EE203 - Electrical Circuits Laboratory

Experiment - 1 Simulation

DC Voltage and Current Measurements

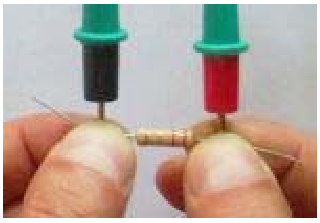
Objectives

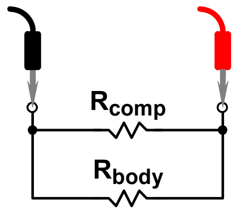
1. Become familiar with functions and features of LTspice.
2. Measure resistance of components, voltage across various points, and current through various branches of a circuit.
3. Observe consequences of Kirchhoff's Voltage Law and Kirchhoff's Current Law.
4. Understand operation of a potentiometer.

Background

Resistance Measurements

Measuring resistance while holding a component as shown below results in errors, because hand-to-hand body resistance, $\mathbf{R_{body}}$, is connected in parallel with $\mathbf{R_{comp}}$ of the component. The body resistance measured with simple multimeter probes typically varies between **50 kΩ** and **10 MΩ** depending on the pressure applied to the probe tips and skin conductivity. Dry skin has much higher resistance compared to wet or sweaty skin.



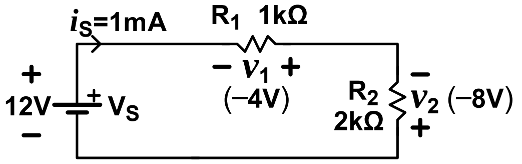


Touching multimeter or oscilloscope probe tips and circuit componets may affect other measurements as well as resistance readings. $\mathbf{R_{body}}$ can have a significant loading effect on weak signal sources. A ***weak signal source*** can be a sensor or a circuit block that can only provide output currents much less than **1 mA**. For example, in some optic devices a light sensor photodiode generates only a few **nA** (**nA** = nanoampare **=** $\mathbf{10^{-9}}$ **A**) signal that can easily be affected by $\mathbf{R_{body}}$. Human body also acts like a big antenna that picks up **50 Hz** radiation from surrounding power cables and electrical equipment. This **50 Hz** signal appears as unwanted noise when it is passed on to a circuit. Significance of this **50 Hz** noise depends on its **relative amplitude** compared to the useful voltage or current signals in the circuit.

Kirchhoff's Voltage Law

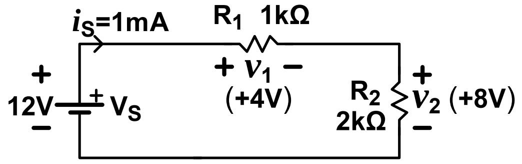
Kirchhoff's voltage law states that voltages across the circuit elements on any loop in a circuit add up to zero. Polarities of all voltages must be the same (i.e. from

–'ve to +'ve) in clockwise or counter-clockwise direction to obtain zero as the result of addition, as shown in the first circuit on the right.



$V_S + v_1 + v_2 = 0$
$12V + (-4V) + (-8V) = 0$

$V_S = (-v_1) + (-v_2)$
$12V = 4V + 8V$



$V_S - v_1 - v_2 = 0$
$12V - 4V - 8V = 0$

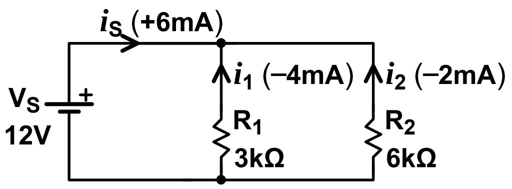
$V_S = v_1 + v_2$
$12V = 4V + 8V$

If the voltage polarity on an element is reversed, then this voltage is subtracted instead of being added in the calculation. Polarities of v_1 and v_2 are reversed in the circuit shown on the right, and Kirchhoff's Voltage Law is applied accordingly. The calculations can be verified by applying Ohm's law with the loop current and resistance values given on the circuit diagram. The polarity notation of the second diagram is preferrable, since one can immediately see that the supply voltage is equal to the summation of the voltage drop on the other circuit elements in the loop.

