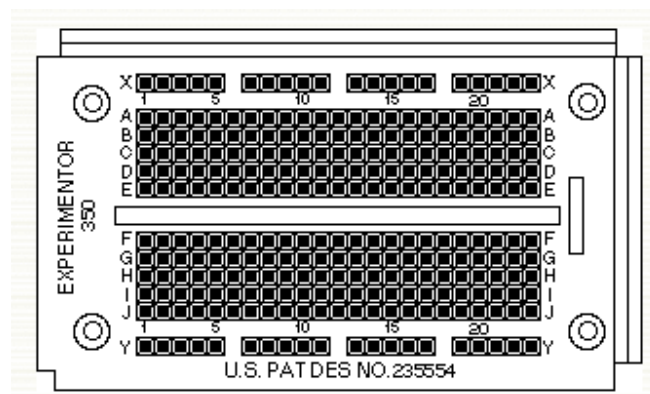

Basic Measurements / Resistive Circuits

Objective: To learn to use two basic lab tools - the Digital Multimeter (DMM) and the DC power supply – and to use these tools to evaluate resistive circuits.

Background Information

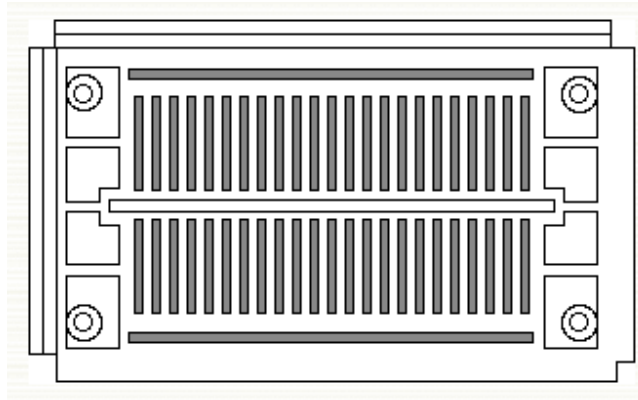
Breadboards: The best method of experimenting with ICs and building simple circuits with leaded components such as resistors is to use a "breadboard" to build circuits. Breadboards, more formally known as *solderless modular sockets*, get their name from the early days of radio, when it was common to build vacuum tube circuit prototypes on a wooden breadboard.

Today's breadboards are a grid of insulating plastic atop a pattern of conducting metal strips. Here is a top view of a typical breadboard:



Component leads and wires are inserted into the holes and make contact with the conducting metal strips underneath, thus "connecting" them together.

The pattern of conducting strips underneath the insulating plastic is shown below. Notice there are two horizontal strips along both sides of the breadboard and a series of shorter vertical strips. The two horizontal strips are normally used for power supply connections, with one strip being the supply voltage and the other being the ground connection. (Breadboards with four horizontal strips are available, and are used for circuits requiring dual polarity or multiple voltage power supplies.) The horizontal strips are often known as *rails*.



Note the gap separating the vertical strips. The dual in-line package (DIP) IC is normally placed across this gap. One row of pins is one side of the gap, and the other row of pins is on the opposite side.

Leaded components such as resistors, capacitors and transistors are connected between vertical strips or between a strip and the power or ground rail. Wires can also be used as jumpers to interconnect vertical strips.

Bend the leads at 90 degrees to keep the components flat against the surface of the board. A 2 dimensional layout is much easier to troubleshoot for wiring errors than a 3 dimensional mess of wires, components and clip leads.

Breadboards come in a variety of sizes, and are usually measured in terms of the number of connection or "tie points" provided. Some breadboards come with binding posts for connecting a power supply; deluxe models have power supplies built in and with additional supports for potentiometers, LEDs, and meters

The ECE shop will provide a suitable medium size breadboard at a cost of \$20.

DMM: The multimeter is the most fundamental measurement tool for use with electrical circuits. It is called a multimeter because it is capable of multiple types of measurements. The Tektronix CDM250 bench multimeter which we will be using combines the capabilities of three fundamental meters:

Ammeter	Measures current	
Voltmeter	Measures voltage	
Ohmmeter	Measures resistance	

When you see a symbol for one of these meters in a circuit schematic, understand that you are intended to configure the multimeter in the appropriate mode to make the desired measurement.

The multimeter is further specified as a digital multimeter, indicating that the measurement value is displayed as a number, that is digitally, rather than via the position of a moveable pointer.

The resolution of a meter is the smallest change in measured value which can be detected. For example, a digital meter which displays voltage with two decimal places – e.g. 2.00V – has a resolution of 0.01V, or 10mV*. The voltage being measured could be anywhere between 1.995 and 2.005V. Depending on where in that range the voltage was, a change in voltage less than 0.01V might or might not change the displayed value, but a change of 0.01V definitely would.

