

ECE 3300
Electrical Circuits: Laboratory
The DC Power Supply and the Multimeter
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This Unit introduces the student to the basic operation of the Rigol DP 832 power supply. It also covers the basic operation of the Rigol DM 3058E Multimeter.

Learning Objectives

By the end of this unit, the student should have an understanding of the use of the Rigol DP 832 power supply and the Rigol DM 3058E Multimeter. More specifically, the student should:

- Have a working knowledge of the various control keys of the [Rigol DP 832 power supply](#).
- Interpret the voltage and current display of the Rigol DP 832 power supply.
- Be able to properly connect the Rigol DP 832 power supply to a load/circuit.
- Be able to identify and connect to the +5V, 30V supplies on the Rigol DP 832.
- Be able to adjust the Rigol DP 832 power supply settings to generate constant voltage and constant current signals on the +6V, +30V supplies.
- Be able to set the limit current and limit voltage on the power supply according to the power rating of the load.
- Be able to set the power supply for voltage tracking of the 30V supplies.
- Know how to connect a voltmeter to a circuit to measure voltage drop between two nodes.
- Know how to connect an ammeter to a circuit to measure current flow in a branch.
- Know how to connect a resistor (capacitor) to a multimeter to measure resistance (capacitance).
- Be able to explain the difference between an ideal voltmeter and a practical voltmeter.

- Be able to explain the difference between an ideal ammeter and a practical ammeter.
- Have a working knowledge of the control keys of the [RIGOL DM 3058E multimeter](#).
- Know how to connect the RIGOL DM 3058E multimeter to a circuit for proper current and voltage measurements.
- Be able to use the RIGOL DM 3058E multimeter to measure DC voltages and DC currents in a circuit.
- Be able to use the multimeter to measure the frequency of an AC voltage or current signal.
- Be able to use the multimeter to measure the RMS value of AC voltages and currents.
- Be able to use the multimeter to measure the RMS value of an AC signal with bias.

The DC Power Supply

A DC power supply is used to generate either a constant (with respect to time) voltage (CV) or a constant current (CC). That is, it may be used either as a DC voltage source or a DC current source. In this lab, the DC power supply will primarily be used as a DC voltage source.

Ideally, the DC voltage source output does not depend on the value of the load (i.e., resistance of the load); this means that any current can flow through the voltage source, as dictated by the load. Here, the power delivered by the source is equal to the product of V_s and the current I_s through the source, or $P = V_s I_s$. The implication, then, is that the DC voltage source is in fact a power source. The symbol for an ideal voltage source is shown in Figure 1-a.

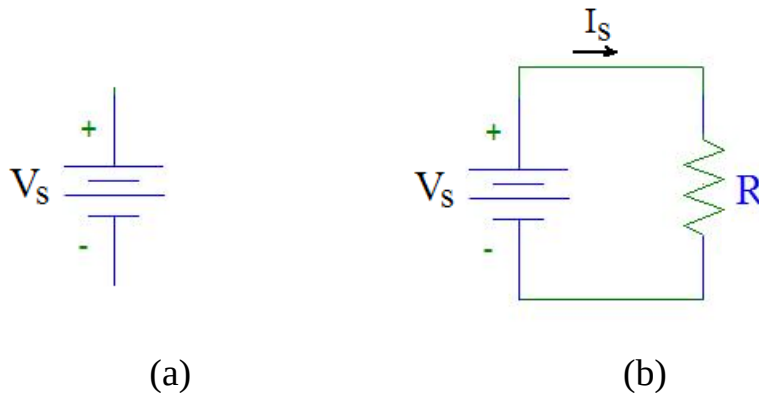


Figure 1. (a) Symbol for a DC voltage supply, and (b) a simple DC circuit.

The simplest circuit involving a DC voltage source is shown in Figure 1-b. Here, the voltage across the resistor (V_s) is constant and is set by the voltage source. On the other hand, the current in the resistor is determined by the value of R , according to Ohm's Law $I = V_s/R$ (for this circuit, $I = I_s$); we say that the current through the resistor is inversely proportional to resistance. For example, if $R = 1\text{k}\Omega$ and $V_s = 5\text{V}$, then, $I = 0.5\text{mA}$. In the limit as $R \rightarrow 0\Omega$ (i.e., the load is a short circuit), the current would approach infinity! This is physically impossible, because it implies that the source is capable of supplying infinite power (power dissipated in the resistor is given by $P = V_s I = \frac{V_s^2}{R} \rightarrow \infty$, as $R \rightarrow 0$).

In practice, a DC voltage supply can maintain a constant output voltage, but only over a finite range of supplied current. Typically, and as a safety feature, the DC power supply allows the user to set the *maximum (limit) current* (I_{max}) that can be delivered to the load. Here, if the user accidentally connects the power supply to a circuit that has very low input resistance, the supply will limit the current and prevent damage to the circuit. In this situation, the supply voltage drops from its initial set value to a lower value that is consistent with Ohm's law. For example, consider the circuit in Figure 1-b with a practical DC power supply. Let V_s and I_{max} be set to 6V and 40mA, respectively. Now, consider two scenarios: (1) $R = 1000\Omega$ and (2) with $R = 100\Omega$. In the first scenario, and according to Ohm's law, the resistor (and supply) current is equal to $6/1000 = 6\text{ mA}$. This value is well below the 40mA maximum supply current; therefore the supply is capable of maintaining the 6V across the resistor. On the other hand, for the second scenario, the required load current is equal to $6/100 = 60\text{mA} > I_{max}$. Here, the power supply internal circuit is forced to adjust its output voltage; otherwise, Ohm's law would be violated. Therefore, the power supply (delivering the maximum current of 40mA) automatically changes its V_s to $(100\Omega)(40\text{mA}) = 4\text{V}$.

The Rigol DP 832 Power Supply

The DC power supply used in the lab is a triple output, Rigol DP 832; we will refer to it as the DC power supply. This section is a tutorial on the basic functions of this instrument. The front panel of the DC power supply is shown in Figure 2.



