

# Voltage Current and Resistance

Equipment: Capstone with 850 interface, knob adjustable analog DC voltmeter, knob adjustable analog DC ammeter, voltage sensor, current sensor, RLC circuit board, 8 leads

## 1 Purpose

To learn how voltages and currents are generated and measured with the 850 interface and other equipment, and to investigate how voltage and current are related in resistors.

## 2 Voltage

If two points have a voltage difference (also, called a potential difference) between them, then work is done by the electric field on a charge that is moved from one of the points to the other. The work is path independent. Voltage (same as voltage difference) always refers to 2 points, as in the “voltage across a resistor.” If one of the two points is not specified, it may be that the second point is the earth or ground. Voltage is measured in joules per coulomb (J/C), which is defined as Volts (V).

It is often a good approximation to assume that in a circuit, each connecting wire is an equipotential, as is done for this experiment. For example, if the ends of a resistor are connected to two wires, the voltage across that resistor can be measured by connecting the two leads of the voltmeter to anywhere on the two wires.

The crust of the Earth is not a great conductor. Nevertheless the Earth is often assumed to be an equipotential and voltages are often measured with respect to “ground.” A good water pipe is often taken as ground potential.

Voltage can be generated by batteries, power supplies, and signal generators. Batteries maintain a DC (time independent) voltage across 2 terminals (metal electrodes) by chemical means. Power supplies are usually associated with DC voltages and signal generators with AC (time dependent) voltages, but with modern technology this distinction has become blurred.

An AC voltage between two points varies with time. The time dependent voltage across the terminals of a signal generator may repeat itself in a length of time called the period (T). The voltage for 1 period is often called 1 oscillation or 1 cycle. The inverse of the period,  $1/T$ , is called the frequency which is usually denoted by  $f$  or  $\nu$ . Frequency is the number of periods or oscillations per second. The basic unit of frequency is hertz (Hz), when the period is measured in seconds. The shape of the voltage vs time graph is called a waveform. Common waveforms are sine, square, triangular, and ramp.

In these labs, voltages may be obtained from the 850 interface. The 850 interface has two terminals on the right which can supply DC and AC voltages. The voltage across these terminals is controlled by the signal generator window. In addition to DC, the repetitive AC waveforms include sine, square, triangle, and ramp.

Voltage between 2 points on the surfaces of two conductors can be measured by a voltmeter. This device has 2 leads (wires). When the two leads of the voltmeter are placed across the two conductors, the voltmeter reads the voltage between the 2 points. Voltmeters make measurements by drawing some charge or current that changes the voltage. An ideal voltmeter will draw no charge or current, so the experimenter should be sure that the voltmeter used draws so little current that the measurement does not significantly affect the voltage being measured.

Many modern digital voltmeters draw very little current and are said to have a high internal resistance. Still in use are analog voltmeters that draw current that is passed through a multi-turn coil. The coil is situated in a magnetic field and experiences a torque. This torque moves the coil against a spring. A needle attached to the coil indicates the voltage. This type of voltmeter has a relatively low internal resistance and can draw a non-negligible amount of current. Analog voltmeters will be used in this lab.

### 3 Current

While current, or perhaps current density, can be defined for charges moving in space outside of conductors, here we are primarily concerned with charges moving in conducting materials. For a wire, current is defined as the amount of charge that passes a point in a wire per unit time. The units are coulombs per second (C/S), or amperes (A).

Current in a wire can be measured by breaking the wire and connecting the 2 wire ends to an ammeter, a device that measures current. The measured current passes through the ammeter. A common type of ammeter is similar to the moving coil voltmeter. Another way to determine current is to use a low value resistor and measure the voltage across the resistor (see Ohms law below). In either case, the resistance of the ammeter should be low enough so that the original current in the circuit is not significantly reduced by insertion of the ammeter.

For AC circuits, current can be measured with a “clamp-on” ammeter without breaking the circuit. This type of ammeter, which depends on electromagnetic induction for its operation, is very useful but will not be used in this lab.

In addition to voltage supplies, which try to maintain a prescribed voltage across their two terminals no matter what current is drawn, there are also current supplies. These try to deliver a prescribed current (in one terminal and out the other) no matter what voltage appears across the terminals. Current supplies are important but will not be used in this lab.