* This assumes the nearest value displayed would be either 1.99 or 2.01, and not 1.95 or 2.05. In the latter case the resolution would be 0.05V. The data sheet of the meter provides the manufacturer's guaranteed resolution.

Power Supply: As the name implies, a power supply supplies power to the circuit under test. As a circuit element, the bench power supply will act as an ideal voltage source. The HP 6237B actually provides three output voltages which can be adjusted. The adjustment procedure is outlined in the Equipment Tutorial.

References: Read the relevant sections of the Equipment Tutorial posted on the class website. General information on resistors can be found at:

<http://www.doctronics.co.uk/resistor.htm>

<http://en.wikibooks.org/wiki/Electronics/Resistors>

Note especially the explanation of the color code and the E24 series of resistor values.

Experiment

Part 1: Voltage Measurements

Set the bench DMM to measure DC Volts on the 20V full-scale range. Connect the DMM to the +18V output of the power supply. (Note: “+18V” is a label which indicates the maximum value of this particular output. The actual voltage is only +18V if we set it to +18V.) The V/ Ω terminal of the DMM should be connected to the +18V terminal of the power supply, and the COM terminal of the DMM should be connected to the COM terminal of the power supply. Schematically, the connection is

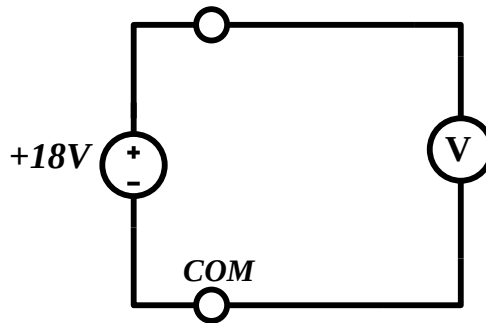


figure 1

Electrons are, of course, colorblind, so the measurement will be the same regardless of the colors of the test leads. For your own benefit, however, it is recommended that you follow the convention of using black for the common lead and red for the V/ Ω ohm lead.

1. Turn on the DMM and the power supply. Adjust the power supply to get a reading of 7.0V on the DMM. To which full-scale range must the DMM be set if the display only shows one digit past the decimal? (i.e. 7.0 and not 7.00 or 7.000) What is the lowest range that can be used to measure 7V? How does the DMM display an out-of-range measurement?
2. Compare the voltage measured by the DMM to the voltage displayed on the face of the power supply. Do they agree? What would you say is the resolution of the voltmeter on the power supply? (refer to the Background section for a definition of resolution.)
3. Now use the DMM to set the +20V output to +10.0V. Does the meter on the power supply agree with the DMM? Be sure the "METER" switch on the power supply is set correctly.
4. Use the DMM to set the -20V output to -5.0V. Does the meter on the power supply agree with the DMM?
5. Verify that the three outputs are still at the desired values:
+18V output @ +7.0V,
+20V output @ +10.0V, and
-20V output @ -5.0V.
Now make the following measurements:
+18V output with respect to the +20V output
+18V output with respect to the -20V output
+20V output with respect to the -20V output
6. Verify that there is a jumper wire connecting the COM terminal to the Ground terminal on the power supply. Measure the three output voltages with respect to the Ground terminal using the DMM. Are they the same as when referenced to COM?

Now remove the jumper wire. What are the voltages of the three outputs measured with respect to Ground? What are they if measured with respect to COM?

Replace the jumper wire, but note that it is optional. The COM terminal is the common terminal for the three outputs, not the ground terminal. When we create circuits in later labs that have a common node, or “local ground”, we will use the COM terminal for that node.

Part 2: Resistance measurements

Configure the DMM for resistance measurement by pressing the Ω button. Select the 20k range. The schematic below shows the connection for a simple resistance measurement. We will use the Power Resistor Decade Box for R in this step. Connect the V/ Ω terminal of the DMM to either red terminal on the decade resistor box, and the COM terminal of the DMM to either black terminal. Note: the two red terminals on the decade box are internally connected to each other, as are the black terminals.

1. Set R to 5k. Some of the older boxes may use “m” as the prefix for 1000 rather than “k”. What is the actual value of R ? What is the lowest range of the DMM you can use to measure this resistance?

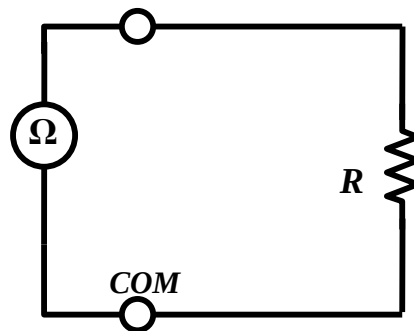


figure 2

2. Now add your handheld DMM to the circuit as shown in figure 3. Configure the handheld DMM as a voltmeter by selecting one of the DC Volt ranges with the rotary switch. Does the resistance measurement change when the voltmeter is added?