Figure 2. The Rigol DP 832 Power Supply.

This power supply provides three separate DC voltage outputs; it delivers 0 to +30V and 0 to -30V outputs (with supply current in the range 0 to 3A), and 0 to +5V output (with supply current in the range 0 to 3A). The voltage and current of each supply can be adjusted independently. The $\pm 25V$ supplies also provide 0 to $\pm 25V$ *tracking output* to power operational amplifiers and other active circuits requiring symmetrical voltages. Figure 3 shows a close-up image of the three sets of output terminals. Figure 4 depicts five different ways of connecting (a load) to the DC power supply. The generated voltages can be used as floating voltages in a circuit; they can also be used with the “+” or the “-” terminal connected to the circuit ground node.

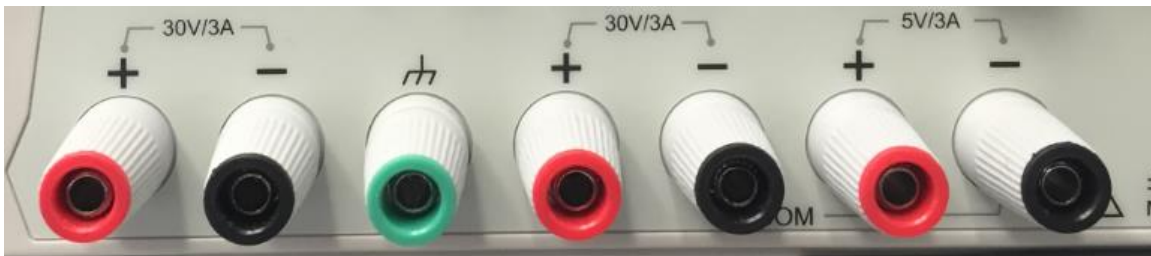
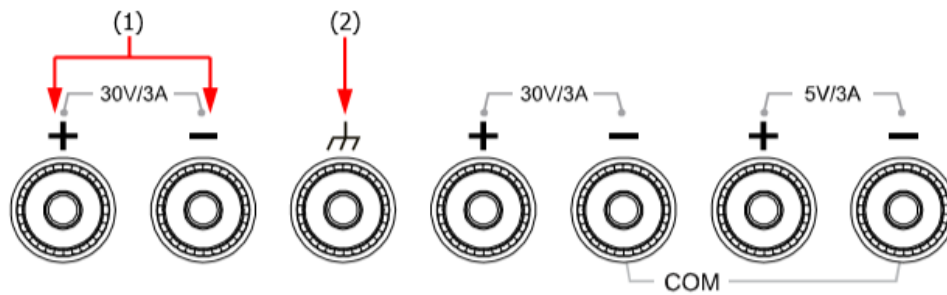


Figure 3. Close-up image of the DC power supply output terminals.

DP832:



(1) Channel output terminals: used to output the voltage and current of the channel.

(2) Ground terminal: this terminal is connected to the instrument chassis and ground wire (the ground terminal of the power cord) and is in grounded state.

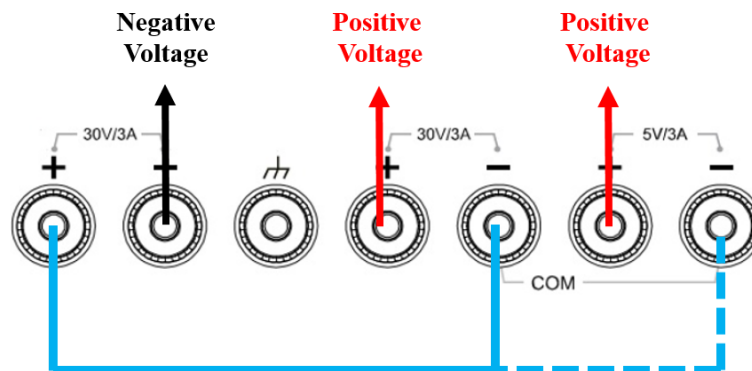


Figure 4. Connecting to the DC power supply.

Negative voltage

The DP832 power supply can generate the negative by following steps:

1. Connect the positive terminal of Ch1 to the negative terminal of Ch2 and 3. Which these three terminal are your circuit ground.
2. The negative terminal of Ch1 is then the negative output, the positive terminal of Ch2 the positive output and Ch3 is positive and referenced to the same ground.



The DC power supply output terminals (binding posts) accept banana plugs. Figure 5 shows banana plug test leads, with two different terminations, for use with the DC power supply.



Figure 5. Banana connector terminated (left) and alligator clip terminated (right) test leads for use with the DC power supply.

Using the front panel keys and control knob, the user can adjust the voltage and current of a selected output (refer to Figure 6). The front panel includes two 4-digit meters (with vacuum-florescent display) that display the voltage and current values of a selected supply output. Note: the supply current meter will read zero if no load is connected to the power supply.



Figure 6. Front panel control keys and knob

Each outputs of the DC power supply can be enabled or disabled by toggling



the key. The  keys allow the selection of the output supply. Once selected, the voltage value can be adjusted using the control knob or num-pad. The control knob can selectively adjust digits. Digits are selected



using the and keys. The **OCP** and **OVP** function allows the user to preset a proper overcurrent/overvoltage protection value, i.e. the *voltage* and *current limits* on the selected supply output.

The following steps allows the user to set up the DC power supply for constant voltage (CV) operation:

1. Select proper the channel according to the desired output voltage

2. Set the voltage:

Method 1

Press **Voltage** and use the left/right direction key to move the cursor; then, rotate the knob to quickly set the voltage and the default unit is V. After selecting the digit to be set, you can also use the up/down direction key to modify the value of the corresponding digit. The default unit is V

Method 2

Press **Voltage**, use the numeric keyboard to directly input the desired voltage value and press **V** or **mV** or press the unit selection key ( or ) to select the desired unit. Besides, you can also press **OK** to select the default unit (V). During the input, you can press **Back** to delete the character currently before the cursor or press **Cancel** to cancel the input.

