



## The Art of Electrical Measurements

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### Purpose:

Introduce fundamental electrical engineering tools and the art of making electrical measurements.

### Equipment Required:

- 1 - Analog Multimeter
- 1 - Variable Power Supply
- 1 - Protoboard
- 2 - 1/4 W Resistors

*Note:* While the analog multimeter is far from being new technology, it is an instrument that every engineer should know how to use, and what sources of error can occur with this device. That is why we have included this experiment.

### Prelab:

Before coming to the laboratory read Chapter 1 and Section 2-1 in *The Analysis and Design of Linear Circuits*. Prepare your lab journal by making room for a table of contents and sequentially numbering all of the pages.

### Procedure:

#### 1. The Multimeter

The multimeter is a basic circuits laboratory tool used to measure the two premier signal variables *current* (in amperes, A) and *voltage* (in volts, V) as well as an important element parameter *resistance* (in ohms,  $\Omega$ ). There are two common types of multimeters, digital (DMM) and analog (AMM). Although we will be using an analog multimeter for this exercise, much of the following discussion of the AMM applies to DMMs as well.

The multimeter (or meter for short) is connected to the circuit-under-test via two *leads* (or *probes*). The leads usually have a male banana connection on one end which plugs into the meter. The other end can have either a "grabber" type connection such as an alligator clip, or a bare metal tip much like the point of a pencil. The meter leads are normally color-coded, one red and one black. It is standard practice to connect the black lead to the negative (or reference) jack on the meter, and the red lead to the positive jack.

The value indicated by the AMM is determined by comparing a pointer, or needle, to one of the scales printed on the face of the meter. The particular scale used for the measurement is determined by several controls on the front of the AMM. These controls provide for combinations of three measurement parameters; *function*, *scale* and *zero ohms*.

The function switch determines which variable the AMM will measure; volts, amperes or ohms. Direct current volts and amperes measurement functions, typically labeled VDC and ADC, are available on most AMMs. Some meters also provide a measurement function for time-varying signals, usually labeled VAC and AAC, which are collectively known as "alternating current" (AC) signals. The AC notation indicates that the signal changes periodically with time. The DC notation is used to indicate that the signal has a constant



magnitude in the time domain. We will be dealing exclusively with DC circuits in exercises I through IX in this manual.

This experiment uses a widely accepted vernacular to describe the three standard functions on AMMs and DMMs. *Ohmmeter* identifies an instrument used to measure resistance. *Ammeter* and *voltmeter*, as you might suspect, describe instruments used to measure current and voltage. These terms are often used in reference to a multimeter which is set to the specific function described by the term.

The scale switch is used to set the sensitivity (or range) of the AMM. Typically, AMMs can measure voltage and current on four or more different scales, with the capability of making measurements spanning three or more decades. For example, the Simpson 260 AMM has six current ranges; 0 - 50 $\mu$ A, 0 - 1 mA, 0 - 10 mA, 0 - 100 mA, 0 - 500 mA and 0 - 10A.

For voltage and current functions, the number selected by the scale switch indicates the maximum value that can be measured on that particular scale. (The procedure for measuring resistance is slightly different and is discussed below.) Therefore, if you set the scale switch to 50 V, the scale that ends with "50" is used to determine the measured value. Note that the numbers on the scales are generic, "50" for example, could mean 50  $V_{DC}$ , 50  $mA_{DC}$ , or 50  $\mu A_{DC}$  depending on the function selected and the position of the scale switch.

Resistance measurements are usually an iterative process. Unlike the voltage and amperage functions, AMMs require that the meter be zeroed on the particular resistance scale that is used. But unless you have some knowledge of the value of the resistance you cannot, in advance, select and zero the proper scale.

## 2. Measuring resistance

The resistance value of the element being measured is determined by multiplying the number read from the meter face times the scale factor. For example if you are attempting to measure a resistor with a nominal value of 1 k $\Omega$ , you would set the scale switch to Rx100. Under these conditions, the needle would point at the "10" on the ohms scale, the scale factor would be 100, therefore the measured resistance is  $10 \times 100 = 1 \text{ k}\Omega$ . The greatest accuracy for resistance measurements is achieved when a range is available that will place the needle in the middle of the scale, between 3 and 30. However, it is not always possible to meet this criteria.