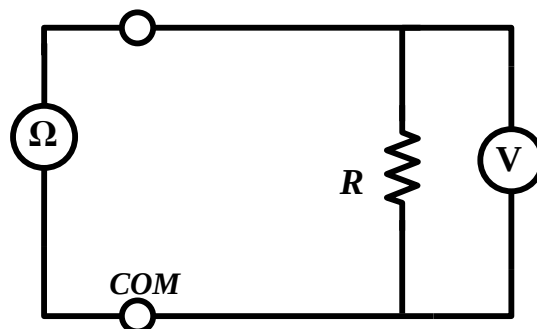


figure 3

3. Make a table in your lab notebook and record the measured resistance and the voltage across the resistor for $R=1k$, $2k$, $5k$, and $10k$, using the $20k$ range on the benchtop DMM. Repeat using the $200K$ range. Using Ohm's law with the measured resistance and voltage values, calculate current in the resistor for each measurement. What is the average current for each of these two resistance ranges of the ohmmeter?

4. Remove the handheld DMM from the circuit and reconfigure it as an ammeter. Do this by rotating the switch to select one of the DCA settings. We will use the $200\mu A$ range. With the ohmmeter on the $20k\Omega$ scale and R at $5k$, add the ammeter as shown in figure 4 below. Is the measured current close to the current you calculated in step 3 for this case? What is the measured resistance now? What must the series resistance of the ammeter be for this setting?

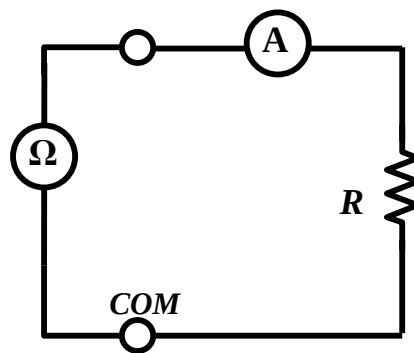


figure 4

5. Set R to 0 so that only the resistance of the ammeter is being measured. Change the ammeter to the $2mA$ scale. Does the resistance change? Record the ammeter resistance for each scale, and then move the lead from the ammeter's $V/\Omega/mA$ input to the $10A$ input and record the resistance.

Part 3: Continuity Test

A *continuity test* is a resistance measurement where the specific resistance is not important; any reasonably low value of resistance (less than a few ohms, for example) will indicate existence of a metallic connection.

1. Using the ohmmeter and jumper wires, check for continuity between the sockets in and around a sample row in your breadboard. Circle the sockets which are

connected in row 6, for example. Is there any continuity between rows 5 and 6, or 6 and 7, or across the gap between columns e and f?

2. Test the continuity between the ends of one of the red, + strips. Do the same for one of the blue, – strips. Are the different + and – strips connected to each other? Show the result of these tests in your report.

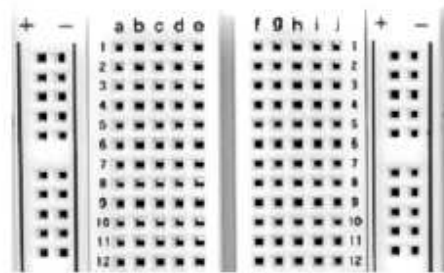


figure 5

Part 4: Simple Resistor Networks

For each of the resistor sets in Table 1 below, calculate $R_1 + R_2 + R_3$,

$1/\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$, and $1/\left[\frac{1}{R_1 + R_2 + R_3}\right]$. (note: one of these is incorrect, but we include it because it represents a common mistake).

1. Get three $1\text{k}\Omega$ resistors and measure their actual resistance values. Connect the three resistors in series on your breadboard and use the multimeter to measure the total resistance (R_s). Does your measurement match one of your calculations (within the tolerance of the resistors)?
2. Repeat step 1 for the next four resistor sets in the table. From your results, come up with an equation that relates the total resistance of a series connection with the individual resistances.
3. Next, connect each set of resistors in parallel and measure the resistance of the network (R_p). Again, try to match your results to one of the calculated values, and determine the relationship between total resistance of a parallel connection and the individual resistances.

TABLE 1: Calculated (columns 2 to 4) & measured (columns 5 & 6) resistances of a series combination of resistors.