Changing polarities on a circuit diagram is nothing but a different notation. If a voltage polarity is reversed, this simply means that the measurement probes must be swapped when this voltage is measured. If the voltage shown as "+ v_1 –" has a positive amplitude, then the multimeter shows a positive value. If the polarity is reversed as "– v_1 +" on the same element, then you swap the probe connections and the multimeter shows a negative value. In any case, the calculations give the correct results within mesurement error tolerances.

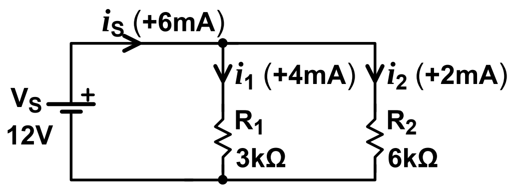
Kirchhoff's Current Law

Kirchhoff's current law states that the sum of all currents flowing into a node is zero. In other words, current flowing through a branch had to be distributed into other branches, and total current inflow is always equal to total outflow. Directions of all currents must be towards the node to obtain zero as the result of addition, as shown in the first circuit on the right.



$i_S + i_1 + i_2 = 0$
$6mA + (-4mA) + (-2mA) = 0$

$i_S = (-i_1) + (-i_2)$
$6mA = 4mA + 2mA$



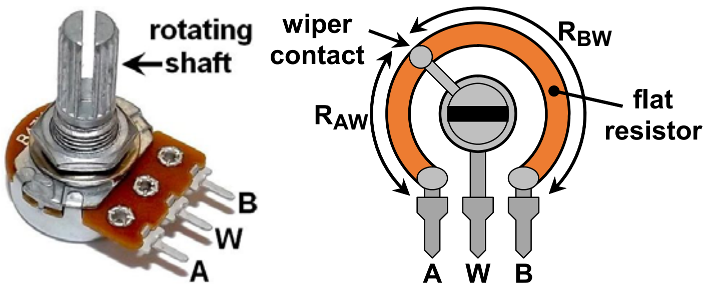
$i_S - i_1 - i_2 = 0$
$6mA - 4mA - 2mA = 0$

$i_S = i_1 + i_2$
$6mA = 4mA + 2mA$

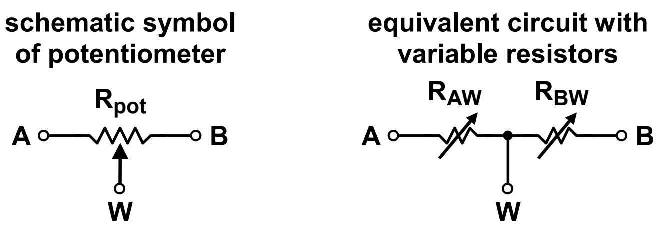
If the current polarity on a branch is reversed, then this current is subtracted instead of being added in the calculation. Arguments similar to the polarity notations of voltages are applicable to the polarity notations related to current measurements and application of Kirchhoff's current law. In this case, the polarity notation of the second diagram is preferrable, since one can immediately see that the total supply current is divided between the two circuit branches.

Potentiometer

Potentiometer is a three-terminal device that allows manual adjustment of the resistance between its terminals. Terminal **W** is the **wiper** or ***center*** terminal. The wiper contact moves over a circular, flat resistor when the potentiometer shaft is rotated. Resistances between terminal **W** and other terminals are proportional to the lenght of the flat resistor that remains between the wiper contact and end points.



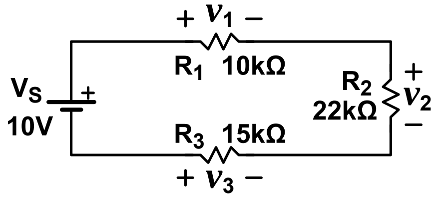
Schematic symbol of a potentiometer is given on the left in the following figure. The potentiometer can be seen as two variable resistors which are connected in series. The total resistance, $\mathbf{R_{pot} = R_{AW} + R_{BW}}$, remains constant all the time. $\mathbf{R_{AW}}$ increases from **0 Ω** to $\mathbf{R_{pot}}$, and $\mathbf{R_{BW}}$ decreases from $\mathbf{R_{pot}}$ to **0 Ω** as the adjustment shaft rotates clockwise between the end points. The total resistance, $\mathbf{R_{pot}}$, is indicated on the schematic and on the potentiometer enclosure.