While making resistance measurements avoid touching your skin to both probe tips at the same time. The resistance of your body can have a substantial affect on the reading. Connect the resistor between the probe tips and select a range that places the needle as close to the center of the scale as possible. Disconnect the resistor, and touch the probe tips together. Adjust the zero ohms knob so that the needle points precisely at the zero on the ohms scale. Reconnect the resistor. If the needle is still between the 3 and 30 on the scale, read the actual value, and the process is complete. If instead the needle falls close to either end of the scale, attempt to find a scale factor that will place the needle closer to the middle of the meter face, re-zero, then re-read the value.

- a. Set the AMM to measure resistance on the most sensitive scale, usually labeled Rx1. Short the two meter leads by touching the metallic points together. Use the zero knob on the front of the meter to adjust the pointer so it is aligned with the zero printed on the ohms scale. Switch the scale knob to Rx100, Rx10000, etc. Observe and record whether or not the needle stays zeroed.
- b. One of the resistors provided to you is painted one solid color; set this resistor aside for now. Determine the nominal value of the other resistor by reading the color code. Record this nominal value in your journal. Select a resistance range that, for this resistor, will place the needle somewhere in the middle of the scale. Zero the meter on this scale, then measure the resistor value. Remember to re-zero if you change scales. You will be able to accurately read the AMM to two significant places.



Interpolate the third digit. In your journal record the measured value of the resistor, clearly indicating that this value was obtained using the AMM.

3. Measuring voltage and current

It is good engineering practice to start with the meter set to the highest range and, after making contact with the circuit-under-test, switch down to the appropriate range. This procedure helps to avoid meter damage that can occur when the needle is "pegged" at the high end of the scale.

- a. Set the function switch on the front of the AMM to DC voltage (VDC), and the range switch on the highest scale.
- b. Turn on the power supply and turn the output voltage all the way up. Be careful to observe the proper polarity, then touch the AMM leads to the output jacks on the power supply. If the needle deflects the wrong way, i.e. to the left instead of to the right, the meter lead positions need to be reversed. Select a scale that places the needle as high as possible on the scale, without pegging the needle. Measure and record the maximum output voltage of the supply.
- c. Turn the output voltage all the way down and measure and record the minimum voltage this power supply can produce.

4. The Protoboard

A protoboard (Fig. 1) is a tool used for constructing and testing (or breadboarding) a circuit. Don't let the size fool you. Even small protoboards can accommodate surprisingly large and complex circuits. Skill at using a protoboard is an item found in every practicing engineer's tool box. However, there is a knack to using one.

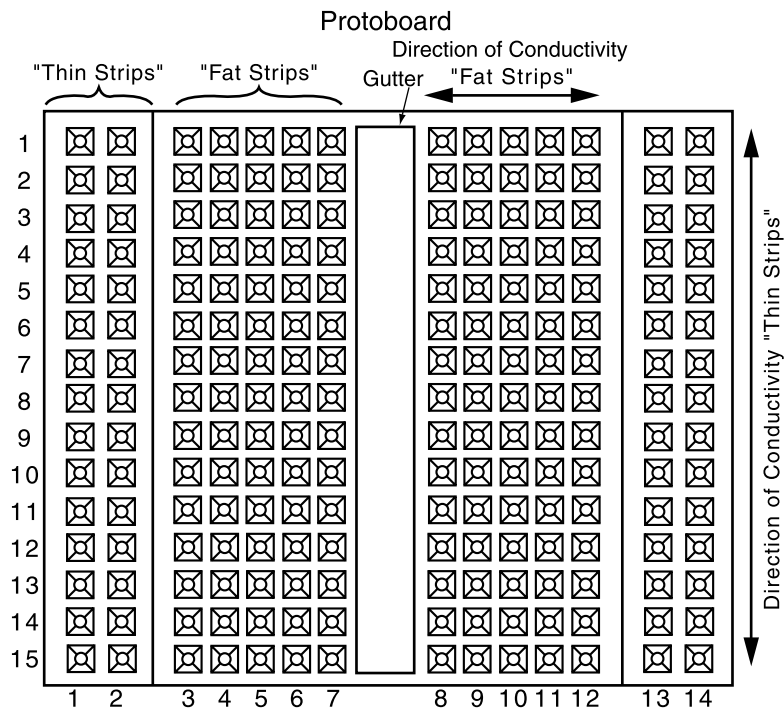


Figure 1



The protoboard has two or more white plastic strips with lots of holes in them. The thin strips usually have two columns and many rows of holes. As shown in Fig. 1, these thin strips conduct in the long direction, along the columns. Therefore, any wire inserted in column 1 will share a common node with any other wire inserted in column 1 no matter which row you select. The same is true for column 2. However, columns 1 and 2 are not connected together. These thin strips are usually reserved for signals that will be used in several places in your circuit, such as the  $\pm V_{DC}$  delivered by the power supply.

