using an oscilloscope and visually confirmed via an LED connected to the circuit's output.

CIRCUIT DIAGRAM:



Use the following formula to calculate the T_1 & T_2:

$$T_1 = 0.693 * (R1 + R2) * C$$

$$T_2 = 0.693 * R2 * C$$

Assume the capacitor values greater than 1µF.

To understand the pin diagram of the IC 555, always download and read the data sheet of the IC from websites like mouser, digikey, etc. These documents give you the necessary information like the power requirements, pin connections, current requirements.

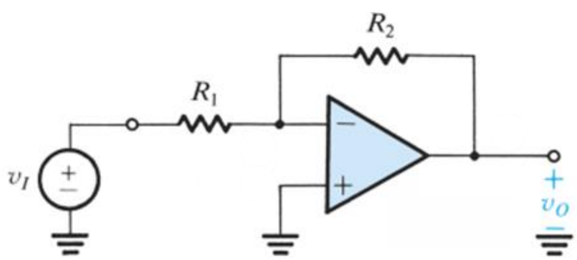
QUESTIONS: **10 points**

1. List all the pin function/names for the IC 555 used from the data sheet.
2. From the data sheet, write all the values for the following *Electrical Characteristics*:
   - Supply Voltage.
   - Input Voltage.
   - Output Current.
   - Operating Temperature.
3. Looking at the circuit, what is the name/type of the circuit we have implemented other than the name "Square Wave Generator"?
4. What will happen if we attach a resistor of 470Ω and a red LED in series to the output terminal? Explain your output in detail.

2. Implementing and verifying the output of a circuit for an OPAMP:

This section details the procedure for implementing a circuit under test on a breadboard and subsequently verifying its output using an oscilloscope. Specifically, we will focus on constructing an inverting amplifier utilizing the **IC741 operational amplifier.**

CIRCUIT DIAGRAM:



PROCEDURE:

Circuit Assembly:

1. Connect the positive terminal of your dual DC power supply (e.g. +12V) to pin 7 of the IC741.
2. Connect the negative terminal of your dual DC power supply (e.g. -12V) to pin 4 of the IC741.
3. Connect the common ground of the DC power supply to a designated ground rail on your breadboard. This will serve as your circuit's ground reference.
4. Connect one end of the input resistor (R_1) to pin 2 of the IC741.
5. The other end of R_1 will be connected to the function generator's output.
6. Connect one end of the feedback resistor (R_2) to pin 6 of the IC741.
7. Connect the other end of R_2 to pin 2 of the IC741, sharing the connection point with R_1.
8. Connect pin 3 of the IC741 directly to the common ground rail on your breadboard.
9. Connect the positive output terminal of the function generator to the free end of R_1.
10. Connect the ground terminal of the function generator to the common ground rail on your breadboard.

Function Generator Setup:

1. Configure the function generator to output a sine wave.
2. Set the frequency to 100 Hz.
3. Adjust the amplitude to 1 V peak-to-peak (Vp-p). Most function generators will have a Vp-p setting. If not, set the amplitude to 0.5 V peak (Vp).

Oscilloscope Setup and Measurement:

1. Connect the probe of oscilloscope **Channel 1** across the input signal. Place the probe tip at the connection point between the function generator output and Rin.
2. Connect the ground clip of the **Channel 1** probe to the common ground rail on your breadboard.
3. Adjust the vertical scale (Volts/Div) and horizontal scale (Time/Div) on **Channel 1** to clearly display the 1 Vp-p, 100 Hz input sine wave.
4. Use the oscilloscope's measurement functions to confirm the input voltage and frequency.
5. Connect the probe of oscilloscope **Channel 2** to pin 6 of the IC741.
6. Connect the ground clip of the **Channel 2** probe to the common ground rail on your breadboard.
7. Adjust the vertical scale (Volts/Div) and horizontal scale (Time/Div) on **Channel 2** to clearly display the output sine wave.
8. Observe the phase relationship between the input and output signals. Use the oscilloscope's measurement functions to determine the output voltage.

Use the following formula to calculate the gain of the circuit and select appropriate values for R1 and R2:

$$\text{Av} = -\frac{R_2}{R_1} * \text{Vin}$$

QUESTIONS: **10 points**

1. List all the pin function/names for the IC 741 used from the data sheet.
2. From the data sheet, write all the values for the following *Electrical Characteristics*:
   - Supply Voltage.
   - Input Voltage.
   - Output Current.
   - Operating Temperature.
3. After you have performed the experiment on the breadboard, take a photograph of your breadboard and the connections to the circuit. Also, take a photograph of the output you observe on the oscilloscope.
4. Write down the values of the input and output waveform from the oscilloscope. Also, write the theoretical values you obtain from the formula used. Explain in detail, the difference between both the values.
5. Compare the phase of the output signal to the input signal. What do you observe, and why?