Cornerstone Electronics Technology and Robotics I Week 7
Series Circuits

- **Administration:**
  - Prayer
- **Series Circuit Principles and Equations:**
  - A series circuit is one with all the loads in a row, like links in a chain. In this lesson, the loads are resistors. There is only one path for the electrons to flow. If one of the resistors is removed, the current stops.
  - **Resistance in a Series Circuits:**
    - The total resistance in a series circuit is equal to the sum of all of the resistors.

$$R_T = R_1 + R_2 + R_3 + \ldots + R_N$$

Where:

R_T = Total resistance
R_1 = Resistance of R_1
R_2 = Resistance of R_2
R_3 = Resistance of R_3
R_N = Resistance of R_N
N = The number of resistors in the series circuit.

Figure 1A

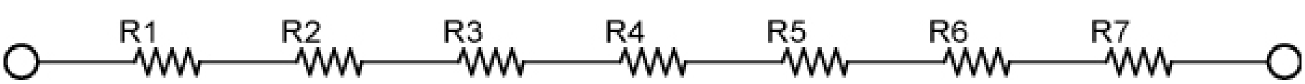
For example, if N = 2 then the series resistor circuit appears like this:

And the corresponding total resistance equation is:

$$R_T = R_1 + R_2$$

Figure 1B

If N = 7 then the series resistor circuit is:



And the corresponding total resistance equation is:

$$R_T = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7$$

Figure 1C

    - More than one resistor in series can substitute for a resistor value that is unavailable.
    - In a series circuit, the large resistor dominates if it is series with a small resistor.
    - Complete Series Circuits Lab 1 – Series Resistors
- **Voltage in a Series Circuit:**
    - Kirchhoff's Voltage Law: The total voltage applied to a series circuit is equal to the total of the individual voltage drops across each resistor in the series circuit. (In more general terms, the algebraic sum of all voltages, both source and drops, around a closed loop is equal to zero.)
    - Mathematically:

$$V_T = V_1 + V_2 + V_3 + \ldots + V_N, \text{ or}$$

$$V_T - V_1 - V_2 - V_3 - \ldots - V_N = 0$$

Where:

V_T = Total voltage applied to the series circuit
V_1 = Voltage drop across R_1
V_2 = Voltage drop across R_2
V_3 = Voltage drop across R_3
V_N = Voltage drop across R_N
N = The number of resistors in the series

- Example of Voltage in a Series Circuit (Figure 2):
  - The voltage at Point D is 0 volts when both multimeter leads are connected to the same point.
  - Leaving the common lead at Point D, the voltage jumps to +10 V at Point A because the battery supplies the energy to increase the potential by +10 V.
  - There is a 2 V drop across R_1 (-2 V) causing the voltage at Point B to drop to +8 V.
  - Likewise, R_2 causes a further 3 V drop (-3 V) in the voltage bringing the voltage at Point C to +5 V.
  - Finally, R_3 drops the voltage 5 more volts (-5 V) to return the voltage back to 0 V at Point D.

