

## Voltage, Current, and Resistance I

## Lab 6

Equipment SWS with 750 interface, Power Amplifier II, analog DC voltmeter, analog DC ammeter, voltage sensor, current sensor, RLC circuit board, 4 black leads, 4 red leads

MUST READING “Electrical Safety” at the beginning of this manual.

## 1 Purpose

To learn how voltages and currents are generated and measured with the SWS 750 interface and other equipment, and to investigate how voltage and current are related in resistors.

## 2 Voltage

Two points have a voltage between them if work is done by the electric field as a charge 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 defined as the work done on a unit positive charge by the electric field as the unit positive charge is moved from one of the two points to the other point. The units are joules per coulomb (J/C), which is defined as Volts (V).

With real wires that have resistance and are carrying current the electric field inside the wire is not zero and the conductor is not at one potential: that is, the wire is not an equipotential. It is often a good approximation to assume that in a circuit each connecting wire is an equipotential. This approximation is made in the labs of this course. For example, if the ends of a resistor are connected to two wires, the voltage across the resistor can be measured by connecting the two leads of the voltmeter 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 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.

The voltage between two points may be a function of 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  $\nu$ . The basic unit of frequency is the hertz (Hz) when the period is measured in seconds. The frequency is the number of periods or oscillations per second. The shape of the voltage vs time graph is called the waveform. Common waveforms are sine, square, triangular, and ramp.

In these labs voltages may be obtained from the SWS 750 interface and from the SWS Power Amplifier II. The SWS 750 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. The maximum frequency produced by the SWS 750 interface is 50 kHz (The 700 interface does not have terminals for voltage output. It will drive the Power Amplifier II with a maximum frequency of 5 kHz.)

Voltage between 2 points which are 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 on the two conductors the voltmeter gives the voltage between the 2 points touched, usually either in digital or analog (meter) form. To make a measurement the voltmeter has to draw some charge or current. An ideal voltmeter will draw no charge or current. An actual voltmeter will draw some charge or current and change the voltage being measured. 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 current. This moving coil type of voltmeter has a relatively low internal resistance and can draw a non-negligible amount of current. It is also called a D'Arsonval meter. For instructional purposes one of these voltmeters will be used in this lab.

In any region where there are conductors with charges there may be a voltage between 2 points in space (the points not being in or on conductors). A voltmeter will not measure the voltage difference between 2 such points because space cannot provide the necessary charge or current to make the voltmeter work. In addition, just moving the voltmeter leads around in space will probably alter the voltages in space. But the voltages on conductors connected to a good power supply will be unaffected by waving the voltmeter leads in the space around the conductors.

### 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 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. 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 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 Comment on Measuring Voltage and Current

To measure a voltage between two points in a circuit, connect the two leads (wires) of your voltmeter to those points. To measure the current in a circuit wire, “break” the wire and connect the two ends to an ammeter. (This usually is jargon for the following procedure. Unplug one wire and connect it to the ammeter. Plug one end of an extra lead into the ammeter and complete the circuit with the other end of the extra lead.) In both cases you will change the voltage and currents in the circuit. This can be minimized by using voltmeters with as high a resistance and possible, and ammeters with as small a 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 SWS.
2. The SWS voltage and current sensors. These are analog sensors. Each sensor plugs into an analog channel of the interface. In the right experimental set-up window you must drag the analog plug to 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 the icon of the display you want to the sensor icon.
3. Internal measurement of the output voltage and output current of the interface or the Power Amplifier II. For the interface, in the right experimental set-up window click the sample V and sample I buttons. Drag display icons to the terminal icons marked V and I. The output voltage for the Power Amplifier II is measured in the same way as the interface output voltage. The output current of the Power Amplifier II is measure by dragging a display icon to the Power Amplifier II icon.

## 5 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

$$V = IR. \quad (1)$$

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.

## 6 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 formulae are easily extended to 3 or more resistors.

## 7 Voltage From The 750 interface

An output voltage can be obtained from either the 750 Interface or from the Power Amplifier II which sits on top of the Interface. In this section you will learn how to obtain voltages from the terminals of the 750 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  $-5\text{ V}$  to  $+5\text{ V}$  with respect to ground. These terminals can supply a maximum current of 300 mA. For AC signals the minimum frequency is 0.001 Hz and the maximum is 50 kHz.

