



Lab 2 –Operation of the Digital Instruments and Basic Measurements

By: Gary A. Ybarra
Christopher E. Cramer
Duke University
Department of Electrical and Computer Engineering
Durham, NC

1 Purpose

The purpose of this exercise is to learn to properly use the instruments at the lab bench and the correct method of measuring physical quantities with each instrument. You will be using four Agilent Technologies digital instruments in this course:

- Agilent E3611A DC power supply
- Agilent 33120A Function Generator
- Agilent 34401A Digital Multimeter
- Agilent 54600B Oscilloscope or Agilent 54622A Deep Memory Oscilloscope

2 DC Power Supply

The DC power supply is used to generate either a constant voltage (CV) or a constant current (CC). That is, it may be used as either a DC voltage source or a DC current source. You will be using it primarily as a voltage source. Recall that DC is an acronym for direct current. DC means constant with respect to time.

The Agilent E3611A DC power supply has two range settings. The first range setting allows the power supply to produce between 0 and 20 volts (V) and has a maximum current capacity of 1.5 amps (A). The second range setting allows it to generate between 0 and 35 V with a maximum current capacity of 0.85 A.

The voltage produced by the power supply is controlled by the knob labeled **voltage**. The current is limited by adjusting the knob labeled **current**. As long as the circuit does not attempt to draw more current than the value set by the current knob, the voltage will remain constant. This is often a difficult concept for students to grasp. Current limiting allows the power supply to be set such that it will not generate more current than desired. This can be useful as a safety feature, preventing electrocution due to accidental contact with terminals. In addition, current limiting can prevent damage to equipment and parts which may be unable to handle excessive currents. More details about current limiting will be presented in the experimental procedure.

3 Function Generator

The Agilent 33120A function generator is used to provide voltages that vary with time. It has four primary waveforms: sine, square, triangular and ramp. There are three parameters that can be varied for each waveform:

1. peak-to-peak voltage (0-10 V)
2. frequency (0-15MHz)
3. DC offset

To set any of these features, press the button labeled with the feature you wish to modify. The present setting of this feature will appear. Notice that one of the digits is blinking, turning the dial will affect this digit; you may change which digit is flashing by pressing the left or right arrow keys. It is also possible to enter a number directly by pressing the button marked **Enter Number**. After pushing this button, you may enter a number on the key pad. Pressing **enter** immediately following will alter the setting to the new value.



4 Digital Multimeter

The Agilent 34401 digital multimeter measures voltage, current and resistance. There are separate settings for measuring AC and DC values. If you examine the **softkey** pad on the lower left of the multimeter, you will find primary functions in black and alternate functions in blue. The alternate functions are accessed by pressing the **shift** softkey and then the function softkey. For example, to measure DC voltage, you press the **DC V** softkey. To measure DC current, you press the **shift** softkey followed by **DC I** which is the same softkey used for DC voltage.

The multimeter also has the capability of measuring other quantities such as the frequency and period of periodic waveforms. There are three vertically aligned holes (banana jacks) in the multimeter located at the top right of the meter front panel. To measure voltage, place the positive terminal in the top hole, with the negative terminal in the center hole. The top hole is labeled **Hi** in red, and **V Ω** in black. To measure current place the *from* terminal (the terminal at which current enters the multimeter) in the bottom hole (labeled in red as **I**), and the *to* terminal in the center hole. Other than that, the operation of the digital multimeter is almost entirely automatic; simply set the multimeter to the type of measurement you wish to make by pressing the button labeled voltage, current, etc. and read the value from the display.