Potentiometers are usually mounted behind control panels of electronic equipment. Knobs are attached to the rotating shafts on the front side of control panel to allow easy adjustment of the resistance. Knobs that control voltage setting of DC supplies, amplitude and offset setting of signal generators are the typical examples.

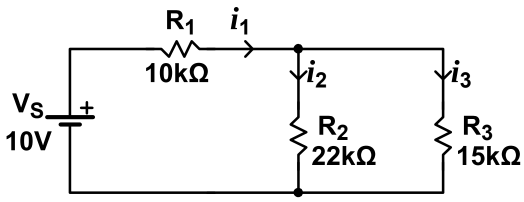
Preliminary Work

1. Calculate v_1, v_2 and v_3 for the circuit shown below. Enter the results in the table given for procedure step **2.2**.



2. If the polarity of V_S is reversed, what happens to v_1, v_2 and v_3?

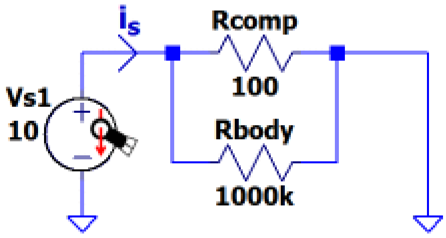
3. Calculate i_1, i_2 and i_3 for the circuit shown below. Enter the results in the table given for procedure step **3.2**.



4. If the polarity of V_S is reversed, what happens to i_1, i_2 and i_3?

Procedure

1.1 Create a new schematic in LTspice and build the following circuit.



- **Vs1** is a voltage source set to constant **10 V**.
- **R**comp is the resistor value that needs to be measured.
- **R**body is the body resistance connected in parallel, and it introduces some error in mesurement of **R**comp.
- Place the SPICE directive "**.tran 3m**" to set the simulation duration to **3** milliseconds.

1.2 Run the simulation first, and measure the current $\mathbf{i_S}$ through **Vs1** voltage source. Place the mouse pointer over **Vs1** to see the current probe as shown above and left-click to display the **I(Vs1)** current through **Vs1** on the waveform window. You can zoom into the DC plot to obtain five significant digits (i.e. 100.01mA) on the waveform window.

1.3 Calculate the parallel resistance **R**par that is measured according to the **I(Vs1)** current:

$$\mathrm{Rpar} = \frac{\mathbf{Vs1}}{-\mathbf{I(Vs1)}} = \frac{\mathbf{10\ V}}{-\mathbf{I(Vs1)}}$$

1.3 Calculate the **% error** between **R**comp and the calculated **R**par:

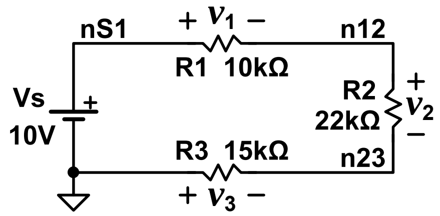
$$\mathbf{\%\ error} = \frac{\mathrm{Rpar} - \mathrm{Rcomp}}{\mathrm{Rcomp}} \times \mathbf{100}$$

1.4 Record your measurements in the table given below. Repeat measurements for the other **R**comp and **R**body values listed in the table.

Rcomp	**R**body	**I(Vs1)** current measured on **Vs1** supply	**R**par resistance calculated with **I(Vs1)**	**% error** between **R**comp and the calculated **R**par
100 Ω	**1000 kΩ**			
1 kΩ	**1000 kΩ**			
10 kΩ	**1000 kΩ**			
100 kΩ	**1000 kΩ**			
100 Ω	**100 kΩ**			
1 kΩ	**100 kΩ**			
10 kΩ	**100 kΩ**			
100 kΩ	**100 kΩ**			

2.1 Build the following circuit on the LTspice schematic window.

- ➢ Set DC power supply output to **10V**.
- ➢ Assign labels (**nS1**, **n12**, **n23**) to the circuit nodes to easily identify voltage plots on the waveform window.
- ➢ Place the SPICE directive "**.tran 3m**" to set the simulation duration to **3** milliseconds.



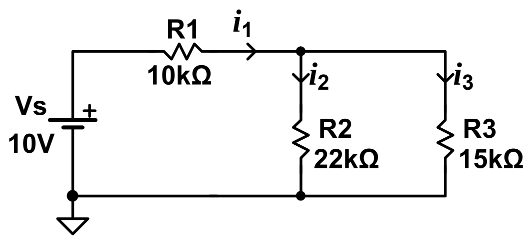
2.2 Measure the voltages shown on the schematic given above and record their values in the following table.

