ECE201 Laboratory 1
Basic Electrical Equipment and
Ohm's and Kirchhoff's Laws

(Created by Prof. Walter Green, Edited by Prof. M. J. Roberts)

Objectives

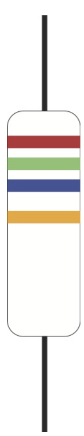
The objectives of Laboratory 1 are

- learn to operate an oscilloscope, a voltmeter and a multimeter,
- learn to build circuits using a breadboard,
- verify Ohm's and Kirchhoff's Laws by building circuits and measuring voltages and currents,
- measure and calculate equivalent circuit resistance.

We start by familiarizing ourselves with some common circuit elements.

The Resistor

One of the most widely used passive components in an electric circuit is the resistor. ("Passive" means being able to dissipate or store energy but not able to generate energy.) Resistors come in various sizes according to the power they can safely dissipate. They are made from various materials such as carbon or wound wire. The diagram below is that of a carbon resistor. The value of the resistor can be identified from the bands around the device with the color code as shown in Figure 1.1.



Resistance	Value	Tolerance	
Black	0	Gold	5%
Brown	1	Silver	10%
Red	2	None	20%
Orange	3		
Yellow	4		
Green	5		
Blue	6		
Violet	7		
Grey	8		
White	9		

$$\text{Resistance in ohms} = [\text{1st Band}][\text{2nd Band}] \times 10^{[\text{3rd Band}]}$$

Example: 470 kΩ → Yellow, Violet, Yellow

Figure 1.1 The color code for resistors.

The Capacitor

The capacitor is another passive circuit element. The number on the capacitor indicates its value. For example, a capacitor marked 105 is 10 X 10^5 X 10^{-12} farads or 1μF. Capacitors can be polarized and non-polarized. Common materials from which they are made include mylar, polystyrene for a non-polarized capacitor and an electrolytic material for a polarized capacitor. In the most basic form, a capacitor is composed of two conductors (plates) separated by a dielectric as shown in Figure 1.2.

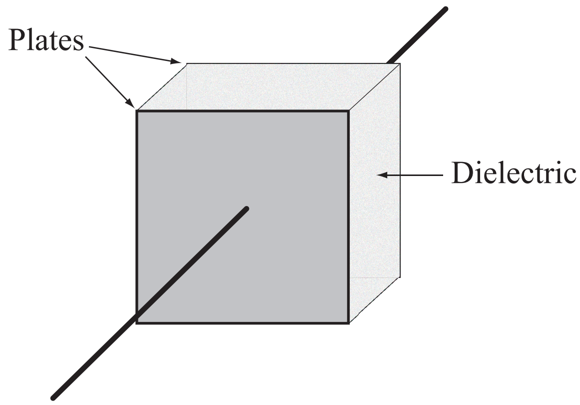


Figure 1.2 A parallel-plate capacitor

The equation for calculating the capacitance in farads of a parallel-plate capacitor is $C = \frac{\varepsilon A}{d}$ where A is the area of one plate in meters, ε is the permittivity of the dielectric material in farads/meter and d is the separation between the two plates in meters.

The Inductor

A coil of wire, as shown in Figure 1.2, forms an inductor. The wire may be wrapped around either a magnetic or nonmagnetic material.

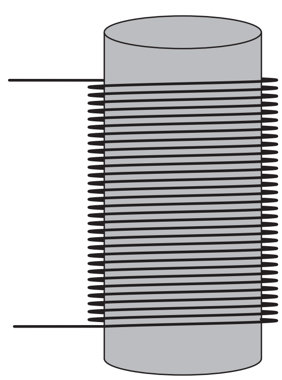


Figure 1.3 A coil of wire forming an inductor.

The equation for calculating the inductance in henrys of a wire-solenoid inductor is $L = \frac{N^2 \mu A}{l}$ where N is the number of turns of wire, A is the cross-sectional area of the coil in square meters, μ is the magnetic permeability of the material on which the wire is wound in henrys/meter and l is the length of the coil in meters.

The Potentiometer

A potentiometer ("pot") is a variable resistor. The device we use in our lab looks like a small rectangular box with three leads and a screw. Between the two end leads, the resistance value is fixed. Between the center lead and either of the corner leads turning the screw changes the value of the resistance. This is often shown in a circuit as given in Figure 1.4 below. The number on the potentiometer gives the maximum value of resistance. A 1 kΩ pot can be adjusted between 0 and 1 kΩ. For example if the number on the pot is 104 that means the resistance between the two end leads is $10 \times 10^4 = 100\text{k}\Omega$.

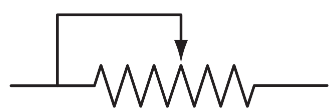


Figure 1.4 The schematic symbol for a potentiometer

Breadboard

A breadboard holds circuit components in place and connects them electrically. A breadboard is shown in Figure 1.5. The breadboard has many strips of metal that run underneath the plastic top. The metal strips are arranged as shown in the Figure 1.5. These strips connect to the holes on top of the board. This makes it easy to connect components together when building a circuit.