### 4 Resistors and Ohm’s Law

In a conductor or semi-conductor there are mobile charges that can move if there is an electric field. If there is an electric field in a conductor, a current will flow. The electric field is supplied by charges that have been provided by a voltage or current source. These charges reside on the surfaces of the conductors. The force of the electric field on the mobile charges is opposed by frictional forces that result from collisions of the mobile charges with ions in the lattice of the conductor. A device designed to impede the flow of current is called a resistor. The voltage across a resistor is the voltage between the two points that are the ends of the resistor. If  $V$  is the voltage across a resistor and  $I$  is the current through the resistor, in many cases it is found that to a good approximation the ratio  $V/I$  is a constant. This ratio is called the resistance  $R$ . The units of  $R$  are ohms ( $\Omega$ ). This relationship is called Ohms law and can be written

$$V = IR. \tag{1}$$

While Ohms Law is often an excellent approximation there are situations where it is quite inaccurate. An example would be the filament of a light bulb. As the current through the filament is increased and the bulb gets hotter, the resistance of the filament increases. The reason for this is that the ions in the lattice vibrate with greater amplitude and are more effective in scattering the mobile charges.

The power dissipated in a resistor is given by VI. For an ohmic resistor the power dissipated can be written  $I^2R$  or as  $V^2/R$ . The 2 most important specifications for a resistor are its resistance and its power rating.

## 5 Resistors in Series and Parallel

If 2 resistors  $R_1$  and  $R_2$  are connected in series the combination is equivalent to a single resistor  $R$ , where  $R$  is given by

$$R = R_1 + R_2. \quad (2)$$

If 2 resistors are connected in parallel they are equivalent to a single resistor  $R$  given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}. \quad (3)$$

These formulas are easily extended to 3 or more resistors.

## 6 Comments on Measuring Voltage and Current

To measure a voltage between two points in a circuit, connect the two leads (wires) of your voltmeter across those points. To measure the current in a circuit wire, “break” the wire and connect the two ends to an ammeter in series. In both cases, you will change the voltage and currents in the circuit. This can be minimized by using voltmeters with as much resistance as possible and ammeters with as little resistance as possible.

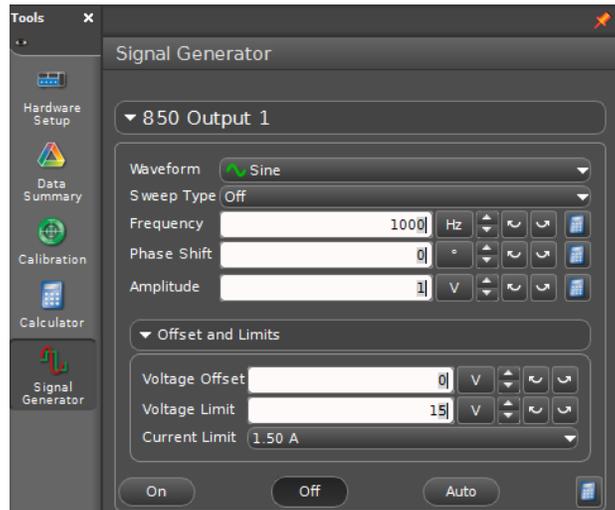
In these labs, there are three groups of voltage and current sensors that you will learn how to use.

1. Analog voltage and current meters that are not part of Capstone.
2. The Capstone voltage and current sensors. These are sensors that plug into an analog channel of the interface. On the right, in the Hardware set-up window you must click the channel and choose the sensor. The output of the sensor can be monitored by a display. Drag a digits icon located in the displays column to the center of the screen, click **Select Measurements** and choose which sensor you want displayed.
3. The internal measurement of the output voltage and output current of the interface. On the experimental set-up window, click the two output terminals of the 850 interface. When you click on the output terminals of the 850 interface a window will pop up as shown in the next figure. Select **Output Voltage - Current Sensor**. Drag a digits display to the screen and in **Select measurements** you can select either the output voltage or current output of the interface.

## 7 Explanations on obtaining voltages from the interface

An output voltage can be obtained from the 850 Interface. In this section, you will learn how to obtain voltages from the terminals of the 850 interface. The two terminals are on the right side of the interface. The left terminal is at ground potential and has the standard ground symbol affixed to it. The voltage of the right terminal can be adjusted from  $-15\text{ V}$  to  $+15\text{ V}$  with respect to ground. These terminals can supply a maximum current of  $1\text{ A}$ . For AC signals, the minimum frequency is  $0.001\text{ Hz}$  and the maximum is  $200\text{ kHz}$ .