5 Oscilloscope*

An oscilloscope is used to view a voltage waveform on a screen. An electron beam is generated in the cathode ray tube, directed at the back of the screen, and swept in time along the X-Axis. A voltage applied to the scope probes is amplified and applied to a pair of horizontal metal plates through which the electron beam passes. This voltage deflects the beam in the vertical direction (Y-Axis). The sweep in the electron beam combined with vertical deflection results in the appearance of a waveform on the screen of the scope. The scope has two probes: one for Channel 1 and one for Channel 2. The probes are very expensive (approx. \$200 each), so please be careful with them. Each channel has a vertical placement knob which moves the waveform for that channel up and down. Each channel also has a knob which selects the vertical scale of the waveform in terms of volts per division. Divisions are the visible grid lines on the oscilloscope screen. The knob which sets the horizontal scale in time per division controls both channels.

The majority of all measurements made in this lab can be performed automatically with the Agilent 54600 scope. To see the waveform, press **Auto-scale**. The **Auto-scale** button will be used more than any other on the scope. When you want to capture a waveform on the screen, the first thing to think of is **Auto-scale**. This takes the waveform at the input and displays it so that the entire peak-to-peak voltage is displayed as well as several periods.

To measure voltage, push the button marked **voltage** which is located to the right of the screen near the top of the front panel. This will bring up a menu at the bottom of the screen, listing available voltage measurements. The first choice is to select either channel 1 or 2 for measurement. After that, you may select: Peak to Peak voltage (V_{p-p}), average voltage (V_{ave}), or rms voltage (V_{rms}). By pressing the corresponding softkeys, you will automatically get the selected measurement.

For more choices, press the softkey labeled **Next Menu**. The next menu will allow you to select: V_{max} , V_{min} , V_{top} , V_{bot} , V_{amp} , V_{over} or V_{pre} . Time measurements can be obtained by pressing the **Time** button (located next to the **voltage** button). This will give you the following menu options: Frequency, Period, Duty Cycle, +Width, -Width, Rise Time, Fall Time, Delay and Phase Difference. This last command, Phase Difference, is useful for computing the difference in phase between waveforms on channels 1 and 2.

* The 54622A has a slightly different menu structure (e.g. the "voltage" button is "Quick Meas" on the 54622A)



6 Discussion: Methods of Measurement

Discuss with the rest of the class how you would go about measuring voltage across and current through a resistor using the multimeter. How would you place the leads? The following hints may be helpful:

1. As a voltmeter, the multimeter has infinite resistance. (Ideally)
2. As an ammeter, the multimeter has zero resistance. (Ideally)

7 Experiment - DC Measurements

Record each measured value.

5. Set the DC power supply to provide 3 V as shown in the digital display on the power supply front panel. (**See important note below**)
6. Set the multimeter to measure DC voltage, making sure the leads are set for voltage, not current measurement.
7. Measure the voltage using the multimeter.
8. Disconnect the multimeter from the power supply and connect the oscilloscope leads to the power supply.
9. Adjust the volts/division knob on the oscilloscope until the voltage appears on the screen. (This should occur around 1 volt/division.)
10. Measure the voltage by using the automatic measuring features of the oscilloscope.
11. Using the same screen, measure the voltage by hand, i.e. count the divisions and multiply by the number of volts per division. (This number can be found in the upper left corner of the screen.)
12. Set the DC power supply to 0 V.
13. Push and hold the **CC Set** button. While holding down the **CC Set** button, adjust the **current** knob until the **Amps** value displayed on the front panel shows 0.05 A. Then release the **CC Set** button.
14. Connect a 50 Ω resistor to the power supply.
15. Connect the multimeter across the resistor and set it to measure DC voltage.
16. Increase the voltage (slowly) across the resistor. At approximately what voltage do you expect to observe something unusual? If the change from CV to CC occurs at a voltage **read by the voltmeter** different from what you expected, explain why.

Important Note: Be careful with the DC power supply leads. **Avoid letting them touch at any time.** When the power supply leads touch, a short circuit is formed which can cause serious damage to the power supply. Consider what would happen if you shorted the wall socket, or a car battery! Short circuits can be dangerous, and special care should be taken to avoid them.