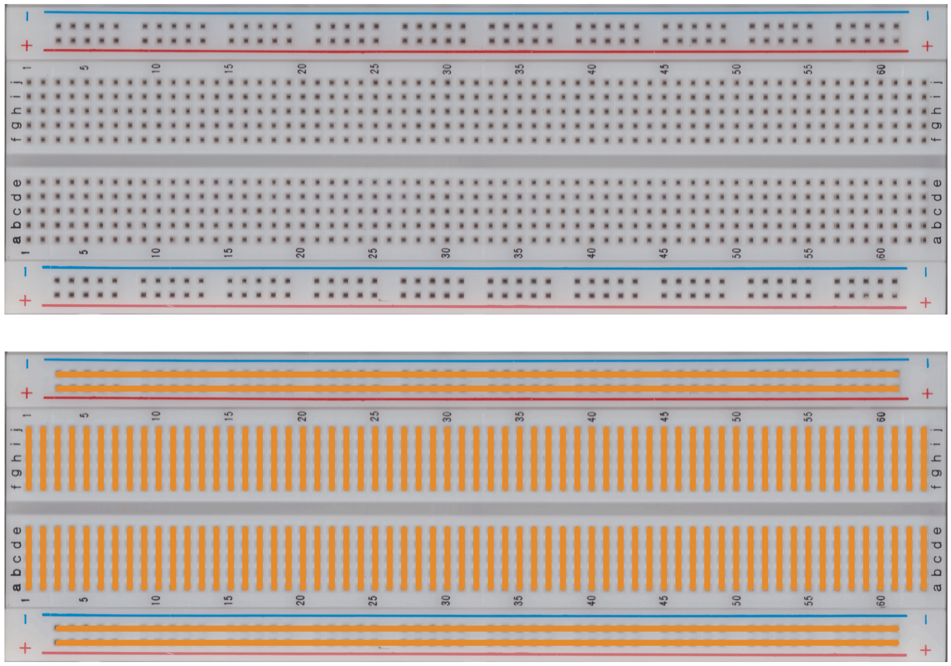


Figure 1.5 Breadboard and breadboard connection pattern

Equipment

The following two sections explain the operation of the laboratory digital multimeter, HP34401A and the function generator, HP33120A. The operations will be further explained by the lab instructor before you proceed with the laboratory. If you have any trouble operating the laboratory equipment, ask the instructor for help.

Digital multimeter

A digital multimeter is used to make measurements of voltage, current or resistance. Two leads are required for making measurements. Usually one lead is red (positive) and one lead is black (negative).