  $V_T - V_1 - V_2 - V_3 = 0$

  $10\text{ V} – 2\text{ V} – 3\text{ V} – 5\text{ V} = 0$

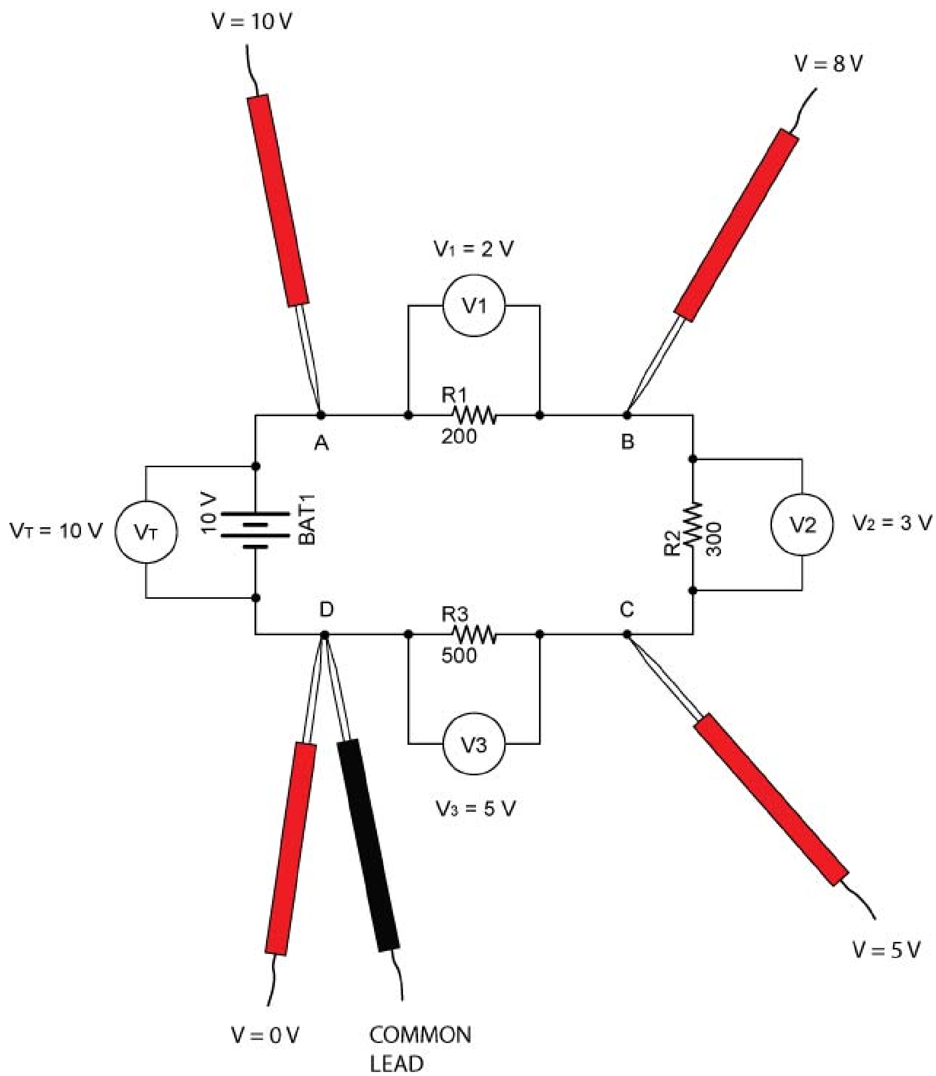


Figure 2

- Complete Series Circuits Lab 2 – Kirchhoff's Voltage Law

- **Current in a Series Circuit:**
  - A series circuit provides only one path for the current so it must have the <u>same</u> value at any point in the circuit.
  - Mathematically:

    $I_T = I_1 = I_2 = I_3 = \ldots I_N$

    Where:

    I_T = Total current
    I_1 = Current through R_1
    I_2 = Current through R_2
    I_3 = Current through R_3
    I_N = Current through R_N
    N = The number of resistors in the series

  - Example of Current in a Series Circuit (Figure 3):

