



## Electric Circuit Theory, Experiment 1: The Linear Resistor and OHM's Law

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### **Purpose:**

To demonstrate that the resistor is a linear element and to calculate the resistance of several samples.

### **Equipment:**

- Agilent 33120A Function Generator
- Agilent 34401A Digital Multimeter
- Agilent 54600B Oscilloscope

### **Introduction:**

In each of the following experiments, you will "write" a program to instruct the instruments on the lab bench to perform prescribed measurements on your circuits. In some cases your program will analyze the data received by the instruments, and will present the results on the computer screen in graphical and/or tabular form.

The reason why the word "write" is in quotation marks is that the programming language you will use, Agilent VEE, has a purely graphical, rather than text, interface. Conventional program statements will be replaced by objects, or icons on the computer screen, and the order of execution of the objects will be determined by "wires" that connect the icons.

**Before performing any of these experiments, you should read the introductory document, entitled Using Agilent VEE, then work through the four exercises that you will find there.**

The first step in programming any Agilent VEE-controlled experiment is to place on the screen an **Panel Driver** object for each of the instruments to be used. (Recall that there is no instrument panel object for the triple power supply; you must use a **Direct I/O** object.) These objects will be used to set the default configurations for the instruments; they will not be connected by wires to anything else on the screen. Instructions for setting the defaults will be given in each experiment. The settings will be made on the Main Panel of each object unless another panel is designated. Only the necessary settings will be specified; all others are immaterial.

As is often the case, a program may not perform as expected on the first try. If this occurs, two useful debugging tools are available. They can be activated with the menu commands

***Debug --> Show Data Flow*** and  
***Debug --> Show Execution Flow***.

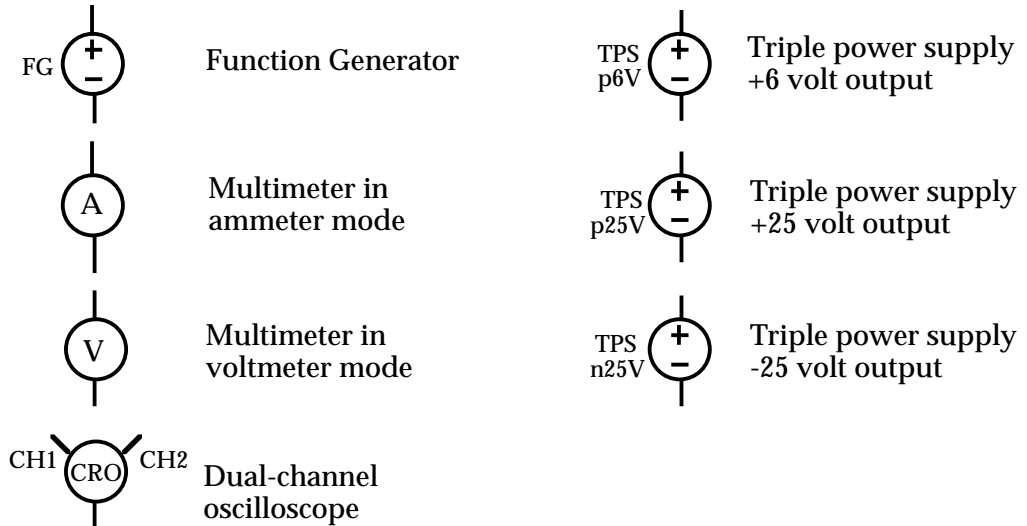
To use these to best advantage, set the slowest speed for these processes with **File** —> **Default Preferences** on the **General** tab, in the **Debug** group, click the **Data Flow Rate** arrow to show the drop-down list. Set the rate to **1(Slowest)**.

When the program is run, you will see symbols representing data and commands moving along the wires between objects, and each object will be highlighted when it is active. Operating in this mode is also useful to assist you in understanding how Agilent VEE works. But don't use these options all the time, because they slow down execution considerably.



Always begin an experiment setup by clicking the **reset** button on each instrument panel object. If you don't, the instrument may not be in the proper operating mode when you run the experiment.

The following symbols will be used in the circuit schematics:



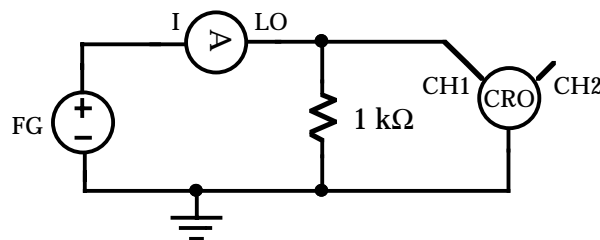
Instructions will be given in considerable detail for setting up and running the program for the first experiment only. It is assumed that you will then be familiar with the basic operations of Agilent VEE.