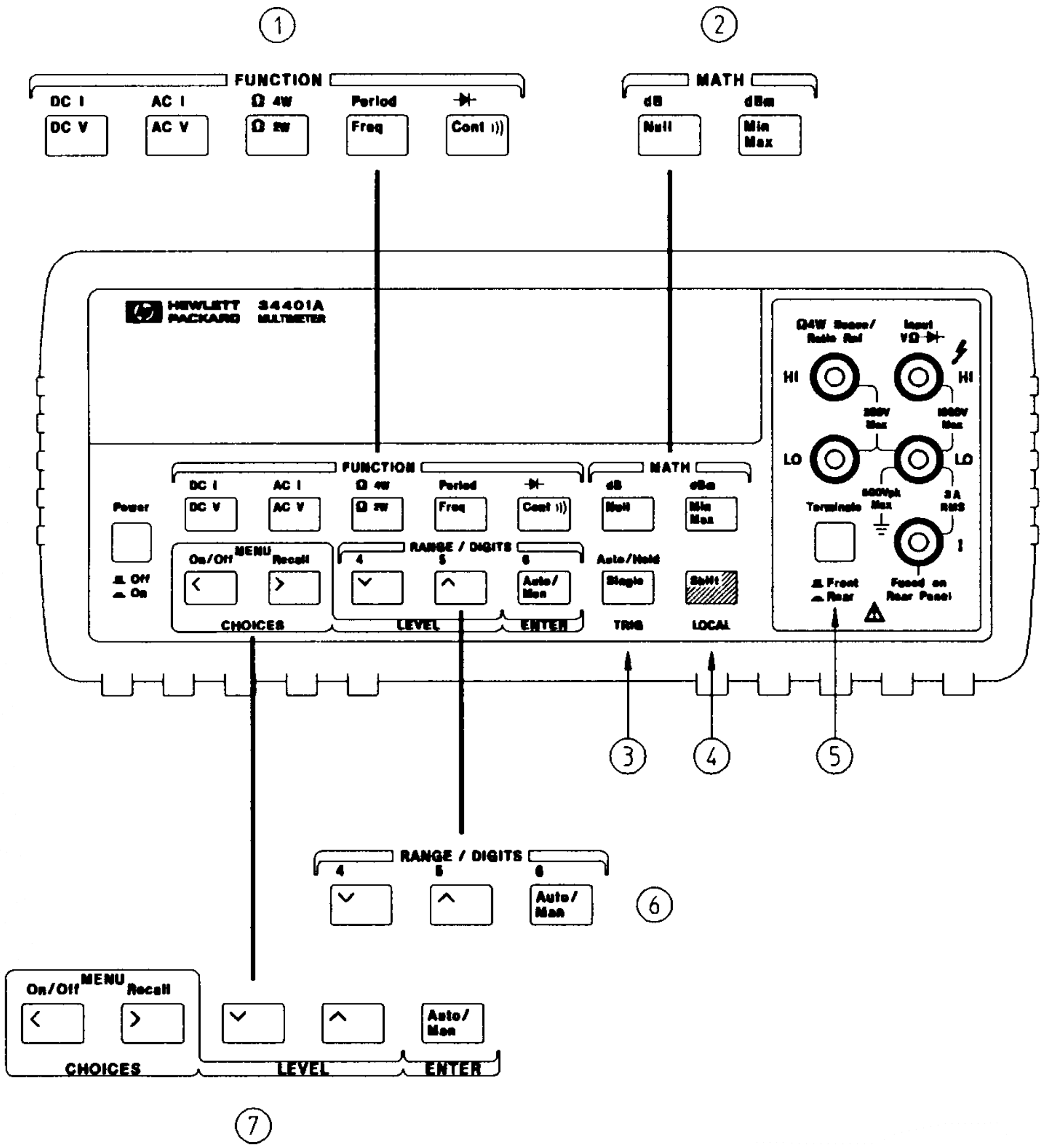
Measuring Voltage and Resistance

Both AC and DC voltage can be measured by the digital multimeter by selecting the DC V or AC V buttons. From the section marked "5" in Figure 1.6 one can see that there are three sockets along the second column labeled HI, LO and I. To measure voltage, the red lead (positive) should be connected to the HI socket while the black lead (negative) should be connected to LO.

To measure resistance, the same lead configuration as used for measuring voltage should be used. However, the leads can be reversed. The polarity of the leads is not significant when measuring the resistance of a resistor. (It is important however when determining the polarity of a diode.) Before making the resistance measurement press the Ω button shown in section 1 of Figure 1.6. Make sure that there are no other connections to the resistor when making this measurement.

Measuring Current

To measure current the black lead should be connected to the same socket as in voltage measurement (LO) but the red lead should be connected to the socket labeled I. The multimeter should be in series with the circuit elements whose current you are measuring. If positive current is flowing from the red to the black lead the current indication on the multimeter will be a positive number. If positive current is flowing from the black to the red lead the current indication on the multimeter will be a negative number. The buttons DC I or AC I can be chosen by pressing SHIFT + DC V or SHIFT + AC V.

