Voltage Current and Resistance I

Equipment: Capstone with 850 interface, analog DC voltmeter, analog DC ammeter, voltage sensor, RLC circuit board, 4 black leads, 4 red leads

1 Purpose

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

2 Voltage

If two points have a voltage difference between them (also, called a potential difference) 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.

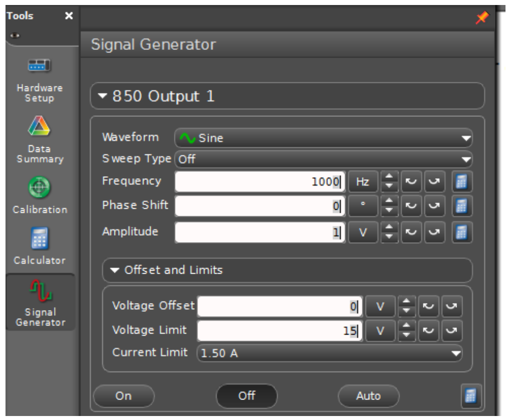
The crust of the Earth is not a great conductor. Nevertheless the Earth is often assumed to be an equipotential and voltages are often measured with respect to "ground." A good water pipe is often taken as ground potential. Why?

Voltage can be generated by batteries, power supplies, and signal generators. Batteries maintain a DC (time independent) voltage across the 2 terminals (metal electrodes) by chemical means. Power supplies and signal generators maintain voltages across their terminals by using elements such as transformers, diodes, resistors, capacitors, transistors, etc. 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 ideal voltage source maintains the prescribed voltage across its terminals no matter how much current is supplied from the terminals. Ideal voltage sources do not exist.

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 ν. Frequency is the number of periods or oscillations per second. The basic unit of frequency is the 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 the 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 in 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. In essence to determine the current being drawn through a resistor you need to place the ammeter in series with the resistor. A common type of ammeter is similar to the moving coil voltmeter. Another way is to use a low value resistor and measure the voltage across the resistor (see Ohms law). 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 applied 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 that is designed to impede the flow of current is called a resistor. If V is the voltage across a resistor and I is the current through the resistor, then in many cases it is found that a good approximation of the ratio V/I is a constant. This ratio is called the resistance R. The units of R are ohms (Ω). 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 increases the bulb gets hotter and the resistance of the filament increases.

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

$$R = R_1 + R_2. \tag{2}$$

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

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{3}$$

These formulas are easily extended to 3 or more resistors.

6 Comment on Measuring Voltage and Current

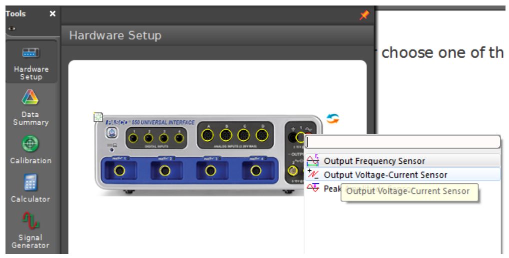
To measure a voltage between two points in a circuit, connect the two leads (wires) of your voltmeter across those points. To measure the current in a circuit wire, "break" the wire and connect the two ends to an ammeter in series. In both cases you will change the voltage and currents in the circuit. 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 measuring devices that you will learn how to use.

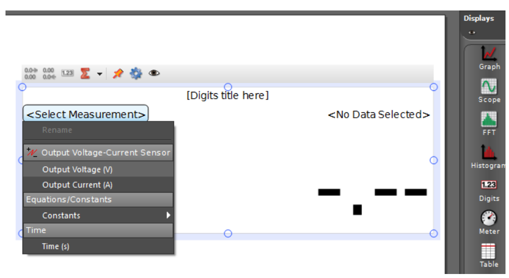
1. Analog voltage and current meters that are not part of Capstone.

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 sensor icon appears below the channel. 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 internal voltage or current output of the interface.

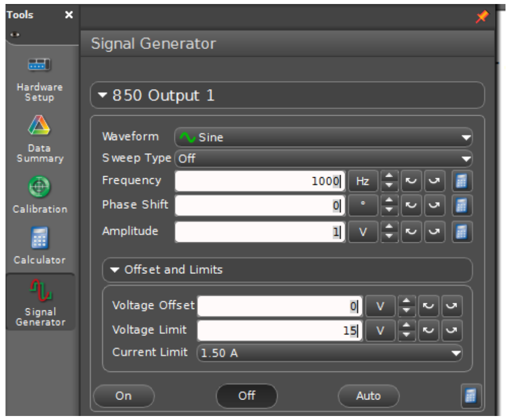


7 Voltage From The 850 interface

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 $-15\ V$ to $+15\ V$ with respect to ground. These terminals can supply a maximum current of 1 A. For AC signals the minimum frequency is 0.001 Hz and the maximum is 200 kHz.

Take the analog DC voltmeter, which is on the bench, and turn the knob to the least sensitive scale (300 V). (Always use the least sensitive scale when initially inserting a measuring device into a system.) Using a red lead with banana plugs to connect the positive (red on the right) terminal of the interface to the positive terminal (plus sign) of the analog voltmeter. Use a black lead to connect the negative terminal of the interface (black on the left) to the negative terminal of the voltmeter (minus sign).

Go back to Capstone. Click on the signal generator icon in the experimental setup window. The signal generator window will appear. Next, click on 850 Output 1. See image below.