8 Experiment - Resistance Measurement

The standard resistor color code is shown on the back of the door to the lab. Here is a quick synopsis: Most resistors have four colored bands. The first three bands indicate the nominal value of the resistor and the fourth band indicates the tolerance in value. The first two bands form the mantissa, and the third the exponent of 10.



Color	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

The tolerance band is typically either gold or silver. A gold tolerance band indicates that the measured value will be within 5% of the nominal value. A silver band indicates 10% tolerance. For example a resistor with color code brown-black-red-silver indicates a nominal value of $1\ \Omega$ k. The first two bands (brown-black) produce the mantissa (10) and the third band (red) is the exponent of ten ($10^2 = 100$). So the value is $10 \times 100 = 1\ \text{k}\Omega$. Since the tolerance band is silver, we can expect the measured value of the resistor to be between $900\ \Omega$ and $1100\ \Omega$.

1. Select a $1\ \text{k}\Omega$ resistor (color coded brown-black-red).
2. Place the resistor in the spring board at your lab station.
3. Set the multimeter to measure resistance. To do this, press the softkey labeled Ω **2W**. Determine the actual value of the resistor. The words "actual" and "measured" may be used interchangeably.
4. Compute the percent difference between the actual (measured) value of the resistor and the nominal value of $1\ \text{k}\Omega$ as indicated by its color code.

You will now create a sequence of carbon resistors. Based on their measured values, you will draw conclusions about the relationship between their physical dimensions and resistance.

8.0.1 Graphite Resistor

1. Using a pencil, draw a rectangle whose length (approximately 1") is twice its width on a sheet of paper. Fill in the rectangle with pencil mark. Measure and record the resistance over the length and then over the width of the graphite resistor.
2. Using a pencil, draw a square whose side-length is approximately 1". Fill in the square with pencil mark. Measure and record the resistance over the width of the graphite resistor.
3. Based on your measurements, draw conclusions relating the physical dimensions and resistance.

8.0.2 Measuring the Resistance of Your Body

1. Holding one probe between the thumb and forefinger of each hand, measure the resistance of your body between your hands. Squeeze the probes tightly so that good contact is established. Record the value of your body's resistance.
2. Considering that a current of 100-200 mA through your heart will almost certainly kill you, how much voltage across your hands would be lethal?

9 Experiment - Current and Ohm's Law

1. Assemble the circuit in Figure 1 with the voltage source set to 10V and using the same (nominal $1\ \text{k}\Omega$) resistor as measured in the beginning of Section 8.
2. Set the multimeter to measure dc current. Make sure that the leads are in the correct jacks in the front panel of the multimeter.
3. Measure the current flowing through down through the resistor. **An ammeter measures the current flow from the red probe to the black probe within the meter.** Does this value agree with Ohm's Law ($i = \frac{v}{R}$)?



4. Measure the current flowing through the resistor in the opposite direction. This is done by reversing the leads of the ammeter. Does this value agree with Ohm's Law ($i = \frac{v}{R}$)?

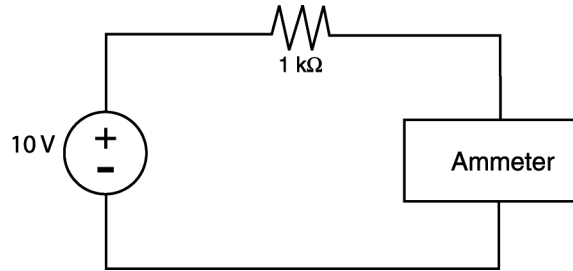


Figure 1: Circuit illustrating the measurement of current.

10 Experiment - Ideal vs. Practical Voltmeter and Ammeter

10.1 Voltmeter

An ideal voltmeter has infinite resistance: It is an open circuit. Although it is impossible to make a physical voltmeter with infinite resistance, a well designed voltmeter exhibits a very large internal input resistance. In some experiments, it is important to take into account the finite, non-ideal, internal resistance.