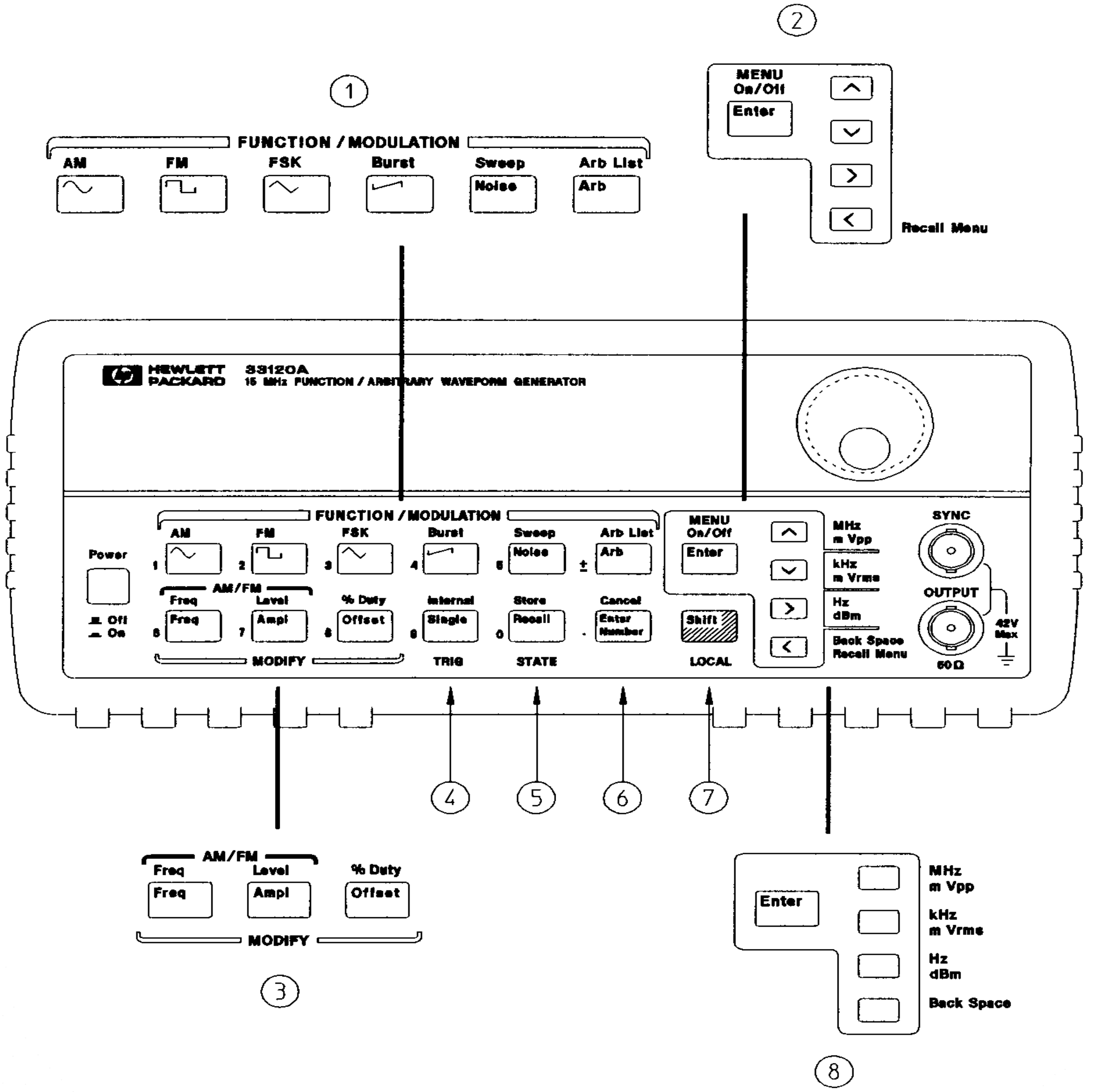


1 Measurement function keys
2 Math operation keys
3 Single trigger / autotrigger / reading hold key
4 Shift / local key
5 Front / rear input terminal switch
6 Range / number of digits displayed keys
7 Menu operation keys

Figure 1.6 HP34401A Multimeter

Function Generator

The function generator can be used to generate various signals such as sinusoids and square and triangular waveforms. Figure 1.7 shows the front panel of the function generator. This panel is used for entering waveform amplitude and frequency information. A BNC cable must be connected to the socket labeled OUTPUT in order to obtain the signal from the function generator. The amplitude can be adjusted to meet the requirements by following the procedure in outlined in Figure 1.8.



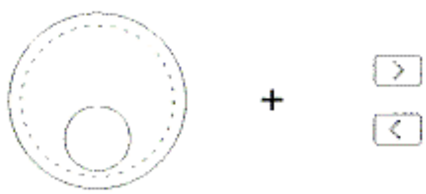
1 Function / Modulation keys
2 Menu operation keys
3 Waveform modify keys
4 Single / Internal Trigger key
(*Burst and Sweep only)*
5 Recall / Store instrument state key
6 Enter Number key
7 Shift / Local key
8 Enter Number "units" keys

Figure 1.7 The HP33120A Function Generator

Front-Panel Number Entry (continued)

You can enter numbers from the front-panel using one of three methods as presented below.

Use the knob and the arrow keys to modify the displayed number.



Use the arrow keys to edit individual digits.

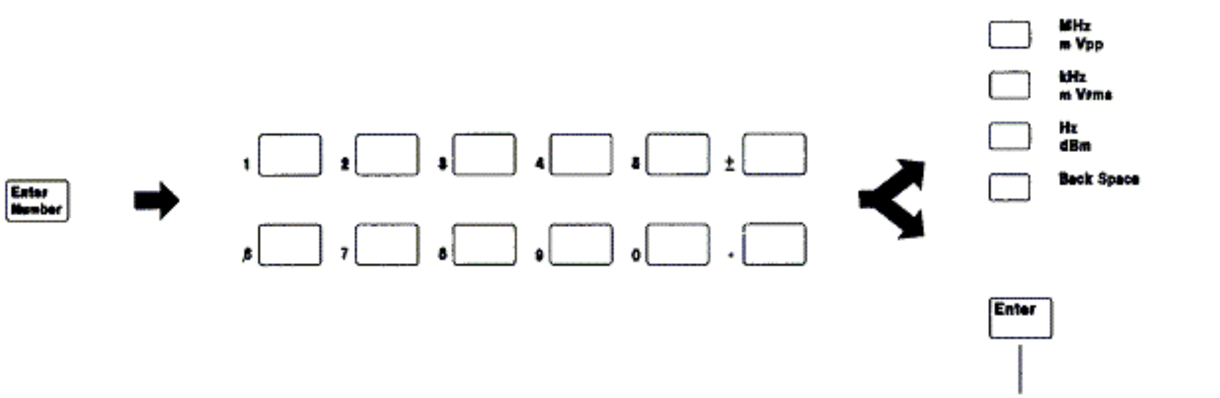
Increments the flashing digit.

Decrements the flashing digit.

Moves the flashing digit **to the right.**

Moves the flashing digit **to the left.**

Use the "Enter Number" mode to enter a number with the appropriate units.