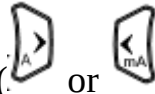
3. Set the current

Method 1

Press **Current** and use the left/right direction key to move the cursor; then, rotate the knob to quickly set the current and the default unit is A. After selecting the digit to be set, you can also use the up/down direction key to modify the value of the corresponding digit. The default unit is A.

Method 2

Press Current, use the numeric keyboard to directly input the desired current value and press **A** or **mA** or press the unit



selection key (or) to select the desired unit. Besides, you can also press **OK** to select the default unit (A). During the input, you can press **Back** to delete the character currently before the cursor or press **Cancel** to cancel the input.

4 Set the overcurrent protection

Press **OCP** to set a proper overcurrent protection value (for the setting method, refer to "Set the current"). Then, enable the overcurrent protection function (you can enable or disable the OCP function by pressing OCP) and the output will be turned off automatically when the actual output current is greater than the overcurrent protection value.

Note: In constant voltage mode (CV operation), the voltage values between the meter mode and limit mode are the same (i.e., limit voltage tracks the output voltage), but the current values are not. Also in this mode, if a load change causes the current limit to be exceeded, the DC power supply will automatically crossover to the constant current mode at the preset current limit (I_{max}), and the output voltage will drop (refer to the preceding discussion on this issue).

In order to configure the DC power supply to operate as a DC *current source* [constant current (CC) mode], set the current limit to 0A (or to a small value) and set the voltage limit to the desired maximum value (follow Steps in the above procedure).. The “CC” annunciator (**CC**) should be lit when you turn the channel ON. Now, connect a load and increase the output current, using the knob (and the arrow keys if needed), to the desired value. If at any time the CV annunciator (**CV**) is lit, choose a higher limit voltage value.

Important note: Always keep in mind the power rating of the load. For example, when the load is a resistor with power rating P_{max} ($\frac{1}{4}$ Watt, $\frac{1}{2}$ W, 1W etc.), make sure that the (displayed) power supply output voltage and output current obey the inequality $V_s I_s < P_{max}$ at all times. **In order to avoid**

accidents, you will further restrict the product $V_s I_s$ to a value less than $\frac{1}{2} P_{max}$. Here, $V_s I_s$ is the power dissipated in the resistor.

As a safety precaution, while the DC power supply is in the CV output mode, make sure that the limit current (I_{max}) is set such that $I_{max}^2 R < \frac{P_{max}}{2}$ or

$I_{max} < \sqrt{\frac{P_{max}}{2R}}$. When operating in the CC mode, the limit voltage must obey

$\frac{V_{max}^2}{R} < \frac{P_{max}}{2}$ or $V_{max} < \sqrt{\frac{P_{max} R}{2}}$. **A good practice is to never connect the load to the supply before setting the limit current and limit voltage to satisfy $V_{max} I_{max} < \frac{1}{2} P_{max}$.**

In the *tracking mode*, the two voltages of the $\pm 25V$ supplies track each other within $\pm(0.2\% \text{ of output} + 20\text{mV})$; for example, if the supply voltage is set to $\pm 12V$ then the tracking voltage error between the $+12V$ and the $-12V$ channels would be $\pm(0.002 * 12 + 0.02) = \pm 44 \text{ mV}$. Refer to Figure 7 for the output terminal configuration for the tracking mode.

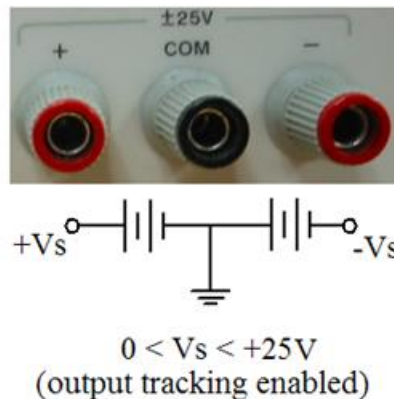


Figure 7. Supplying power in the output *tracking mode*.

To operate the DC power supply in the *tracking mode*, do the following:

1. Press **Utility** → ☐ **System** → **Track Set** → ☐ **Track** to switch between "Synchronous" and "Independent"
 - **Independent:** for two channels (the channels should be of the same instrument) that support the track function, the status of the track function of the other channel will not be affected when the track function of a channel is enabled or disabled. ☐

- **Synchronous:** for two channels (the channels should be of the same instrument) that support the track function, the track function of the other channel will be enabled or disabled at the same time when the track function of a channel is enabled or disabled.
2. Enable the tracking mode by pressing the **Track** key The tracking status icon  will be displayed between CH1 and CH2 . The CH2 supply will now be set to the same voltage that you have set for the CH1 supply. Any change in the voltage value of the CH1 supply will also be reflected in the CH2 supply output (and vice versa).
 3. From the front panel display, verify that the CH1 supplies track each other properly by comparing the voltage values of the CH2 supply



Figure 8. front panel display for step3

The Multimeter

A multimeter is an important measuring instrument. It is generally easier to use to measure electric signal parameters compared to a scope. A multimeter can be quickly configured to measure voltage, current, frequency, resistance and capacitance. The configuration involves: (1) Setting, by pressing a key (or turning a control knob), the multimeter to one of the following *measurement modes*: DC voltage, AC voltage, DC current, AC current or resistance, and (2) connecting test leads to the proper input terminal on the multimeter's front panel. The order of these two steps is very important. **Never change a multimeter's measurement mode while it is connected to a circuit; this could damage the meter and/or the circuit.**

When the multimeter is configured for measuring voltage, it is referred to as a *voltmeter*. Similarly, if the multimeter is configured for measuring current, it is called an *ammeter*. An *ohmmeter* is a multimeter configured for measuring resistance.

The proper connection of a voltmeter to a circuit is shown in Figure 8. **To measure the voltage between two circuit nodes, say the voltage across an electronic component, the voltmeter must be connected across (in parallel with) the component.** The voltage reading is actually the potential difference between two points in the circuit. The voltmeter input terminal consists of a set of two plugs; one plug (usually painted red) labeled “+” and the other plug (usually painted black) labeled “-“. The voltmeter's reading is the voltage at the node connected to the “+” plug measured with respect to the node connected to “-“ plug.