While using the 750 interface to supply voltage, leave the Power Amplifier II plugged into channel C, and if the power amplifier is on, leave it on. This will not affect the voltage output of the interface.

Important If the voltage is being taken from the 750 interface (not from the power amplifier), the power amplifier must not be activated. There should be no power amplifier icon in the right experimental set-up window.

Check the light on the front of the interface to be sure the interface is on. Click the Sample V button in the right experiment setup window. The signal generator window will appear. 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. The on and off buttons when clicked produce 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 REC or MON 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 DC button and 8 AC waveform buttons. From left to right the AC waveforms are sine, square, triangle, up ramp, down ramp, positive only up ramp, and positive only down ramp. Click one button for the type of voltage desired.

In the signal generator window are numbers giving the amplitude and frequency of the interface output. (There is no frequency when the DC button is clicked.) A good way to

change these values is to click the number to highlight it, type in the value you want from the keyboard, and press the enter key. 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 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 MON in the left experiment 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 MON 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 MON and observe the voltmeter. Sketch the voltmeter reading as a function of time. 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.

## 8 Internal Measurements of Voltage and Current

The values of the voltage and current delivered by the 750 interface can be measured "internally" using any of the display windows. This section will introduce you to this capability. You will also measure the resistance of the external analog voltmeter.

Drag a digits display icon to the 2-terminal icon marked with a V. This is just above the Sample V button. A digits display window will open titled "output voltage." Double click in the display area and choose three decimal places. Click the Sample I button. The 2-terminal icon marked I (for current) will be highlighted. Drag a digits display icon to this icon. A digits display window will open titled "output current." Double click in the display area of the output current window and specify 6 decimal places. Program the interface output for +5 V DC and click MON. How do the readings of the output voltage digital display, the voltmeter, and the programmed voltage, compare? What is the current through the analog voltmeter on the 25 V and 5 V scales? Click STOP. What is the internal resistance of this voltmeter on these scales? (The internal resistance is the voltage across the meter divided by the current through the meter.) Generally, on the most sensitive scale of an analog volt meter the voltage is connected directly across the coil of wire. On the less sensitive scales a simple resistor network is used to reduce the voltage.

## 9 Voltage from 750 Interface: Summary

In the preceding sections the procedures for using the 750 interface to provide voltage were introduced. These procedures are summarized.

- There must be no power amplifier icon in the right experimental set-up window.

- Click the sample V button in the right experimental set-up window. The signal generator window will appear.
- Click the auto button in the signal generator window. Voltage will appear at the interface terminals whenever the REC or MON button is in, and the sample V button is in.
- The output voltage of the interface can be monitored by any display. Drag a display icon to the 2 terminal icon marked with a V. The sample V button must be in.
- The output current of the interface can be monitored by any display. Click the sample I button so that it is in. Drag a display to the 2 terminal icon marked with an I.
- Buttons in 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. Enter the value desired from the keyboard and press enter.

## 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 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. A table at the back of this write-up 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. A fourth band, if there is one, gives the tolerance. Silver is  $\pm 10\%$ , gold is  $\pm 5\%$ , and red is  $\pm 2\%$ . No tolerance band means 20%.

On the RLC circuit board are two color coded resistors marked as having values of 100  $\Omega$  and 150  $\Omega$ . Verify these resistance values from the color bands on these resistors. What is the range of acceptable resistance values for 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  $\Omega$  resistor on the RLC circuit board across the interface voltage terminals. Program the signal generator for 5 V DC and set up two digit 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 CIRCUITS!** 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 3 V and 1 V. Compare your 3 resistance values. Is there a trend you can explain? From the File menu click New and then Don't Save.

## 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  $\Omega$  resistor, leaving nothing at the voltage terminals of

the interface. Click the sample V button and then auto. Drag the meter display icon to the 2-terminal voltage icon. The meter display window opens with a center zero meter. Program the interface output for 5 V AC, sine wave output, and 0.2 Hz. Click MON and observe the action of the meter. In turn, click each of the AC waveform buttons. Sketch the voltage outputs as a function of time. Click STOP.

Set up the graph display to observe the voltage output of the interface as a function of time. (Detailed instructions omitted.) For a few of the AC wave forms record data for several periods of the waves by clicking REC and then STOP. Compare to what you just sketched.

### 13 Finishing Up

Please 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	$10^9$