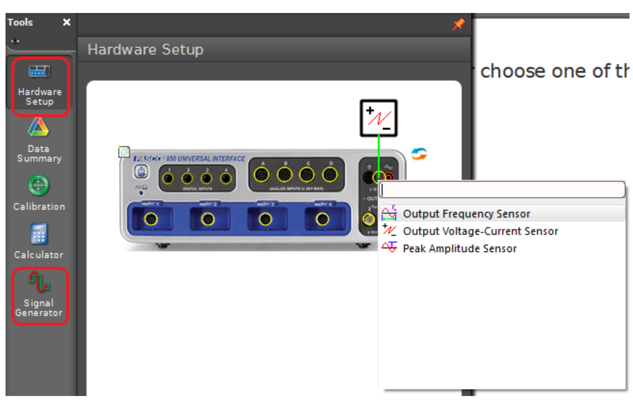


This window controls the voltage output of the interface. There are 3 buttons labeled on, off, and auto, only one of which can be active at a given time. When clicked, the on and off buttons produce either a voltage or no voltage at the interface terminals. When the auto button is clicked a voltage is 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.

In the signal generator window 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?

Set the interface output for 3 V DC and click on Auto. Next, click on the hardware setup, and click on the 850 output. Select **Output Voltage - Current sensor**.



Click Record in the experiment setup window. Increase the sensitivity of the meter to the 3

V scale. What is the meter reading? How does it compare with the programmed voltage? While Record is still active, try changing the analog voltage scale to 10 volts. What occurs to the analog voltmeter and what does it read? Explain. Click STOP.

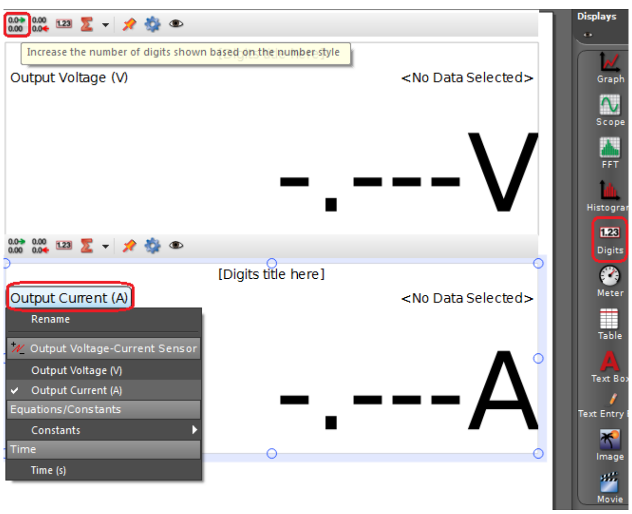
Program the interface output for 3 V AC amplitude, positive up ramp wave, and at a frquency of 0.3 Hz. Increase the sensitivity of the meter to the 3 V scale. Click Record and observe the voltmeter. Sketch the voltmeter reading as a function of time. Change the frequency to 120 Hz. Describe the meter reading and explain your observations. Click STOP. If your voltmeter was center zero (rather than left zero) and you put a 120 Hz sinusoidal voltage across the meter would it read anything? Leave the voltmeter in place.

8 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. This section will introduce you to this capability.

8.1 Measurement using digits displays

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 measurments 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.



Set the analog voltmeter to 10 V DC. Next click on the signal generator icon and program the interface output for 10 V DC and click Record. How do the readings of the output voltage digits display, the voltmeter, and the programmed voltage, compare? Explain. Click Stop.

9 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.

- 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.

10 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 color bands starting at one end of a resistor give the total value of the resistance. The first and second bands give the first and second digits of the resistance. The third band gives the multiplier. A table at the back of this write-up presents the color code scheme. For example, starting at the end, if the colors of the bands are red, black, and red, the resistor would be 2,000 ohm or 2 kΩ or 2k resistor. A fourth band, if there is one, gives the tolerance. Silver is ±10%, gold is ±5%, and red is ±2%. No tolerance band means 20%.

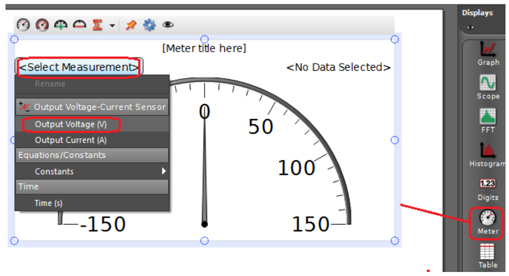
On the RLC circuit board there are two color coded resistors marked as having values of 100 Ω and 150 Ω. Verify these resistance values from the color bands on these resistors. Explain what would be the range of acceptable resistance values of these two resistors?

11 Voltage vs Current for a Resistor - Discrete Measurements

Remove the analog voltmeter from the output terminals of the interface. Connect the 100 Ω resistor on the RLC circuit board across the interface voltage terminals. Program the signal generator for 6 V DC and set up two digits displays to internally measure the interface's output voltage and output current to 3 significant figures. With one finger, keeping the rest of your body electrically insulated, gently touch the resistor. DO NOT DO THIS WITH HIGHER VOLTAGE! Why is the resistor warm? Divide the measured voltage across the resistor by the measured current through the resistor to obtain the resistance to 3 significant figures. Repeat for voltages of 5 V, 4 V, 3 V, 2 v, and 1 V. Compare your resistance values. Create a plot of the voltage vs Current. What is occurring in the plot? Is there a trend? Explain.

12 Waveforms

The AC voltages of the signal generator will be examined as a function of time using the meter and graph displays. Remove the 100 Ω resistor, leaving nothing at the voltage terminals of the interface. Check that the Output Voltage-Current Sensor signal icon of the interface has been selected. Also, verify that 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 ot time of each waveform.

13 Finishing Up

Close and restart Capstone. Leave the sensors plugged into the interface and just disconnect the banana leads connected to all the different meters. Be considerate for your fellow humans and leave your bench in a tidy fashion. Thank you.

Resistor Color Code

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