Use "Enter" for those operations that do not require units to be specified (AM Level, Offset, % Duty, and Store/Recall State).

Figure 1.8 Front-panel number entry

Ohm's Law

The course textbook covers Ohm's Law in detail (Figure 1.9).

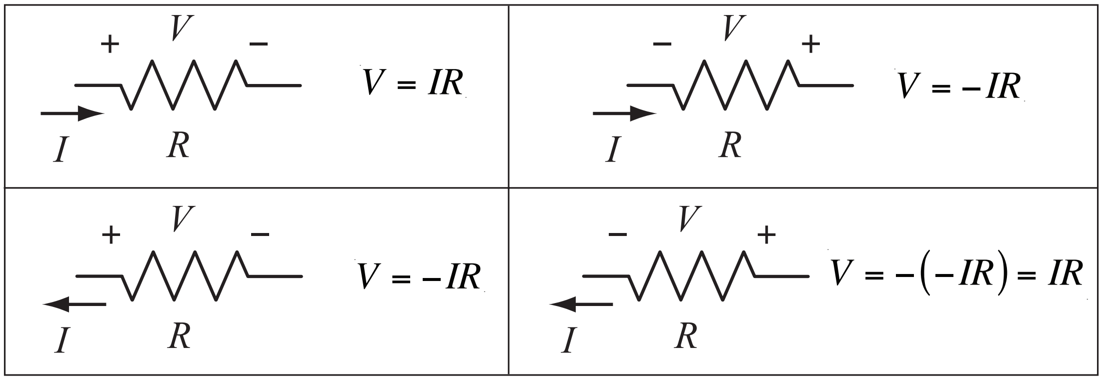


Figure 1.9 Ohm's Law

Kirchhoff's Voltage Law

You should refer to your textbook for an in depth discussion of Kirchhoff's Voltage Law. Basically, KVL (Kirchhoff's Voltage Law) states that the algebraic sum of the voltages around any closed path of an electric circuit is equal to zero. Before we go further, we need to discuss "voltage rise" and "voltage drop."

Once the polarity of the voltage has been assumed across a circuit element, we can talk about voltage rise and voltage drop across the element, but not before we have assumed a polarity. Consider the cases shown in Figure 1.10.

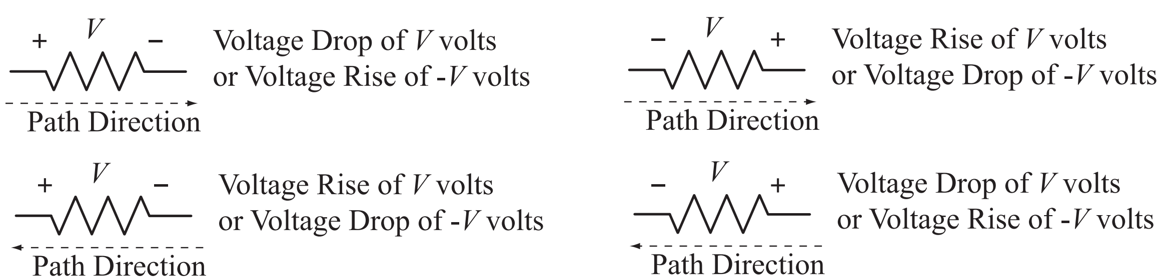


Figure 1.10 Voltage rise and drop

It is important to realize that the arrows in Figure 1.10 <u>are not current arrows</u>. Instead they indicate the direction in which we are traversing a path through the circuit. For any particular circuit element, the current might be in the same direction or the opposite direction. In other words, the voltage rise or drop in KVL calculations depends only on the path direction and the reference voltage polarities on the circuit diagram, not on the current direction.

We can state Kirchhoff's Voltage Law in three ways which all really say the same thing.

- The algebraic sum of the voltage drops around any closed path of an electric circuit equal zero.
- The algebraic sum of the voltage rises around any closed path of an electric circuit equal zero
- The algebraic sum of the voltage rises equal the algebraic sum of the voltage drops around any closed path of an electric circuit.

Consider the circuit of Figure 1.11.

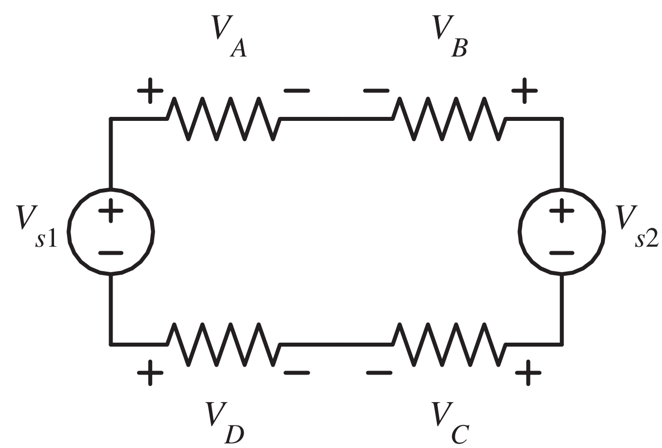


Figure 1.11 Circuit for illustrating Kirchhoff's voltage law

Starting at the lower left-hand corner, going clockwise, using voltage drops we have,