1. Power up the 850 interface.
2. Go to the Hardware Setup window, and then click on the Output 1 terminals of the 850 interface.
3. Click on the signal generator icon in the experimental setup window. The signal generator window will appear. See image below.



This window controls the voltage output of the interface. There are 3 buttons labeled on, off, and auto, only one of which can be active at a given time. When clicked, the on and off buttons produce either a voltage or no voltage at the interface terminals. When the auto button is clicked, a voltage is produced at the interface terminals whenever the Record button is clicked, but the voltage ceases when the STOP button is clicked. **Click the auto button NOW so that you will not have to remember to turn the voltage on and off. Click the auto button whenever you open the signal generator window.**

Also, there is a scroll down menu with DC and 8 AC waveform options. From top to bottom the AC waveforms are sine, square, triangle, up ramp, down ramp, positive only square, positive only up ramp, and positive only down ramp. Select one for the type of voltage desired.

In the signal generator window, there are numbers giving the amplitude and frequency of the interface output. (There is no frequency when the DC button is clicked.) Change these values by clicking the number to highlight it, type in the value and press enter. Try changing the values of both amplitude and frequency. **What happens when you type in a value outside the range of the interface's capabilities?**

## 8 Understanding a DC voltmeter

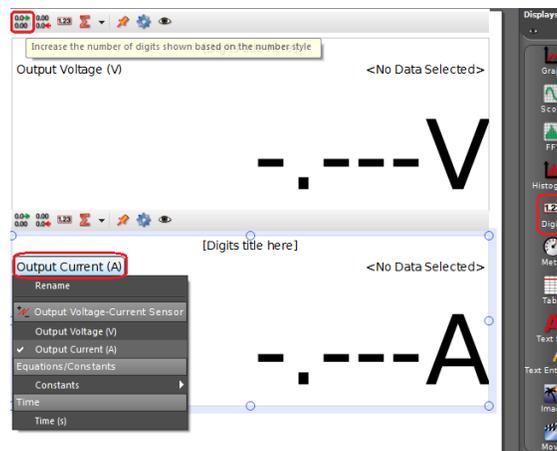
- Set the interface output for 5 V DC.
- Take the analog DC voltmeter, which is on the bench, and turn the knob to the least sensitive scale (500 V). (Always use the least sensitive scale when initially inserting a measuring device into a system.)
- Using a red lead with banana plugs, connect the positive (right) terminal of the interface to the positive terminal (red) of the analog voltmeter. Use a black lead to connect the negative terminals. The negative terminal of the interface is the left one and has a ground symbol. The negative terminal of the voltmeter is black.
- Click Record in the Capstone setup window.
- Increase the sensitivity of the meter to the 5 V scale. **What is the meter reading? How does it compare with the programmed voltage?** While Record is still active, try changing the DC voltage to another value. Click STOP.

Program the interface output for 5 V AC, positive only up ramp, and 0.2 Hz. Click Record and observe the voltmeter. Change the frequency to 100 Hz. Describe the meter reading and explain your observations. Click STOP. QUESTION: If your voltmeter was center zero (rather than left zero) and you put a 100 Hz sinusoidal voltage across the meter would it read anything? Leave the voltmeter in place.

## 9 Internal Measurements of Voltage and Current

The values of the voltage and current delivered by the 850 interface can be measured “internally” using any of the display windows.

Go to the hardware setup window. Make sure that the Output Voltage-Current sensor of the 850 interface is selected. Next, go to the Displays column and setup a digits display for the internal measurements of the Output Voltage and Output Current. On the top left corner of the digits display, you can increase or decrease the number of digits to the right or left. Look at the image below for a better understanding.



## 10 Voltage from 850 Interface: Summary

In the preceding sections the procedures for using the 850 interface to provide voltage were introduced. These procedures are summarized below,

- Click the Output icon of the interface in the experimental hardware set-up window.
- Click the auto button in the signal generator window. This will allow Voltage to appear at the interface terminals whenever the Record button is on.
- The internal output voltage of the interface can be monitored by any display. Set up a digits display for the output voltage.
- The output current of the interface can be monitored by any display. Set up a digits display for the output current.
- The signal generator window allow a choice of DC voltage or 8 AC waveforms.
- To change the output voltage or frequency, highlight the relevant number by clicking the number, or by hitting the up and down arrows.