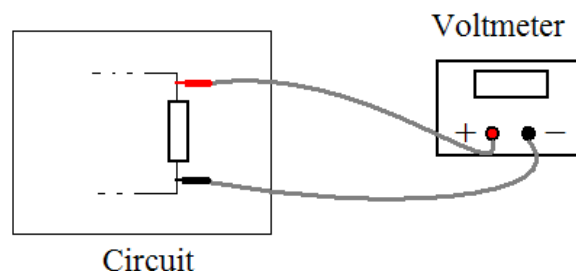


Figure 8. Proper connection of a voltmeter to measure the voltage drop across a circuit component.

In order not to affect the electric behavior of the circuit being measured, the voltmeter is designed to have a very high input (internal) resistance (approx. $10\text{M}\Omega$). Ideally, the voltmeter is modeled as an open circuit; i.e., an infinite resistance component that does not load the circuit it is connected to (Figure 9-a). On the other hand, a practical voltmeter has a large, but finite resistance (Figure 9-b). This resistance must be accounted for when the voltmeter is connected across a high resistance component.

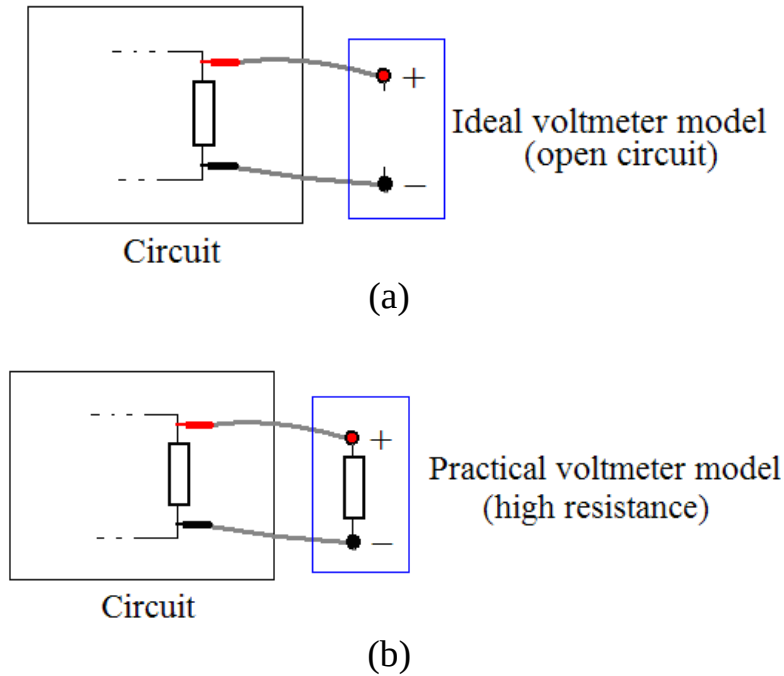


Figure 9. (a) Ideal and (b) practical voltmeter models.

Let us now turn our attention to a generic ammeter instrument. **To measure current in a wire, you have to “break” the wire and connect the ammeter so that the current flows through it.** Figure 10(b) depicts an ammeter inserted in a circuit to measure the branch current “ I_1 ” [shown in Figure 10(a)]. The proper connection should also have the current enter the “+” (red) plug and exit the “-” (black) plug of the ammeter; otherwise, if the current enters the red plug of the ammeter, the ammeter will register a reading of negative I_1 .

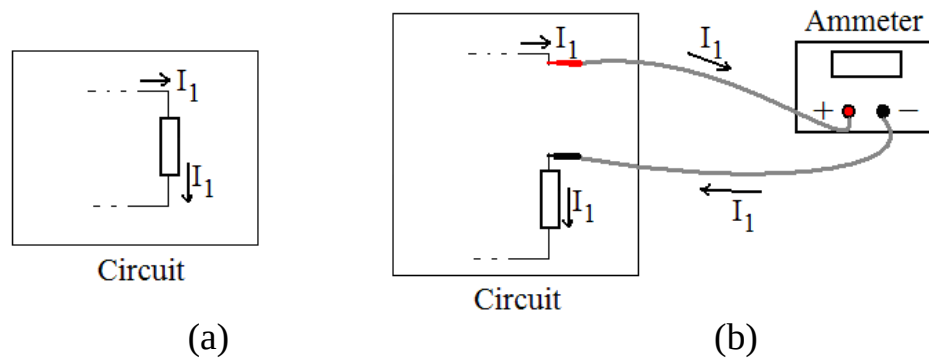


Figure 10. (a) A circuit with branch current I_1 , and (b) proper placement of the ammeter to measure I_1 .

In order not to affect the electric behavior of the circuit being measured, the ammeter is designed to have a very small input (internal) resistance. Ideally, the ammeter is modeled as a short circuit; i.e., a zero resistance component that does not affect the circuit that it is connected to (Figure 11-a). On the other hand, a practical ammeter has a very small, but non-zero resistance (Figure 11-b). This resistance must be accounted for when the voltmeter is connected in series with a component that has a small resistance.