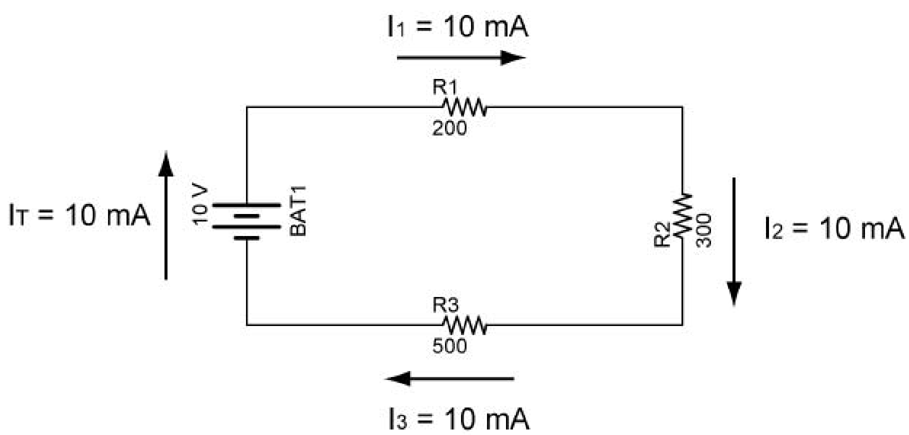


Figure 3

  - Complete Series Circuits Lab 3 – Current in Series Circuits
- **Power in a Series Circuit:**
  - The total amount of power consumed in a series circuit is equal to the source voltage multiplied by the circuit current. The total power consumed is also equal to the sum of the power consumed by each resistor.
  - Mathematically:

    $P_T = P_1 + P_2 + P_3 + \ldots. + P_N$

    Where:

    P_T = Total power consumed
    P_1 = Power consumed by R_1
    P_2 = Power consumed by R_2
    P_3 = Power consumed by R_3
    P_N = Power consumed by R_N
    N = The number of resistors in the series circuit.

- Power also equals the product of the total voltage and the total current.

  $P_T = V_T \times I_T$

  Where:

  P_T = Total power consumed
  V_T = Total voltage applied to the series circuit
  I_T = Total current

- Example of Power in a Series Circuit (Figure 4):

  $P_T = P_1 + P_2 + P_3$
  $P_T = V_1 \times I_1 + V_2 \times I_2 + V_3 \times I_3$
  $P_T = 2\ V \times 0.01\ A + 3\ V \times 0.01\ A + 5\ V \times 0.01\ A$
  $P_T = 0.02\ W + 0.03\ W + 0.05\ W$
  $P_T = 0.10\ W$