To determine the internal resistance of the voltmeter, set up the circuit shown in figure 2. The voltmeter reads the voltage across itself, which includes its internal resistance. Since the circuit has only a single branch, the current flowing through the resistor also flows through the voltmeter. The current is given by the equation:

$$I = \frac{V_S - V_M}{R} \tag{1}$$

From Ohm's Law, if we know the current (I) and the voltage (V_M) we can compute R_M .

$$R_M = \frac{V_M}{I} = \frac{V_M}{\frac{V_S - V_M}{R}} = \frac{R V_M}{V_S - V_M} \tag{2}$$

1. Select a 1 MΩ resistor.
2. Measure its value using the multimeter.
3. Set the power supply to provide 10 V (**Remember, always measure the voltage provided by the power supply with the voltmeter. Do not rely on the digital display on the front panel of the power supply.**)

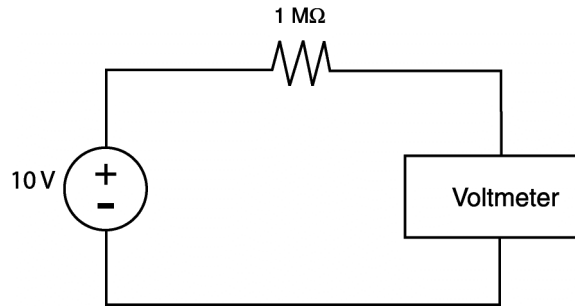


Figure 2: Circuit for measuring the resistance of the voltmeter.

4. Assemble the circuit in Figure 2.
5. Record the voltage measured by the voltmeter
6. Compute the internal resistance of the voltmeter using Equation 2.

10.2 Ammeter

An ideal ammeter has zero resistance so that the circuit in which it has been placed is not disturbed. An ideal ammeter is a short circuit. However, as with the voltmeter, no ammeter can ever be ideal, and therefore all ammeters have some (*hopefully*) small internal resistance. To determine the resistance of the ammeter, we will use the circuit in Figure 1.

According to Ohm's Law, the current in this circuit will be $I = \frac{V}{R}$ where $R = R + R_M$. So the current can be found using the equation:

$$I = \frac{V_S}{R + R_M} \tag{3}$$

By using the known quantities I , V_S and R , we can solve for the unknown quantity R_M .

In the procedure that follows it is extremely important that you take precise and accurate measurements. Record each measurement as precisely as the instrument will allow.

1. Select a 100 Ω resistor. Measure and record its actual value.
2. Set the DC power supply to 1V. Assemble the circuit in Figure 1 using the DC power supply set to 1V. Set the multimeter to the ammeter mode for dc current measurement. Recall this means two things: Place the test leads in the correct banana jacks and press the proper sequence of softkeys.
3. Use the oscilloscope to measure the voltage across the DC power supply.
4. Measure the value of the current using the ammeter.
5. Determine the value of R_M from Equation 3.

11 Measurement of Time Varying Sources

In this section, we will be using the function generator to provide a time-varying voltage which will then be measured using the oscilloscope.

IMPORTANT:

DO NOT let the leads from the function generator touch each other! If the function



generator lead touch each other, either the internal fuse will blow or serious damage to the instrument will occur. It is very important that you keep this in mind at all times.

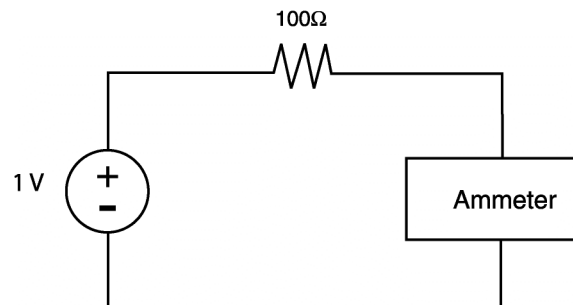


Figure 3: Circuit for measuring the resistance of the ammeter

IMPORTANT: The function generator has an internal resistance of $50\ \Omega$. The voltage displayed on its front panel is the voltage that would appear at its terminals if it were connected to a $50\ \Omega$ load. Under open circuit conditions, the voltage across the terminals of the function generator is **twice** as large as the value indicated on its front panel. This is an important concept and often misunderstood.