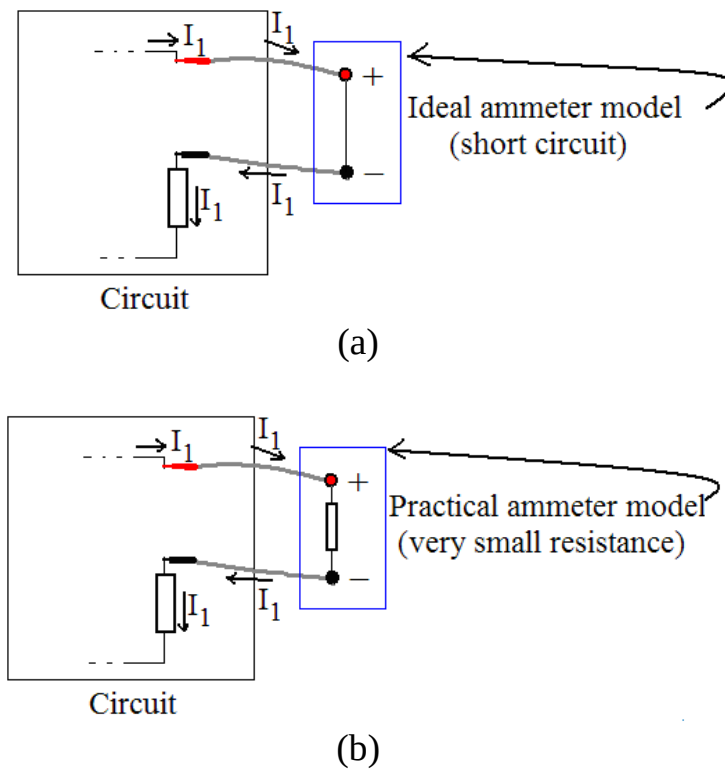


Figure 11. (a) Ideal and (b) practical ammeter models.

The Ohmmeter is used to measure resistance, and is very simple to operate. Basically, you connect the test leads from the ohmmeter across a single resistor (Figure 12). **The resistor to be measured must not be connected to any other components.** The ohmmeter always returns a positive reading.

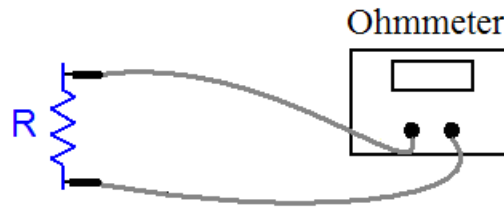


Figure 12. Setup for measuring the value of a resistor.

The resistance of a network of (only) resistors can also be measured. In this case, the ohmmeter will measure the equivalent (or net) resistance of its load (resistive network); see Figure 13. **Note: the ohmmeter must not be connected to a powered circuit.**

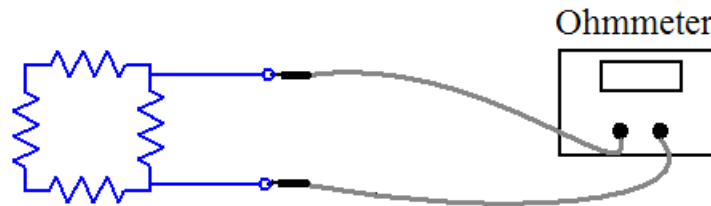
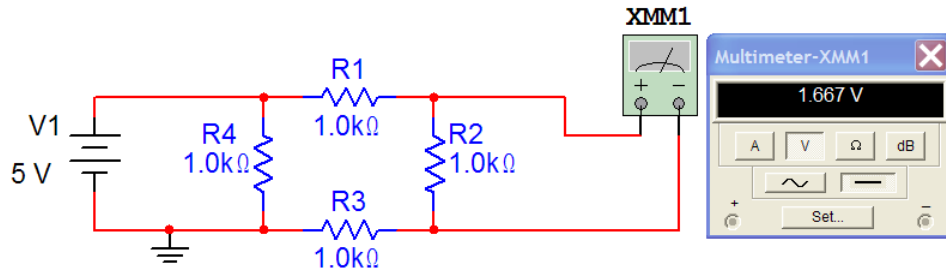


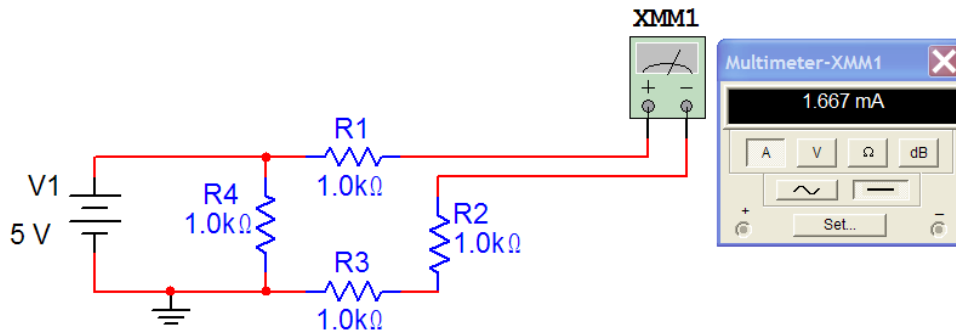
Figure 13. Measuring the equivalent resistance of a network of resistors.

Some multimeters can also measure capacitance of a single capacitor or an unpowered network of capacitors; their operation is very similar to that of an ohmmeter.

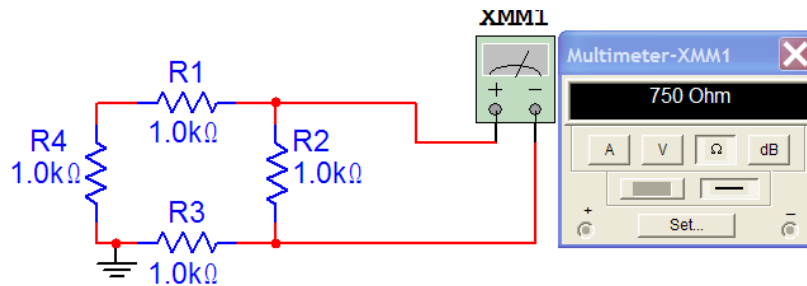
Circuit simulator allow for virtual multimeters. For example, the virtual multimeter in Multisim can measure voltage, current and resistance. Figure 14 shows three simulations where the ammeter was used to measure (a) the DC voltage across R2, (b) the DC current through R2 and (c) the equivalent resistance of a network of four resistors.



(a)



(b)



(c)

Figure 14. Employing Multisim's virtual multimeter to measure (a) DC voltage, (b) DC current and (c) equivalent resistance.