  Also,
  $P_T = V_T \times I_T$
  $P_T = 10\ V \times 0.01\ A$
  $P_T = 0.10\ W$

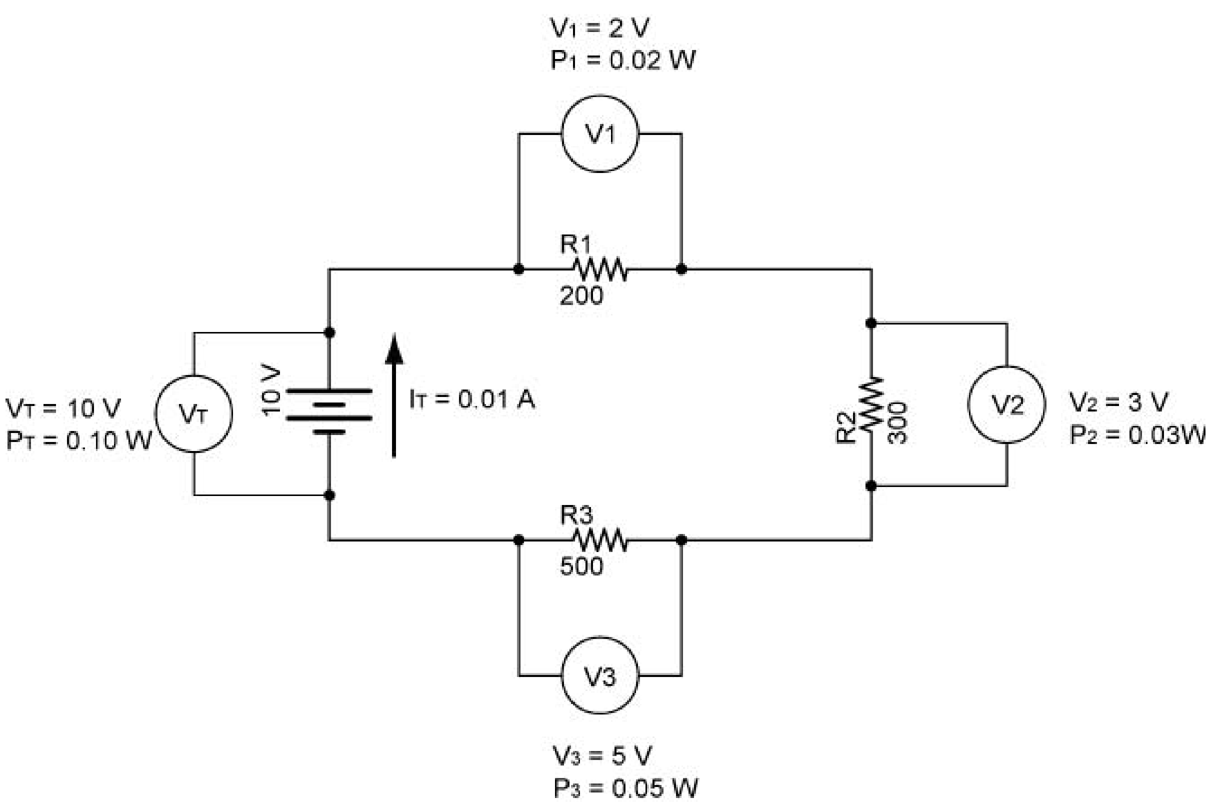


Figure 4

- Complete Series Circuits Lab 4 – Power in Series Circuits

- **Solving for Resistance, Voltage, and Current in a Series Resistor Circuits:**
  - Four equations are used to solve series resistor circuits. They are:

    $$\mathbf{R_T = R_1 + R_2 + R_3 + \ldots + R_N}$$
    $$\mathbf{V_T = V_1 + V_2 + V_3 + \ldots + V_N}$$
    $$\mathbf{I_T = I_1 = I_2 = I_3 = \ldots I_N}$$
    $$\mathbf{V = I \times R}$$

    V = I x R can be applied to the total circuit ($V_T = I_T \times R_T$) and to individual resistors ($V_1 = I_1 \times R_1$).

  - A table will be used to help solve our circuits. Table 1 corresponds to the circuit in Figure 5. All of the known values for resistance, voltage, and current in the circuit in Figure 5 are entered into Table 1.

	Resistance	Voltage	Current
R1	R1 = 200 Ω		
R2	R2 = 300 Ω		
R3	R3 = 500 Ω		
Total		V_T = 10 V	

Table 1

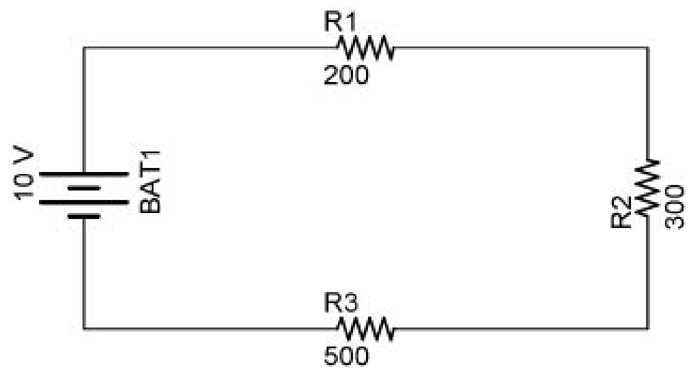


Figure 5

- Table 2 lists all of the unknowns that will be solved.

	Resistance	Voltage	Current
R1	R1 = 200 Ω	V1	I1
R2	R2 = 300 Ω	V2	I2
R3	R3 = 500 Ω	V3	I3
Total	R_T	V_T = 10 V	I_T

Table 2

- Step 1: Find R_T:

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 200\ \Omega + 300\ \Omega + 500\ \Omega$$
$$R_T = 1000\ \Omega$$

See Table 3:

	Resistance	Voltage	Current
R1	R1 = 200 Ω	V1	I1
R2	R2 = 300 Ω	V2	I2
R3	R3 = 500 Ω	V3	I3
Total	R_T = 1000 Ω	V_T = 10 V	I_T