$$-V_{s1} + V_A - V_B + V_{s2} + V_C - V_D = 0$$

Starting at the lower left-hand corner, going clockwise, using voltage rises we have,

$$V_{s1} - V_A + V_B - V_{s2} - V_C + V_D = 0$$

The second equation is simply the first one multiplied through by -1 and therefore really the same equation. If we assume a clockwise reference current through all the elements (Figure 1.12) in the circuit we can use Ohm's law to write

$$V_A = IR_1 \;\; , \;\; V_B = -IR_2 \;\; , \;\; V_C = IR_4 \;\; , \;\; V_D = -IR_3$$

Then, substituting these equations into the previous KVL equation,

$$-V_{s1} + IR_1 - (-IR_2) + V_{s2} + IR_4 - (-IR_3) = 0$$

or

$$(R_1 + R_2 + R_4 + R_3) I = V_{s1} - V_{s2}$$

Now, if we know the two source voltages we can solve for the current through and the voltages across each resistor.

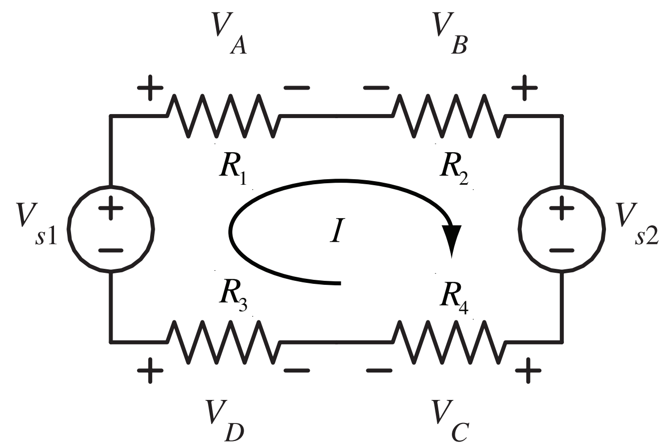


Figure 1.12 Circuit example problem

Kirchhoff's Current Law

Kirchhoff's Current Law can be expressed as follows.

(a) The algebraic sum of the currents entering a junction (node) equal zero.
(b) The algebraic sum of the currents leaving a junction (node) equal zero.
(c) The algebraic sum of currents entering a node equal to the algebraic sum of currents leaving a node.

Consider the node shown in Figure 1.13.

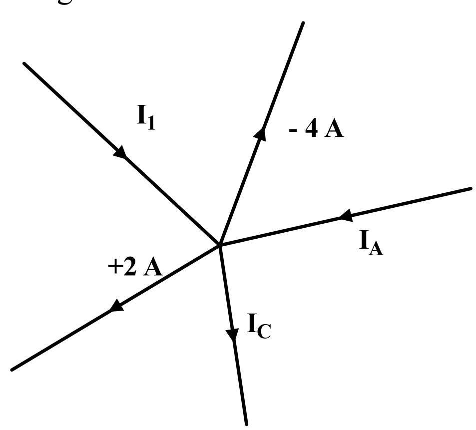


Figure 1.13 Partial circuit illustrating Kirchhoff's current law

Using the algebraic sum of the currents entering the junction equal zero we write

$$I_1 - (-4) + I_A - I_C - 2 = 0$$

Using the algebraic sum of the currents leaving the junction equal zero we write

$$-I_1 + (-4) - I_A + I_C + 2 = 0$$

One equation is just the negative of the other. The conclusion is that either (a), (b) or (c) above may be used to write Kirchhoff's Current Law. Kirchhoff's current law is actually more general than it is stated above. It applies not only to a junction or node in a circuit but also to any part of a circuit. That is, we can draw a closed path anywhere on a circuit diagram and the sum of the currents entering that closed path must be zero.

Prelab Exercises

Complete the following exercises prior to coming to the lab. Turn-in your prelab work to the lab instructor before starting the Laboratory Exercises.

Part 1PE: Study the material above on operation of the laboratory equipment.

Part 2PE: Consider the circuit shown in the diagram.

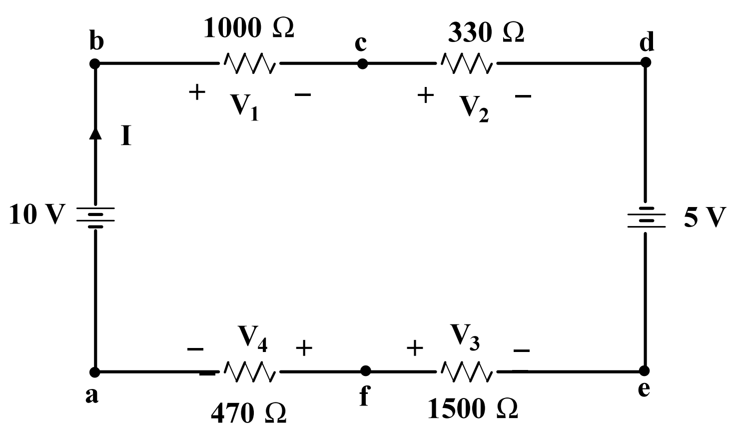


Figure 1.14: Circuit for Prelab Exercise, Part 1PE.