The RIGOL DM 3058E Multimeter

Each workstation in the lab has two digital multimeters (DMMs): A Model RIGOL DM 3058E multimeter and a Model DM-441B multimeter. In this section, the operation of the more versatile dual display RIGOL DM 3058E DMM is described. The front panel of the model RIGOL DM 3058E Multimeter is shown in Figure 15. For the rest of this unit, this instrument will be referred to as the DMM.

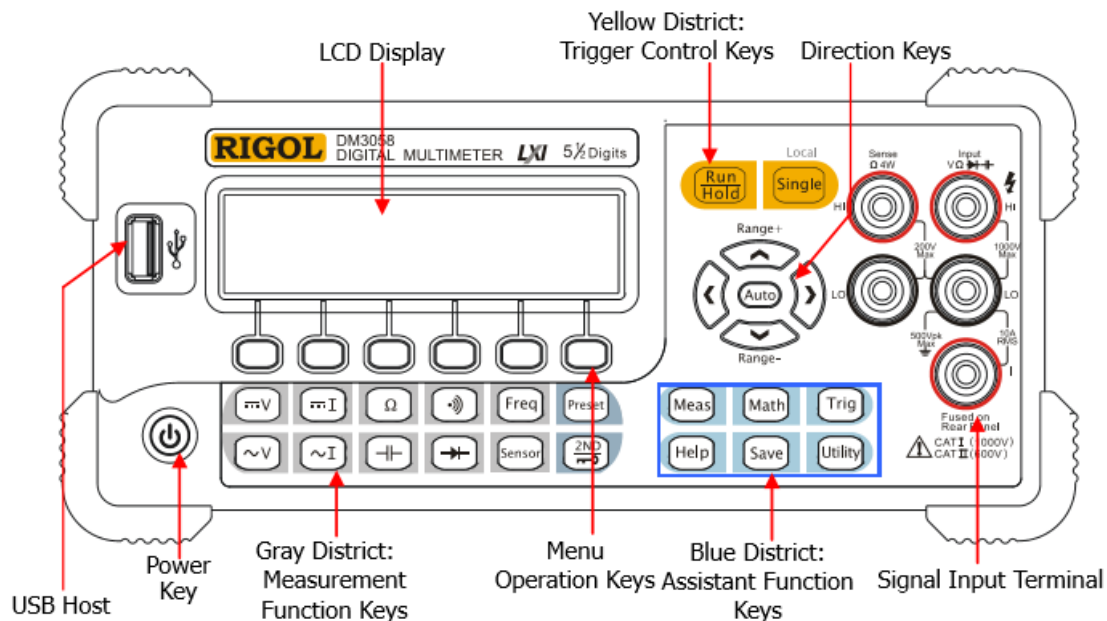
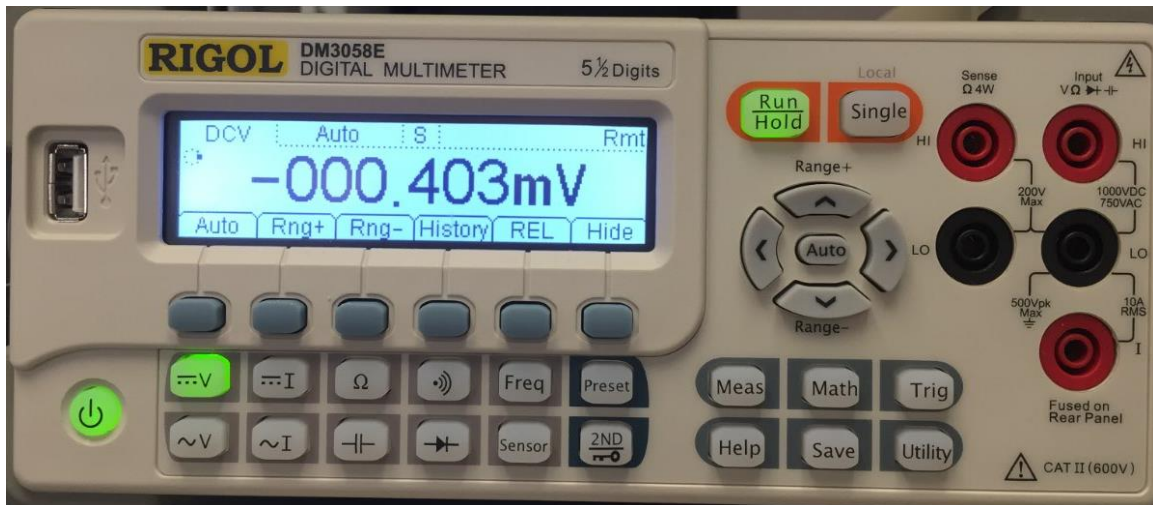


Figure 15. Front panel of the model RIGOL DM 3058E multimeter.

The DMM requires to be powered for several minutes before accurate measurements can be made. The DMM allows the measurement of AC/DC voltage, AC/DC current, resistance, capacitance, frequency, and continuity. These functions are enabled using the primary keys (refer to Figure 16). For example, to configure the DMM to measure DC voltage, press the  key. to configure the DMM to measure AC voltage, press the  key.

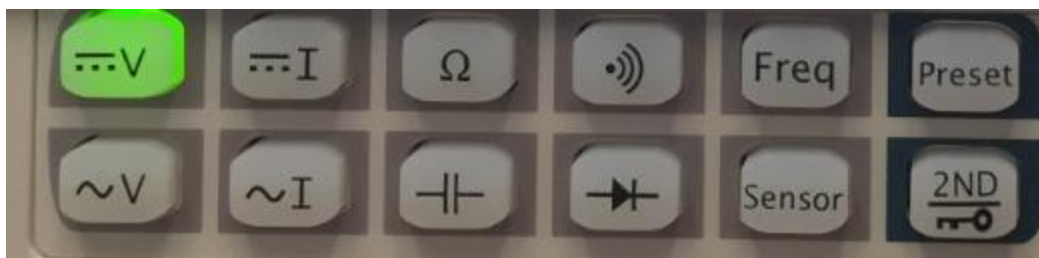
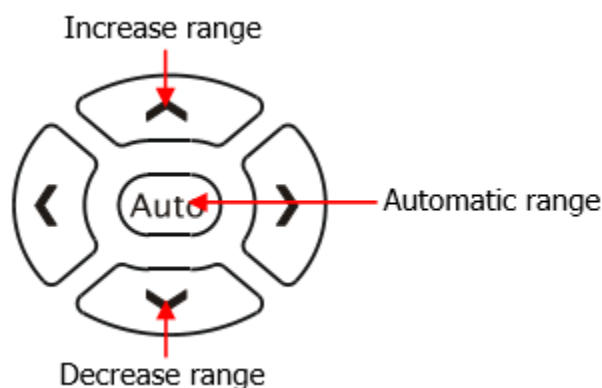


Figure 16. The DMM's push button control keys.