If you are located at a lab station that has no printer, complete items 15-17 after one of the lab stations containing a printer becomes vacant.

1. Set the function generator to produce a 10 kHz sine wave with $6\ V_{p-p}$.
2. Connect the oscilloscope channel 1 probe to the leads on the function generator.
3. Locate the **VERTICAL** section on the front panel of the oscilloscope. It is the section which includes the connections of the scope probes to the scope.
4. Press the softkey labeled **1**. A menu will appear on the bottom of the scope screen. The items that appear on this menu are: channel activation, coupling bandwidth limiter, inversion, vernier, and probe calibration. Examine the setting for **probe**. It should be on **10**. If it is not, set the **probe** value to **10**. This tells the scope that the probe reduces the signal strength by a factor of 10. All of the scope probes in this lab are "10x" probes. It is a good idea to get in the habit of checking the probe setting at the beginning of each lab.
5. Press Auto-Scale on the oscilloscope to view the signal produced by the function generator.
6. Using the automatic features of the oscilloscope, determine the peak-to-peak voltage. Observe that the measured peak-to-peak voltage is approximately **twice** the peak-to-peak voltage shown on the front panel of the function generator.
7. Using the automatic features of the oscilloscope, determine the frequency, and the period of the sinusoidal voltage.
8. Measure the peak-to-peak voltage by hand, i.e. count the vertical divisions from the minimum to the maximum and multiply by the number of volts per division. The **volts per division** setting is shown in the upper left corner of the scope screen.
9. Using the same screen, measure the period of the sine wave, i.e. count the number of horizontal divisions in one period of the sine wave. The **time per division** setting is shown at the top-right-center of the scope screen.
10. Using the formula, $frequency = \frac{1}{Period}$ determine the frequency of the sine wave.
11. Connect the function generator across a $50\ \Omega$ resistor. Leave the settings on the function generator unchanged.
12. Connect the oscilloscope channel 1 probe across the resistor (and function generator).



13. Press Auto-Scale on the oscilloscope to view the signal produced by the function generator.
14. Using the automatic features of the oscilloscope, determine the peak-to-peak voltage. Observe that the measured peak-to-peak voltage is approximately **the same** as the peak-to-peak voltage shown on the front panel of the function generator. Hence, the voltage at the terminals of the function generator is **load dependent**. Whenever you use the function generator to provide a voltage waveform and desire a specific amplitude, you **must** use either the multimeter or the scope to set the desired voltage because the value shown on the front panel of the function generator is valid only for a 50 Ω load.
15. Press the **Print/Utility** softkey on the scope. It is located to the right of **Autoscale**. Then press the **RS-232 Menu** softkey. Make sure the **resolution** is set to **low**. Press the **previous menu** softkey. Consult the 54622A User's Guide for printing on the 54622A Oscilloscope.
16. Turn on the HP Deskjet printer. Wait a few moments and then press the **print screen** softkey on the scope. A printout of the waveform shown on the scope screen should result. Feel free to use the printer to obtain scope traces as needed to document your laboratory experiments.
17. Compare the values for the peak-to-peak voltage and frequency that were 1) specified by the function generator, 2) measured by the oscilloscope and 3) measured by hand. Do the measurements made by hand differ from those made by the oscilloscope? Which do you think are more accurate? Justify your answer.
18. Hold the scope probe in one hand and expose the metallic hook. Touch the hook with your other hand. With your third hand, press the autoscale button on the scope. Continuing to touch the hook., move your hand near a power receptacle or a power cord and observe the change in the waveform shown on the scope. Obtain a printout of the Waveform for two cases. What is the frequency of the waveform? Explain the waveform measured by the scope.