- ➢ Run simulation and display all voltages on the waveform window.
- ➢ Using the mouse pointer, draw a rectangle between the voltage plots on the waveform window. The voltage difference corresponding to the height of the rectangle is displayed (i.e. dy = 1.925V) at the bottom of the window.

	measured voltage	expected voltage calculated in preliminary work	% error with respect to the calculated values
v_1 (V)			
v_2 (V)			
v_3 (V)			

3.1 Build the following circuit on the LTspice schematic window.

- ➢ Set DC power supply output to **10V**.
- ➢ Place the SPICE directive "**.tran 3m**" to set the simulation duration to **3** milliseconds.



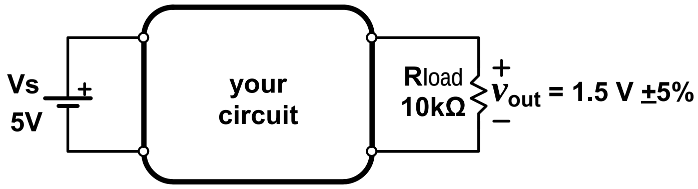
3.2 Measure the currents shown on the schematic given above and record their values in the following table.

- ➢ Run simulation and place the mouse pointer over the resistors to see the current probe. Left-click over each resistor to display the **I(R1)**, **I(R2)**, and **I(R3)** currents on the waveform window.

- You can zoom into the DC plot to obtain three or more significant digits (i.e. 85.2mA) on the waveform window.

	measured current	expected current calculated in preliminary work	% error with respect to the calculated values
i_1 (mA)			
i_2 (mA)			
i_3 (mA)			

4. As a design problem, determine the components of a resistive circuit that will deliver **1.5 V** across a **10 kΩ** load resistor with maximum **±5%** error.



The resistors available for use are **1 kΩ**, **6.2 kΩ**, **10 kΩ**, **15 kΩ**, and **27 kΩ**. You may use more than one resistor of a particular value, but as a design constrait, you cannot use more than three resistors in total. Draw the schematic of your proposed circuit and build it on LTspice. Verify that the circuit meets the design criteria by measuring v_{out}. When your circuit is working, demonstrate the design to the lab instructor.

v_{out} = __________

Questions

Q1. Which values of the resistors (small or big $\mathbf{R}_{comp}$, small or big $\mathbf{R}_{body}$) used in step-1 of the procedure result in bigger error values? Why?

Q2. $\mathbf{R}_{body}$ **= 1000 kΩ** is the typical value of body resistance between dry fingers and $\mathbf{R}_{body}$ **= 100 kΩ** is the typical value for wet fingers. Explain why electrical shocks are much more dangerous in wet places such as bathrooms or kitchens.

Q3. Describe the possible sources of error (if there is any) in resistance measurements in the following cases.

a) Hold both leads of the resistor and the multimeter probes with your fingers.

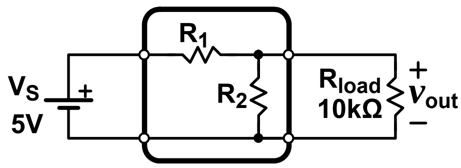
b) Place the resistor on a table made of an unknown material and touch the resistor leads with the multimeter probes only.

c) Hold one lead of the resistor and one of the probes with your fingers and touch the other resistor lead with the multimeter probe only.

d) Have your partner hold both leads of the resistor with his/her fingers and you touch the resistor leads with the multimeter probes.

e) Build the circuit to be tested on a breadboard, and touch the resistor leads with the multimeter probes only.

Q4.a) Calculate the minimum and maximum output voltage of the circuit you designed in step-5 depending on variation of resistances within **±5%** tolerance limits. For example, if the designed circuit has two resistors as follows,



then the minimum output voltage will be obtained when the actual resistances are **1.05**x$\mathbf{R}_1$ and **0.95**x$\mathbf{R}_2$. Similarly, the maximum output voltage will be obtained when the resistances are **0.95**x$\mathbf{R}_1$ and **1.05**x$\mathbf{R}_2$.

b) What type of resistors should be used to make sure that the output voltage will be in the specified error range?