Using the Range selection keys (refer fig 17) toggles between the *auto range* and *manual range modes*. In the auto range mode, the DMM automatically sets the proper range for the measurement being made. In the manual range

mode, the user sets the range using the  and  keys.



The input to the DMM has three connection configurations:

- (1) voltage/resistance/capacitance configuration,
- (2) low current configuration
- (3) high current configuration.

Let us assume that a pair of red and black banana-connector-terminated test leads is being used to connect the DMM to a circuit, or to an isolated component. Figure 17 depicts the DMM input port. For all three connection configurations, the black test lead must be connected to the DMM black female input terminal. For measuring voltage, resistance, capacitance or doing a diode test, the red test lead must be inserted in the DMM red female plug (as shown in Figure 18-a). Figure 18-b shows the proper test lead connection for small current measurement ($I < 10\text{Amp}$).

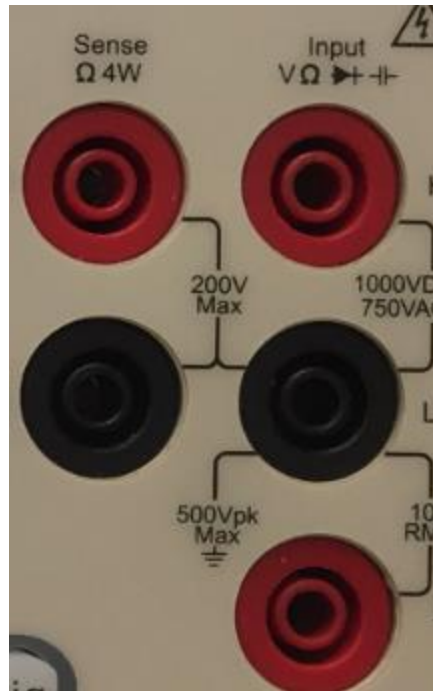


Figure 17. The DMM input port.



(a)



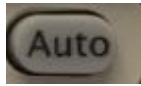
(b)

Figure 18. Test leads connection to the DMM for measuring (a) voltage, resistance and capacitance, and (b) small currents.

The following is a step-by-step example for measuring the DC voltage generated by the DC power supply (refer to the setup in Figure 19):

- Turn ON the DC power supply and the DMM. **DO NOT** connect any test leads between the two instruments, yet.
- Wait several minutes until both instruments warm-up and stabilize for proper operation.
- Set the output voltage of the power supply to, say, 1V.



- Press the  key on the DMM to select DC voltage input mode.
- Press the arrow keys on the DMM to set the desired range. If you have no idea about the value of the input, set the DMM to auto range by pressing the  key.
- Connect the test leads as shown in Figure 19.
- Read the displayed value.

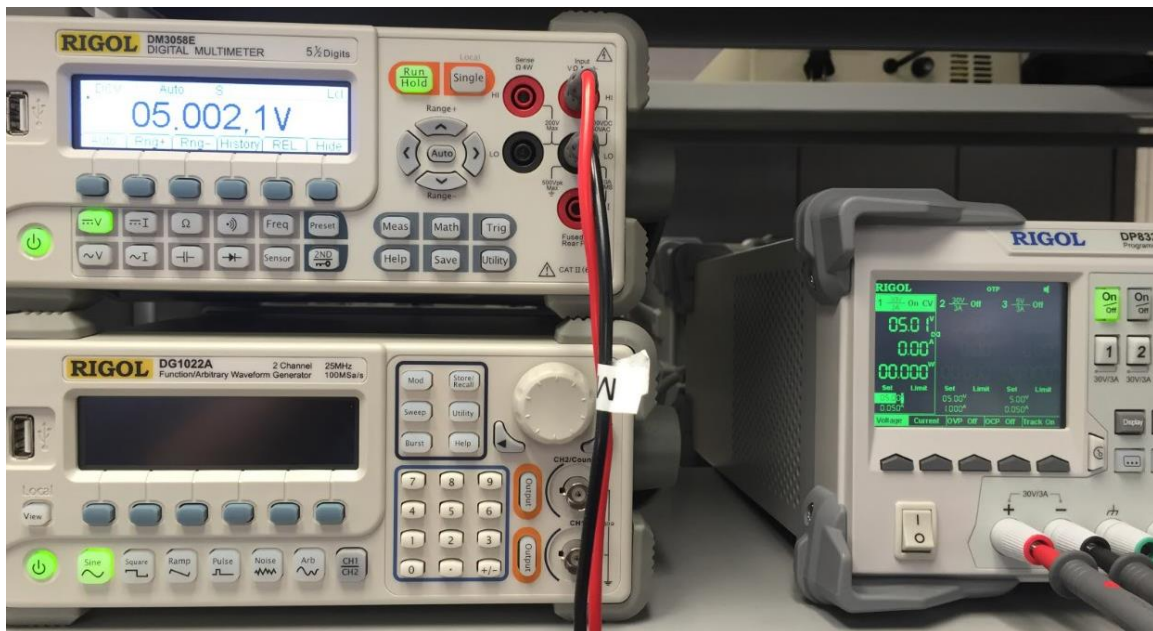


Figure 19. Example setup for verifying the output voltage of the DC power supply.