12 Questions to be Answered

1. Suppose you set the voltage of the DC power supply to 5V. You connect it to a circuit and the voltage provided by the power supply drops to 3V. What happened?
2. What is the "resolution" of a digital display? Compare the resolution of the digital display on the front panel of the DC power supply to the display on the front panel of the multimeter. Why must you use the multimeter to set the DC supply to 0.75V?
3. Suppose you set the function generator such that it produces a 1 kHz sinusoidal voltage with 5V peak-to-peak across a 25 Ω load. What will be the peak-to-peak voltage displayed on the front panel of the function generator?
4. In Section 8.0.2, you measured the DC resistance between your left and right hands. To make this measurement, the ohmmeter applied a small (known) voltage and measured the resulting current. The ratio of applied voltage to resulting current is the resistance between the ohmmeter probes (in this case, the resistance between your left and right hands). Based on the resistance you measured, you calculated the voltage range that would cause 100-200 mA of electric current to flow through your body and termed this "the lethal voltage." However, in "real life," the lethal voltage would be far less than the value you calculated. You are to explain in detail why the lethal voltage is in fact much less than the value you calculated. Your explanation should include the change in skin resistance that occurs when an electric shock occurs and other physiologic effects shock that can be lethal (eg. pulmonary failure).

13 PSpice (to be done outside of lab)

In both the lecture and the lab, PSpice will be a very important tool and will accompany the majority of lab exercises. Unless it is explicitly stated that the Pspice exercise is to be performed in Lab using the HP PC's, the Pspice simulations should be performed outside the



lab using either the Sun Workstations in Room 161 or some other platform such as your own personal PC.

In this exercise, we will use PSpice to compute the current in a simple circuit. The objective of this PSpice exercise is to become familiar with PSpice syntax and how to code the elements as well as the topology of a circuit.

13.1 Basic PSpice information

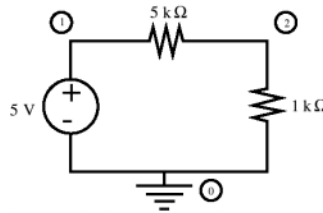


Figure 4: Example PSpice circuit.

All PSpice programs should contain a heading, which should be the first line of the program and; a '.end' line which should be the very last line of the program. Between these two lines there should be commands to specify the circuit which is to be analyzed. To specify a circuit, first label the nodes in the circuit (see Figure 4) with node 0 always being the ground node. Once your circuit is labeled, enter each element in the circuit as follows:

- Voltage Sources: V_{name} $node_+$ $node_-$ value
- Current Sources: I_{name} $node_{from}$ $node_{to}$ value
- Resistors: R_{name} $node_1$ $node_2$ value

V_{name} , I_{name} , and R_{name} are names of the elements which should begin with V, I and R respectively. Examples include V1, I12, R1 and VDUMMY. Only the first letter is important.

To completely specify our example circuit we would write the following code:

```
Example Circuit 1

V1 1 0 5
R1 1 2 5k
R2 2 0 1000

.tran 0.02 2.0
.probe
.end
```

To simulate a circuit on one of the Sun Workstations in Room 161, enter your code into a file ending with a .cin suffix (ex. Spice1.cin) At the UNIX prompt type the command **pspice**. When prompted, enter the filename you chose. After Pspice has finished running, examine the .out file produced by Pspice, If graphical output is desired, type the command probe.

For more information on Pspice, refer to the Pspice tutorial in the EE-61 Course-Pak and the Rashid text.

13.2 Procedure

Write a PSpice program to simulate the circuit built in Section 9 (Fig. 1). After running the PSpice code, check the output (file.out) to determine if the current flowing through the voltage source agrees with Ohm's Law and the value for current you obtained in the section. Include the PSpice code and pertinent results in your lab report.