(a) Determine the current *I* as shown in Figure 1.14.

(b) Determine V_1, V_2, V_3, V_4. Verify that $V_1 + V_2 - V_3 + V_4 = 15$ V.

(c) Determine V_{ac}, V_{fb}, V_{cf}.

(d) Draw a diagram showing how to

(i) connect an ammeter in the circuit to measure I,
(ii) connect a voltmeter to measure V_{cf}.
(iii) connect a voltmeter to measure V_{fb}.

Part 3PE: Consider the circuit shown in Figure 1.15.

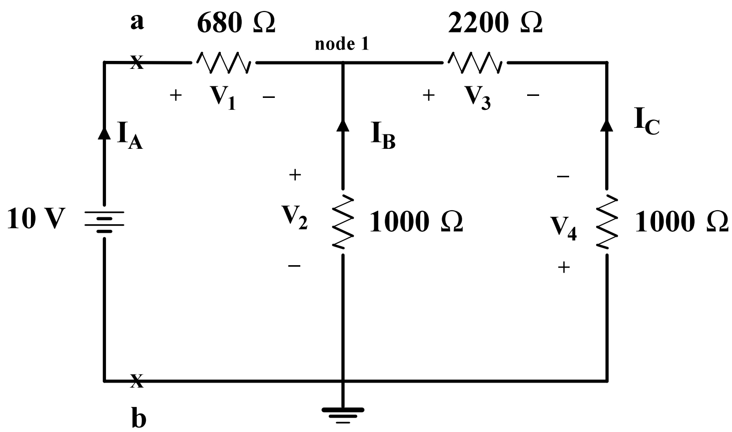


Figure 1.15: Circuit for Prelab Exercise, Part 2PE.

(a) Determine R_{ab} for the above circuit using series and parallel resistance combination.

(b) Find I_A as shown in Figure 1.15. Using this current, find R_{ab} from $R_{ab} = 10 / I_A$.

Compare this value to that of part (a).

(c) Use current division (splitting) to determine I_B and I_C. Verify KCL at node 1.

(d) Determine V_1, V_2, V_3 and V_4. Verify that, $V_1 + V_2 = 10$ V and $V_1 + V_3 - V_4 = 10$ V

(e) In the Laboratory Exercises you will be required to measure V_1, V_2, V_3 and V_4. Show how you connect the voltmeter to measure these voltages.

Laboratory Exercises

Part 1LE. Familiarization and use of circuits laboratory equipment.

(a) Set-up the function generator to produce a sinusoidal wave of 5 V peak-to-peak at a frequency of 60 Hz. Display approximately 3 cycles of the waveform on the face of the oscilloscope.

Obtain a printout of this waveform.

(b) Set-up the function generator so that it produces a triangular wave of 3.5 V peak-to -peak at a frequency of 700 Hz. Display approximately 4 cycles of the waveform on the face of the oscilloscope. Obtain a printout of this waveform.

(c) Measure the peak-to-peak voltage and time period of the wave on the oscilloscope using the (i) cursors and (ii) soft keys.

Part 2LE: Constructing and measuring circuit values in series circuit.

(a) Connect the circuit shown in Figure 1.15. Measure and record the current *I*.

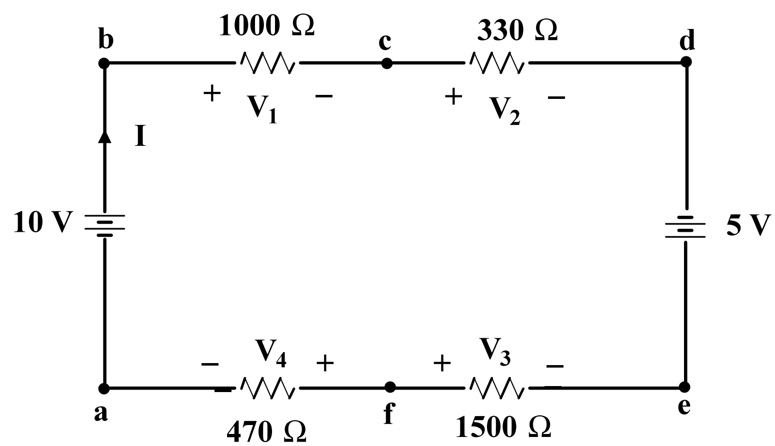


Figure 1.15: Circuit for Laboratory Exercises, Part 2LE .

(b) Measure and record the voltages V_1, V_2, V_3 and V_4 .

(c) Measure and record the voltages V_{ac} , V_{fb} , V_{cf} .

Part 3LE: Constructing and measuring circuit values in a series – parallel circuit.