## 11 Carbon Resistors and the Color Code

Low power carbon composition resistors are usually color coded with respect to resistance value and tolerance. These resistors are cylindrical and have axial leads. Three bands of color starting at one end of a resistor give the value of the resistance. The first and second bands give the first and second digits of the resistance, the third band gives the multiplier, and the fourth band, if there is one, gives the tolerance. A table below presents the color code. For example, starting at the end, if the colors of the bands are red, black, and red, the resistor is a 2,000 ohm or 2 k $\Omega$  or 2k resistor. Silver is  $\pm 10\%$ , gold is  $\pm 5\%$ , and red is  $\pm 2\%$ . No tolerance band means 20%.

Color	Digit	Multiplier
black	0	$10^0$
brown	1	$10^1$
red	2	$10^2$
orange	3	$10^3$
yellow	4	$10^4$
green	5	$10^5$
blue	6	$10^6$
violet	7	$10^7$
gray	8	$10^8$
white	9	$10^9$

On the RLC circuit board, there are two color coded resistors marked as having values of 100  $\Omega$  and 150  $\Omega$ . Verify these resistance values from the color. **What is the range of acceptable resistance values for these two resistors?**

## 12 Viewing AC Waveforms

The AC voltages of the signal generator will be examined as a function of time using the meter and graph displays.

- Remove the leads from the  $100\ \Omega$  resistor, leaving nothing at the voltage terminals of the interface.
- Check that **Output Voltage-Current Sensor** signal icon of the interface has been selected.
- Verify that the **Auto** button of the signal generator is still clicked on.
- Remove the two digits display icons.
- Setup a meter display icon of the Output Voltage. The meter display window opens with a center zero meter.
- Program the interface output for 4 V AC amplitude, sine wave output, and a frequency of 0.3 Hz.
- Click Record and observe the action of the meter.

In turn, select each of the 8 AC waveforms and sketch the voltage outputs as a function of time of each waveform. Click STOP. Explain what is occurring to the voltage as a function of time of each waveform.

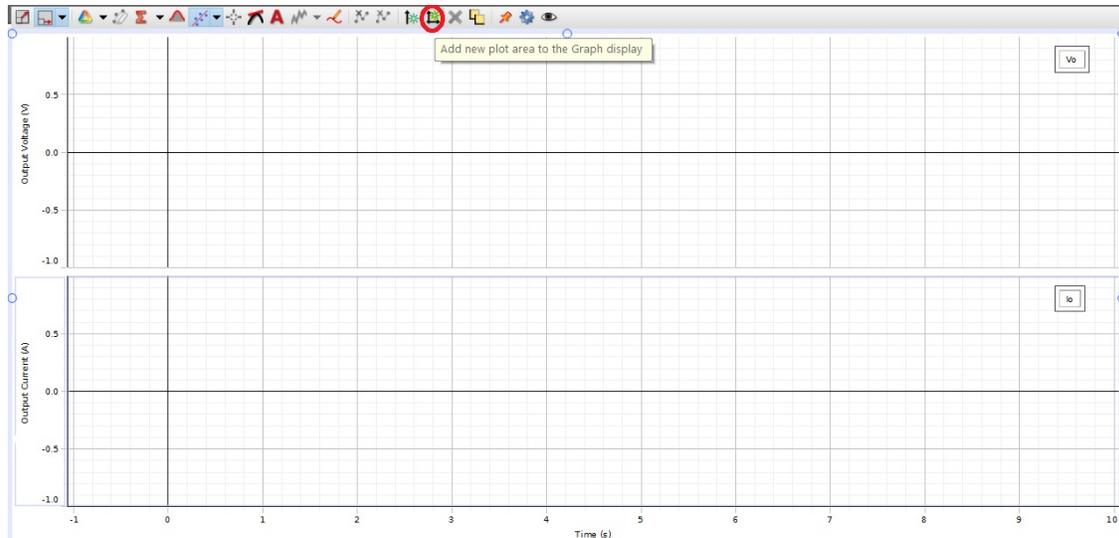
## 13 Voltage vs Current for a Resistor - AC Measurements

Using the AC capabilities of the signal generator, almost continuous measurements of voltage and current can be obtained. This saves time and allows measurements on non-ohmic circuit elements to be made quickly.

- Program the interface voltage output for a triangular wave, 5 V amplitude, and 0.2 Hz.
- Connect the interface output across the  $100\ \Omega$  resistor on the RLC circuit board.
- Open the graph display window by dragging the graph display icon onto Capstone page.
- Program the graph display for 2 plots, and make one the output voltage and the other output current. The horizontal axis should be the default value of time. Look on the top of the next page to see how graph should be displayed and the location of the button to add an additional plot.
- Create a table display of the output voltage and current to log the data.
- Click Record, run for about 10 s, and click Stop.
- Click the **Scale axis** button located on the top left of the graph.