The fat strips conduct in the opposite direction. There are five holes on one side of the gutter, which are all connected together, and five more on the other side that are connected together. The two rows of five do not conduct across the gutter, and thus are *isolated*. The columns in the “fat strip” section do not conduct from one row to the next. Thus, a wire inserted in row 4 of a fat strip will share a node with any other wire inserted in row 4 regardless of the column it is in. This wire does not share a node with a wire inserted in row 3 or row 5. Stated another way, each row on one side of the gutter represents a different node than any other row. Because these fat strips conduct along the row, if you wish to connect row 4 to row 13 you must insert one end of a wire in any hole in row 4 and the other end in any hole in row 13. It is this area, the fat strips with five holes on each side of the gutter, which is used for most of the individual components that comprise your circuit.

Most protoboards also have two or more *posts*. Posts simplify the connection between the power supply, where a banana connector is preferred, and the protoboard, where stripped 22 gauge solid copper wire is required. While any post could be used for any external connection, black is usually reserved for *reference* or ground, while a red post is typically used for  $+V_{DC}$ , or the “hot” lead. Following this convention consistently can speed up the inevitable process of troubleshooting your circuits.

- a. With the power supply off, connect the ground from your power supply to the black post. Connect the hot (positive voltage side of the power supply) to a red post. Using wire with the ends appropriately stripped, make a connection from each post you used to connect the power supply to a different column on a thin strip. Insert one end of the resistor in any row in the “fat strip” region of the protoboard, and the other end into any other “fat strip” row. Using short jumper wires (stripped 22 gauge solid copper) make a connection between the column being used for the  $+V_{DC}$  and one of the rows connected to the resistor. Use another jumper wire to connect the other end of the resistor to the column connected to the negative ( $-V_{DC}$ ) side of the supply.
  - b. Set the function switch on the AMM to VDC, and the scale switch to the range appropriate for measuring 10 V. Turn on the power supply and while measuring the voltage across the resistor, adjust the power supply voltage to 10 V. If you don’t get a reading, check your wires carefully. Record the actual voltage to three significant figures. Now turn off the power supply and remove the jumper wire that connects the ground end of the resistor to  $-V_{DC}$ . Turn on the power supply. What is the voltage across the resistor now? Why?
  - c. Set the function controls on the AMM to read DC amperes. Start with the scale switch set to the highest scale. Touch the positive lead to the end of the resistor not connected to the power supply. Touch the negative lead to the ground, or negative side of the power supply. One step at a time, change the range switch so that more sensitive current scales are selected. If the needle “pegs” at the upper end of the scale, quickly switch back to the next higher scale. Read the current indicated on the meter and record this value in your journal.
  - d. Using the measured values for the voltage across and the current through this resistor, compute the power dissipated by the resistor.
5. Computing resistance and error

In previous sections of this exercise, you determined the value of the resistor by direct measurement using the ohmmeter and by reading the color code. In this section you will



compute the apparent resistance using Ohm's law, and compare the results of these three methods.

- a. Using the measured values of the voltage and current obtained in steps 4b and 4c, solve for the resistance R using Ohm's law.
- b. For the following error calculations, assume that the resistance value determined using the ohmmeter is the actual value of the resistor. Compute error between the measured and nominal (color code) value, using the equation

$$\% \text{ error} = \left( \frac{\text{actual value} - \text{nominal value}}{\text{nominal value}} \right) \times 100\%$$

Repeat these error calculations for the computed resistance of part 5a as the actual value. Record these calculations and the results in your lab journal. In your journal, explain the possible origins of any error in these resistance values.

6. Measure Alvin's resistor

Alvin, an employee of the Rocky Mountain Ohm Company, put too much paint in the resistor striping machine. As a result, he produced thousands of different value resistors that were painted only one color. The company, not wanting to throw away hundreds of dollars worth of resistors, offered them to any and all takers. Your university felt it could test each resistor and thereby take advantage of Alvin's error.

- a. Obtain one of Alvin's resistors. Using the protoboard, connect the resistor to your power supply and measure the voltage across and current through it. Use Ohm's law to compute the resistance. Record the data, calculations and results in your journal.
- b. As a verification, measure Alvin's resistor using the ohmmeter. Record the measured resistance in your journal.
- c. Assume the resistance measured using the ohmmeter is the actual value of the resistance. Compute the error between the actual resistance and the value obtained using Ohm's law (nominal value.)