(a) Connect the circuit shown in 1.16 and use the laboratory ohmmeter to measure R_{ab} .

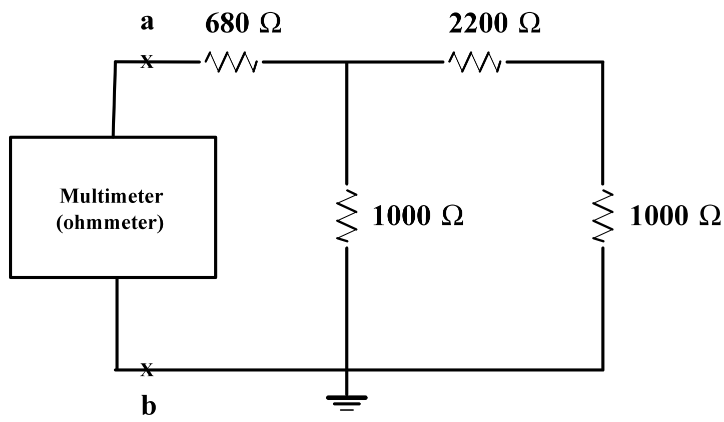


Figure 1.16: Circuit for measuring resistance in lab, Part 3LE.

(b) Connect the circuit shown in Figure 1.17. Using an ammeter, measure and record the the currents I_A, I_B, and I_C.

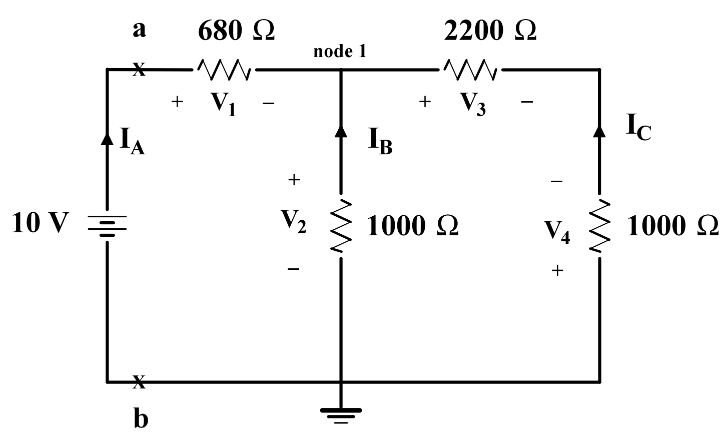


Figure 1.17: Circuit for Laboratory Exercise, Part 3LE .

(c) With the circuit connected as in Figure 1.17, use a voltmeter to measure and record the voltages V_1, V_2, V_3 and V_4.

Before Leaving The Laboratory

Be sure the following is completed before you leave the laboratory.

(a) Check to be sure that you have all the required measured values of Parts 1LE, 2LE and 3LE.

(b) Have the laboratory instructor check your laboratory measurements.

(c) Restore your laboratory station (equipment and chairs) to the condition they were in when you arrived. Remove any debris from the work area and floor.

Thank you for your cooperation.

Questions, Comparisons and Discussions

The following should be completed and included with your laboratory report.

Part 1: Printouts from Parts 1LE(a), (b) and (c).

Part 2:

(a) Compare the current *I* determined in Part 2 PE (a) with the value measured in the laboratory in Part 2 LE(a). Comment on sources of error.

(b) Make a table to compare the voltages V_1, V_2, V_3, V_4, V_{ac}, V_{fb} and V_{cf} determined analytically in Parts 2PE(b) and (c) with the measured values obtained in Parts 2LE(b) and (c). Comment on sources of errors.

(c) Compare R_{ab} calculated analytically in Part 1PE (d) from Equation 1.7 with R_{ab} calculated from the same equation but using the current I measured in the laboratory in Part 2LE (a). Comment on sources of error.

Part 3:

(a) Compare the values of R_{ab} determined analytically in Parts 3 PE(a) and (b) with your measured value of Part 3LE(a). Comment on sources of errors.

(b) Make a table to compare the currents I_A, I_B, and I_C calculated in Parts 3PE(b) and with values of I_A, I_B, and I_C measured in the laboratory work in Part 3LE(b). Comment on sources of errors.

(d) Make a table to compare V_1, V_2, V_3 and V_4 determined in Part 3PE(d) with the laboratory measured values in 3LE(c). Comments on sources of errors.

Laboratory Report

The following should be included in your laboratory report. If you have any questions contact the lab instructor.

(a) Give a short summary (<100 words) of what is to be accomplished in the laboratory work.

(b) Write the procedure followed for each part of your work.

(c) Tabulate (make tables) comparing Prelab Exercises with measured laboratory values.

(d) Include the printouts of Parts 1 PE(a), (b) and (c).

(e) Include the work from the Questions, Comparisons and Discussions section.

(f) Write a brief conclusion (approximately 200 words) about what you learned and what was demonstrated in performing the Prelab Exercises and Laboratory Exercises.

(g) Attach the graded Prelab Exercises at the end of your report.