Resistors	$R_1 + R_2 + R_3$	$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$	$\frac{1}{\frac{1}{R_1 + R_2 + R_3}}$	Measured R_s	Measured R_p
$R_1 = 1k\Omega$ $R_2 = 1k\Omega$ $R_3 = 1k\Omega$					
$R_1 = 1k\Omega$ $R_2 = 1k\Omega$ $R_3 = 2k\Omega$					
$R_1 = 1k\Omega$ $R_2 = 1k\Omega$ $R_3 = 3k\Omega$					
$R_1 = 1k\Omega$ $R_2 = 2k\Omega$ $R_3 = 3k\Omega$					
$R_1 = 1k\Omega$ $R_2 = 4.7k\Omega$ $R_3 = 10k\Omega$					

Part 5: Voltage measurement in a resistive circuit

Verify that the +20V output of the power supply is still set at 10V and make the connections shown in figure 6, using the decade resistor box for R, and set it initially to 1k.

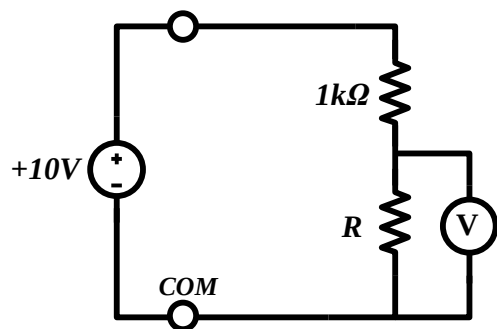


figure 6 (a)

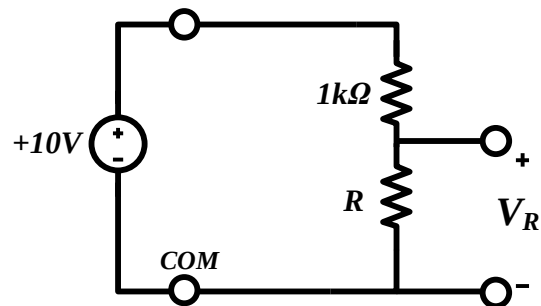


figure 6 (b)

1. With the DMM set to measure DC volts, measure the voltage across R. Fig 6(a) indicates placement of the voltmeter for this measurement. An alternate method for indicating where a voltage measurement is made is shown in fig 6(b). Here the voltage is given a label, V_R in this case, and the polarity of the measurement is defined with + and – signs. The + corresponds to the node where the V/ Ω terminal

is connected, and the – corresponds to the node where the COM terminal is connected.

2. Now measure V_{1k} , as indicated in fig 7, following the convention defined above. Can you verify that Kirchoff's Voltage Law is obeyed?

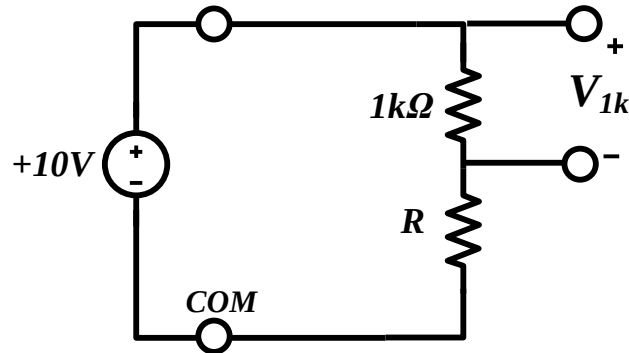


figure 7

3. Measure V_R , the voltage across R , for $R=2.0k$, $4.0k$, and $9.0k$. What kind of relationship do you expect between the voltage and the resistance? Should any of your measured values be above 10V? Why or why not?

Lab report. It will be important to present the results of your measurements in a well organized manner in the lab report. Don't make the reader guess what you did or have to flip between pages to see figures or data at the back of the report. Refer to the Report Guidelines on the course website for details of what is expected in a report.

Discussion questions (to be answered in the lab report):

1. Resistance can be measured, in principle, either by applying a voltage across a resistor and measuring the resulting current, or by forcing a current and measuring the resulting voltage. In part 2, step 2, you measured the voltage and calculated the current in the resistor for various resistance measurements. Does the ohmmeter act more like a constant voltage source or a constant current source in these measurements? Is it perfectly constant? If not, how do you think the DMM is still able to make a precision measurement?

2. Since ideal meters do not disturb the circuit they are measuring, an ideal ammeter has zero resistance. That is, it represents a perfect short circuit. However, we measured significant resistance in our handheld ammeter for some of the settings. Why is this ok? (hint: using Ohm's law, calculate the maximum voltage drop on the ammeter for each current range.)

3. Although real ammeters aren't perfect short circuits, they do have very low resistances. For this reason you should always be cautious before connecting an ammeter to your circuit, or you may get an unintended exercise in replacing fuses. Look at the circuit in

figure 4. Why could we set R to zero in this circuit without blowing the fuse in the ammeter? Note that if the ohmmeter were replaced with a voltage source, we most likely would have.