Open a new graph display with output voltage on the vertical axis and output current on the horizontal axis. The data you just took will appear on this graph. **Does it look like Ohms law is being obeyed?**

To do a more detailed analysis later, we need to save the raw data. Click the table window to bring it into focus. Under the FILE menu, click "Export data". Save the file to the desktop. If you want to save all the data. Also, if you want to export only certain parts of the data then,



- In the table left click and highlight the data you want
- Press CTRL+C to copy the data to the clipboard or right click on the highlighted data and select **Copy values**
- Open Excel or Notepad and Press CTRL+V to paste the data

Capstone exports the table in a column separated format which is easily read by Python's NumPy library. Using python, perform a linear fit analysis on the voltage and current data. Determine the slope,  $y$ -intercept, and their respective uncertainties. **Are they what you expect?** Create a plot of the data with the line of best fit. **What is the intercept and slope of the fitted line. Are they what you expect?**

## 14 Observing Voltage vs Current for a non-ohmic device

The voltage and current for a filament are examined using AC signal. The voltage vs current curve is not a single value and is said to display hysteresis. The same results are not obtained when the voltage is increasing and when the voltage is decreasing.

- Remove the  $100\ \Omega$  resistor from across the interface terminals and replace it with the #50 bulb on the RLC circuit board.
- Use the same parameters as in the previous section and make the same measurements.
- Keep an eye on the bulb. Discuss your results

On the graph of output voltage vs. output current you will see hysteresis. **Can you explain this? Can you figure out which branch of the curve is taken with increasing voltage magnitude and which is taken with decreasing voltage magnitude?**

**Take a plot of output voltage vs output current at a frequency of 0.01 Hz. How is the hysteresis affected?** Explain. Adjust the sample rate on the signal output of the 850 interface to 500 Hz (The default sampling rate of 100 Hz is not sufficient for the next run). Take a plot of output voltage vs output current at a frequency of 20 Hz. **How is the hysteresis affected?** Explain. In both these cases, consider how long you need to take data.

## 15 Measuring Resistors in Series and Parallel

Connect the  $33\ \Omega$  and  $100\ \Omega$  resistors on the RLC circuit in series across the output of the interface. Measure the resistance and compare to the value given by Eq.(2). Measure the resistance in the simplest way you can think of using the equipment you have.

Measure the resistance of these same resistors in parallel, and compare to the value given by Eq.(3). (You should not use the  $10\ \Omega$  resistor. It will draw too much current.)

## 16 Voltage Sensor and Analog Current Meter

In this section, you will familiarize yourself with the Pasco voltage sensor and a moving coil analog current meter. The internal resistance of the analog current meter will be measured and the effects that an analog meter has in the circuit.

The Pasco voltage sensor is an analog sensor. The analog current meter is of the moving coil type. Turn its sensitivity knob to the least sensitive position (1 A) before inserting it into the circuit. When connecting the current meter avoid the red terminal marked 10 A. (When the meter is used on the 10 A scale, the sensitivity is not affected by the sensitivity knob.)

- Connect the  $10\ \Omega$  resistor and the DC current meter in series.
- Connect this series combination across the interface voltage terminals.
- Connect the 2 leads of the voltage sensor across the  $10\ \Omega$  resistor and plug the sensor into analog channel A.
- Click on analog channel A and choose voltage sensor. Use a digits display to measure the output of the voltage sensor.
- Program the interface voltage output for 0.1 V DC. Internally sample the output voltage and output current of the interface using two digital displays and using an appropriate number of decimal places. Click Record.

For the various sensitivities of the analog current meter record the voltage output of the interface, the voltage across the resistor, and the currents measured by the analog meter and the digital meter. **Discuss your results. Does the analog current meter affect the current in the circuit? What is the resistance of the analog current meter on its different scales? How does turning the sensitivity knob change the sensitivity of the current meter?**

## 17 Comment

Parts of these labs have dealt with ohmic and non-ohmic resistors, while other parts have been tutorials dealing with the voltage and current capabilities of Capstone. If you needed to check on the value of a resistor, do not use the procedures in these labs. Pick up a digital multimeter. Time varying voltages are best examined using an oscilloscope.

## 18 Finishing Up

Please leave your bench in a tidy fashion. Thank you.