Table 3

- Step 2: Solve for I_T:

$$I_T = V_T / R_T$$
$$I_T = 10\ V / 1000\ \Omega$$
$$I_T = 0.010\ A \text{ or } 10\ mA$$

See Table 4:

	Resistance	Voltage	Current
R1	R1 = 200 Ω	V1	I1
R2	R2 = 300 Ω	V2	I2
R3	R3 = 500 Ω	V3	I3
Total	R_T = 1000 Ω	V_T = 10 V	I_T = 0.01 A

Table 4

- Step 3: Find I_1, I_2, and I_3.

$$I_T = I_1 = I_2 = I_3 = 0.010 \text{ A}$$

See Table 5:

	Resistance	Voltage	Current
R1	R1 = 200 Ω	V1	I1 = 0.01 A
R2	R2 = 300 Ω	V2	I2 = 0.01 A
R3	R3 = 500 Ω	V3	I3 = 0.01 A
Total	R_T = 1000 Ω	V_T = 10 V	I_T = 0.01 A

Table 5

- Step 4: Solve for V_1, V_2, and V_3.

$$V_1 = I_1 \times R_1$$
$$V_1 = 0.010 \text{ A} \times 200\ \Omega$$
$$V_1 = 2 \text{ V}$$

$$V_2 = I_2 \times R_2$$
$$V_2 = 0.010 \text{ A} \times 300\ \Omega$$
$$V_2 = 3 \text{ V}$$

$$V_3 = I_3 \times R_3$$
$$V_3 = 0.010 \text{ A} \times 500\ \Omega$$
$$V_3 = 5 \text{ V}$$

See Table 6:

	Resistance	Voltage	Current
R1	R1 = 200 Ω	V1 = 2 V	I1 = 0.01 A
R2	R2 = 300 Ω	V2 = 3 V	I2 = 0.01 A
R3	R3 = 500 Ω	V3 = 5 V	I3 = 0.01 A
Total	R_T = 1000 Ω	V_T = 10 V	I_T = 0.01 A

Table 6

- Not every series circuit to be solved will have the source voltage and all of the resistor values. To solve the unknowns for each circuit, use the four equations in bold above in whatever the order is necessary for the solution.
- Since all of the resistances, voltages, and currents are solved in the present problem, the power can now be calculated.

- **Solving for Power in a Series Resistor Circuits:**
  - Two equations are used to solve for power in a series resistor circuit. They are:

    $$P_T = P_1 + P_2 + P_3 + ... + P_N$$
    $$P = V \times I$$

    P = V x I can be applied to the total circuit ($P_T = V_T \times I_T$) and to individual resistors ($P_1 = V_1 \times I_1$).
  - A column for power will be added to the table already used to solve our circuit.

	Resistance	Voltage	Current	Power
R1	R1 = 200 Ω	V1 = 2 V	I1 = 0.01 A	P1
R2	R2 = 300 Ω	V2 = 3 V	I2 = 0.01 A	P2
R3	R3 = 500 Ω	V3 = 5 V	I3 = 0.01 A	P3
Total	R_T = 1000 Ω	V_T = 10 V	I_T = 0.01 A	P_T

Table 7

  - Step 5: Solve for P_1, P_2, P_3, and P_T.

$P_1 = V_1 \times I_1$
$P_1 = 2\ V \times 0.010\ A$
$P_1 = 0.020\ W$

$P_2 = V_2 \times I_2$
$P_2 = 3\ V \times 0.010\ A$
$P_2 = 0.030\ W$

$P_3 = V_3 \times I_3$
$P_3 = 5\ V \times 0.010\ A$
$P_3 = 0.050\ W$

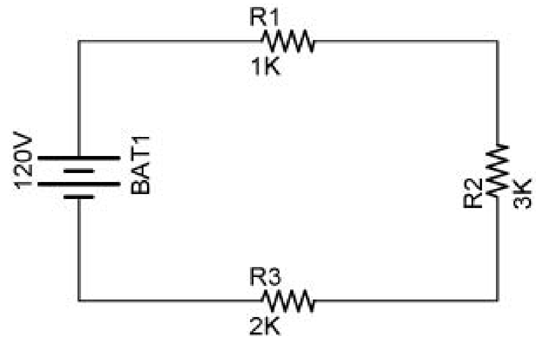
$P_T = P_1 + P_2 + P_3$
$P_T = 0.020\ W + 0.030\ W + 0.050\ W$
$P_T = 0.100\ W$