When in one of the AC measurement modes (e.g., the  ACV  ACI modes), the DMM displays [RMS values](#) on the primary display. Recall that the RMS value of the sinusoidal signal $A\sin(\omega t)$ is equal to $A/\sqrt{2}$. If the input is of the form of a sine wave plus offset, $A\sin(\omega t) + B$, The RMS value is computed according to the following formula:

$$\text{RMS Value} = \sqrt{\left(\frac{A}{\sqrt{2}}\right)^2 + B^2}$$

Waveform	Crest Factor (C.F.)	AC RMS	AC+DC RMS
	$\sqrt{2}$	$\frac{V}{\sqrt{2}}$	$\frac{V}{\sqrt{2}}$
	$\sqrt{3}$	$\frac{V}{\sqrt{3}}$	$\frac{V}{\sqrt{3}}$
	$\sqrt{\frac{T}{t}}$	$\frac{V}{C.F.} \times \sqrt{1 - \left(\frac{1}{C.F.}\right)^2}$	$\frac{V}{C.F.}$

Figure 1 True RMS AC Measurement of Sine, Triangle and Square waves

Somehow, you might want to know the AC+DC true RMS value. You can determine this value by following formula:

$$RMS_{(AC+DC)} = \sqrt{AC^2 + DC^2}$$

Pre-Lab Activity (Experiment 3)

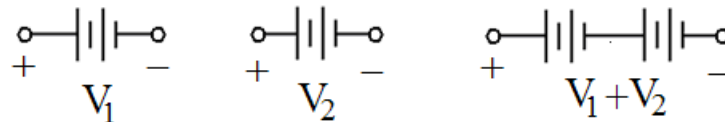
Read the material in this Unit before coming to the Laboratory. Solve the following exercises and submit your solution to your instructor. There will be a 10-15 min quiz on this pre-lab activity at the beginning of the lab session.

Exercises

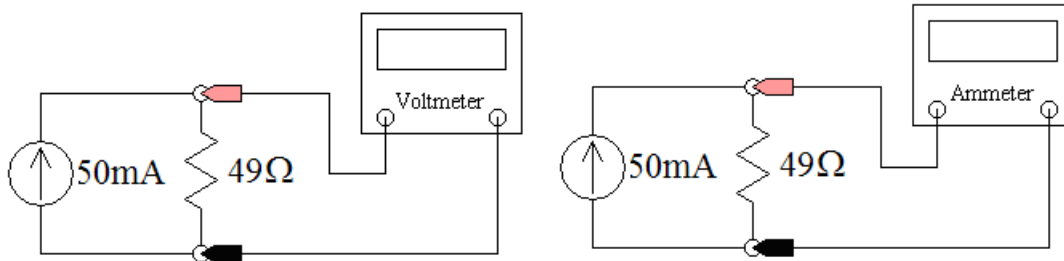
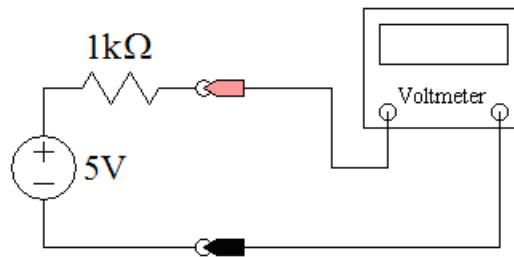
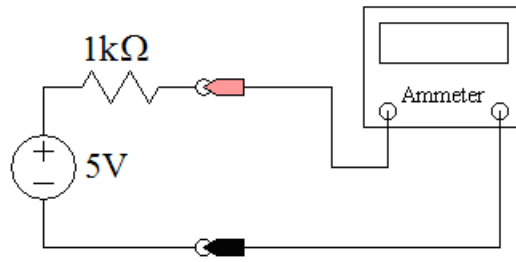
1. Consider the DC power supply with the following settings: +5V supply set to 4.5V output, *limit current* set to 30mA, *limit voltage* set to 5V. What are the readings of the voltage and current displays

if a load $R = 1\text{k}\Omega$ is connected across the +5V supply terminals. Repeat for $R = 47\Omega$.

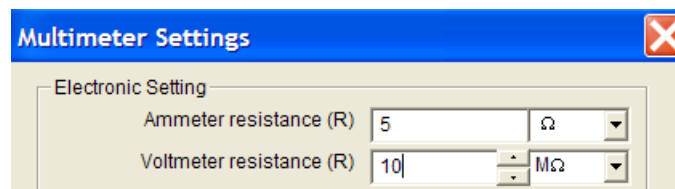
2. Consider the DC power supply with a load of $1\text{k}\Omega$ placed across the +30V supply terminals. The *limit current* for the +30V supply is set to 12mA. At what output voltage value would the power supply go into the *current control* (CC) mode?
3. An DC power supply, operating in the CV mode, is loaded at its +30V supply terminals by a ($\frac{1}{2}$ Watt) 100Ω resistor. What is a safe range for the *limit current*?
4. Assume that the DC power supply is operating in the *tracking mode*, and that the +25 supply output is set to 14V. Determine the tracking error between the -25V supply and the +30V supply.
5. Draw a diagram that shows the proper output terminal connections of the DC power supply for supplying a DC voltage in the range 0 to +56V. Hint, the total voltage of two voltage sources placed in series is equal to the algebraic sum of the individual voltages; refer to the figure below and pay attention to source polarity.



6. Employ Ohm's law to determine the ideal voltmeter and ammeter readings for the following circuits (recall that the ideal ammeter has zero input resistance, and the ideal voltmeter has infinite input resistance).



7. Repeat Problem 6 using Multisim. Set the internal resistance of the voltmeter to $10M\Omega$ and that of the ammeter to 5Ω (refer to the figure below).



Tabulate the error between your answers and the corresponding (ideal) ones of Problem 6.

8. The RIGOL DM 3058E multimeter is used in the AC+DC voltage mode to measure a voltage signal given by $2 + 3\sin(500\pi t)$ Volts. What is the reading of the multimeter.
9. Employ Multisim to find the resistance of the resistor network shown below. Compare your answer to the theoretical value.