**Method:**

The voltage drop across a resistor will be increased in steps, and the current will be measured at each step. A plot of current vs voltage will be displayed. The resistance value will be calculated from the slope of the plot and displayed on the computer screen.

**Hardware Setup:**

Connect the benchtop function generator, multimeter, oscilloscope (using a 10x probe), and a 1 kΩ resistor as shown below:



Remember that the outer sheaths of the coaxial connectors of the function generator and the oscilloscope are permanently connected to system ground. The multimeter and triple power supply, on the other hand, can be operated with all terminals floating, and can therefore be connected anywhere in the circuit, as shown in this schematic. The triple power supply does have a terminal connected to system ground, which can be used if desired.



### Software Setup:

After placing **Panel Driver** objects for the function generator, multimeter, and oscilloscope on the screen, reset each instrument panel object before establishing its default configuration. After resetting, set the following parameters:

Function generator: Function = DC; Units = V peak-peak; Load = Infinity

Multimeter: Function = DC Amps; Auto Range = on

Oscilloscope: Channel 1 sens = 2 V/div; Probe = 10

Place **component drivers** for the three instruments on the screen. Double click them to open them, and add an **offset input** data terminal to the function generator driver, a **readings output** data terminal to the multimeter driver, and a **meas\_v\_avrg output** data terminal to the scope driver. This can be done in either of two ways: place the mouse over the object near the left edge and execute **ctrl a** to add an input terminal, or near the right edge and execute **ctrl a** to add an output terminal; or select the appropriate **add terminal** command from the object menu. The two procedures for deleting a terminal are similar, except that the first method uses **ctrl d** instead of **ctrl a**.

In this experiment, the oscilloscope acts as a dc voltmeter at each step of input voltage. The reason for recording its average value is to minimize the effect of random voltage fluctuations during each interval.

Connect wires from the sequence output pin of the function generator object to the sequence input pins of the multimeter and oscilloscope drivers. These connections tell the two measuring instruments to take a reading after each new input voltage value is received by the function generator. You can observe this sequence by using the debugging procedure described in the introduction to this manual.

The input voltage values will be set by a **For Range** object (**Flow --> Repeat --> For Range**), whose output goes to the input of the function generator driver. After placing the For Range object, edit the boxes to set the initial value, final value, and increment of the voltage. A good choice is -5 V to +5 V in 0.2-V steps. Connect a wire from the For Range output pin to the Function Generator input pin. When numbers are entered in objects such as this, the units (volts, amps, etc.) are never included. The only allowable non-numeric symbols are **n**, **u**, **m**, **k**, and **M** for **nano**, **micro**, **milli**, **kilo**, and **mega**, respectively; leave no spaces. For example, 0.2 may be written 200m.

The sequence of voltage values and the sequence of corresponding current values will be placed into 1-dimensional arrays with **Collector** objects. After placing these on the screen, connect the output of the oscilloscope to the input data pin of a collector, and the sequence output pin of the For Range object to the xeq pin of the collector. Use the **1-DIM ARRAY** option of the collector. All the voltage values will appear at the collector input in sequence. When the scan is complete, the For Range object will send a pulse that commands the collector to gather all the current values into a 1-dimensional array. Connect the second collector in a similar manner to collect the array of current values from the multimeter. It is good practice to rename these and all objects to identify their functions. Renaming is done by double clicking the header of the object and editing the appropriate box in the resulting dialog box.

The i-v plot will be displayed on an **XY Plot** object (**Display --> X vs Y Plot**). It is recommended that you place markers on the plot, which will display coordinates and intervals on the plot. This is done in the **Properties Box** of the XY plot. Right click over the object then select **Properties**, in the **Markers** group, select **Delta**, or Double click the header and in the **Markers** group select **Delta**. Connect the output of the oscilloscope driver to the x-input pin and the output of the multimeter to the y-input pin. Again, it is a good idea to give meaningful names to the pins, as well as to the axis legends.

To calculate and display the resistance value, produce a **Formula** object (**Device --> Formula**). It will have an input pin named **A**, which you can rename to **i** by double clicking the name. Add a second input pin and name it **v**. In the formula box type



$$(\max(v)-\min(v))/(\max(i)-\min(i)).$$

This calculates the inverse slope of the i-v plot from the differences between the maximum and minimum values. Of course, the result will be meaningful only if the plot is a straight line. Connect the outputs of the voltage and current collectors to the appropriate inputs of the Formula object. Use **Display --> Alphanumeric** to produce a display box for the resistance value; connect its input to the output pin of the formula object.

One more object that is useful, but not necessary, is a **Start** button (**Flow --> Start**) connected to the sequence input pin of the For Range object. The program can be run by clicking on this or by using the **Run** command on the menu bar.

Finally, arrange your objects neatly and execute **Edit --> Clean up Lines** to make the screen more readable. Figure 1-1 shows a screen layout for this experiment. You should sketch your arrangement in your notebook.