See Table 8:

	Resistance	Voltage	Current	Power
R1	R1 = 200 Ω	V1 = 2 V	I1 = 0.01 A	P1 = 0.02 W
R2	R2 = 300 Ω	V2 = 3 V	I2 = 0.01 A	P2 = 0.03 W
R3	R3 = 500 Ω	V3 = 5 V	I3 = 0.01 A	P3 = 0.05 W
Total	R_T = 1000 Ω	V_T = 10 V	I_T = 0.01 A	P_T = 0.10 W

Table 8

- Example Problem 1:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.

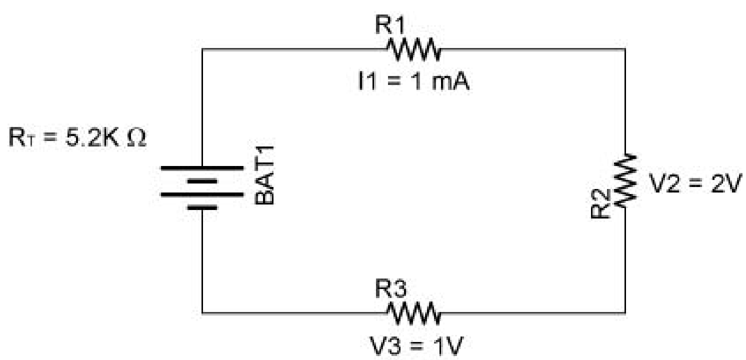


	Resistance	Voltage	Current	Power
R_1	R1 = 1K Ω			
R_2	R2 = 3K Ω			
R_3	R3 = 2K Ω			
Total		V_T = 120 V		

- Remember:

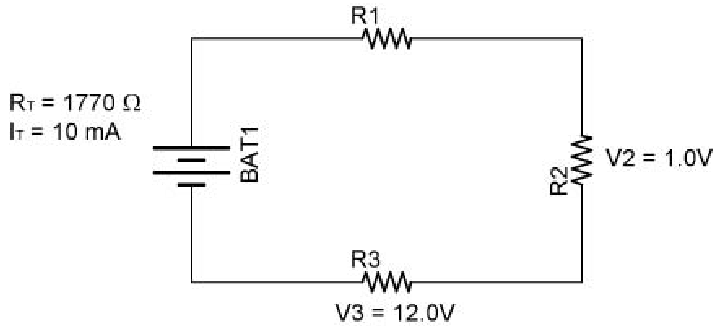
$R_T = R_1 + R_2 + R_3 + \ldots + R_N$
$V_T = V_1 + V_2 + V_3 + \ldots + V_N$
$I_T = I_1 = I_2 = I_3 = \ldots I_N$
$V = I R$

- Example Problem 2:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.



	Resistance	Voltage	Current	Power
R_1			I1 = 0.001 A	
R_2		V2 = 2V		
R_3		V3 = 1V		
Total	R_T = 5.2k Ω			

- Example Problem 3:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.