### Procedure:

Double click on the XY display to open it; then run the program, observing the panel displays of the benchtop function generator and multimeter. You should see the input voltage and current values change with time on the instruments. The arrow in the menu bar will be green while the program is running.

You will also see the plot of current vs voltage being drawn on the XY display. If the plot begins to go off scale, click the **Auto Scale** button. You can choose the axis limits by entering values in the appropriate boxes. You can also move the two markers to any desired positions with the mouse. Their coordinates and the differences between the coordinates are displayed at the bottom.

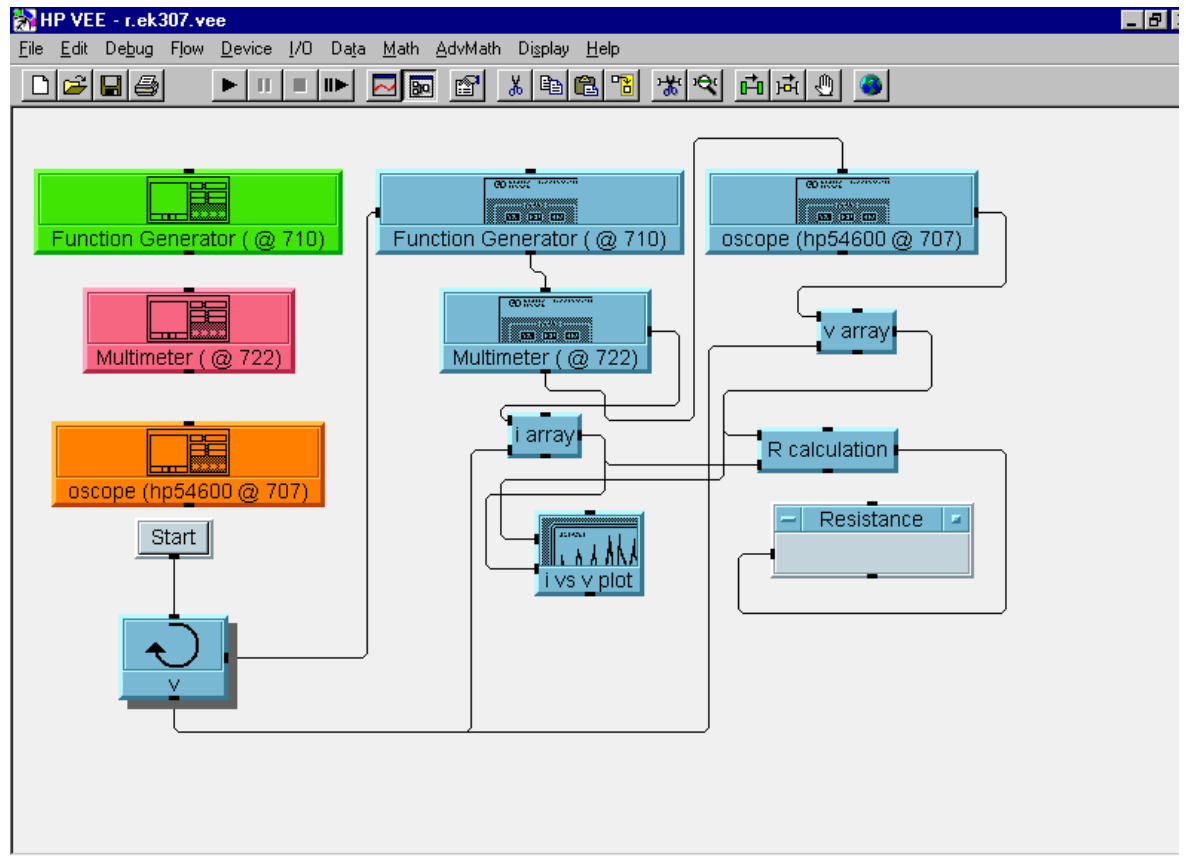
The calculated resistance will appear in the alphanumeric display. Record the measured value and the nominal value of the resistor that you used. Is the difference, if any, reasonable? Why?

Repeat the experiment, using several resistors with widely different values, and record the results. Label and set aside these resistors. You will use them later.

Most of the resistors in your kit have a 0.25-watt power limitation. Repeat the experiment with a 100-ohm, 1/4-watt resistor if you have one, and set the input voltage range to  $\pm 10$  volts instead of  $\pm 5$  volts. Is the plot still linear, or does it show a deviation from linearity? Whichever is the case, explain your observation.

Disconnect the oscilloscope from your actual circuit and remove its component driver from the computer screen. Connect the output pin of the For Range object directly to the inputs of the voltage collector and the XY display, and rerun the experiment, using one of the resistors for which you have recorded a measured value. Is the calculated resistance different? Explain your observation.

Why do you need the two collectors to produce arrays of current and voltage values?



**Fig. 1-1 Agilent VEE Layout for Resistance Measurement**