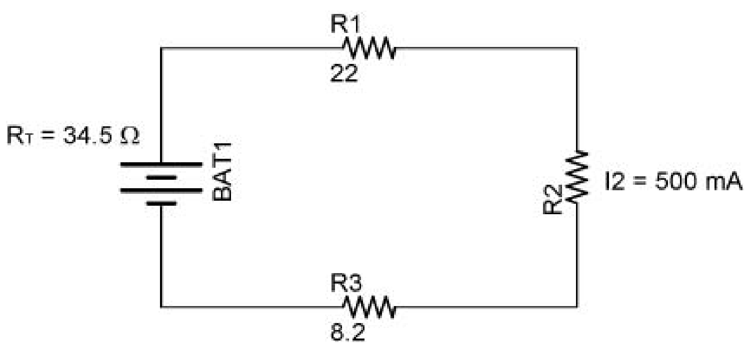


	Resistance	Voltage	Current	Power
R_1				
R_2		V2 = 1V		
R_3		V3 = 12V		
Total	R_T = 1,770 Ω		I_T = 0.01 A	

- Remember:

  $R_T = R_1 + R_2 + R_3 + \ldots + R_N$
  $V_T = V_1 + V_2 + V_3 + \ldots + V_N$
  $I_T = I_1 = I_2 = I_3 = \ldots I_N$
  $V = I R$

- Example Problem 4:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.



	Resistance	Voltage	Current	Power
R_1	R1 = 22 Ω			
R_2			I2 = 0.5 A	
R_3	R3 = 8.2 Ω			
Total	R_T = 34.5 Ω			

- **Voltage Dividers:**
  - Series resistors can be used to divide a voltage into smaller voltages. For example, the following series resistors divide a 12 volt source into 12 volts, 8 volts, and 4 volts using the same value for each resistor. Notice that we are not measuring voltages across each resistor, but voltages from a point, e.g. B (V_{BD}) to the ground point D. The common black voltmeter lead will remain on ground while the red lead will move from point to point as we measure the voltage at a particular point in the circuit. (The voltage drop across each individual resistor is 4V.)

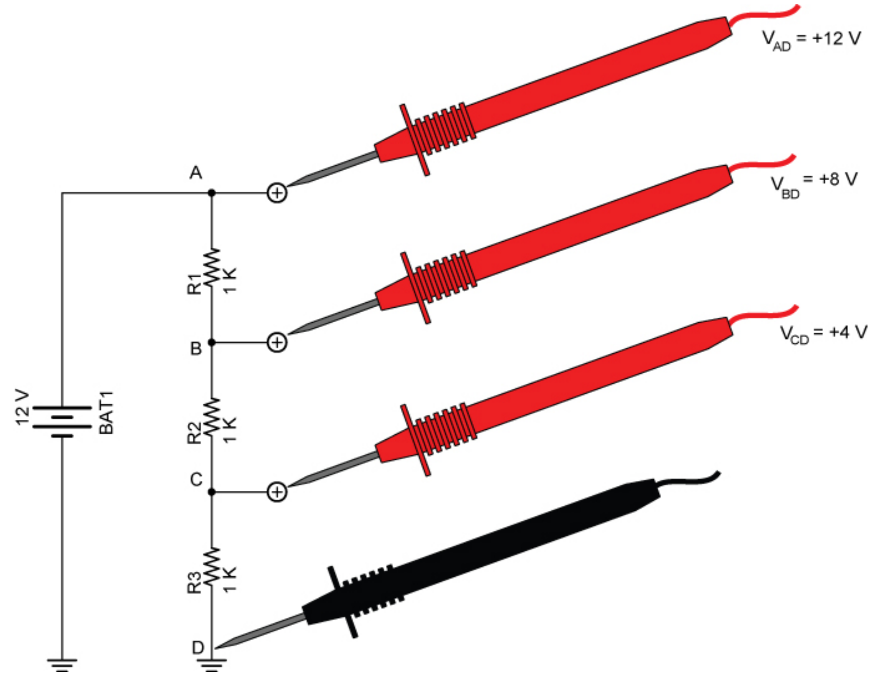
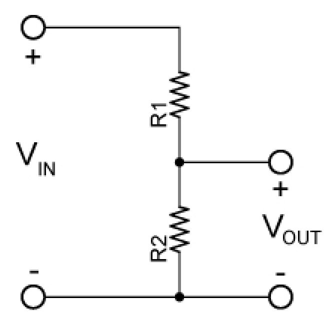


Figure 6 – Series Resistors as a Voltage Divider

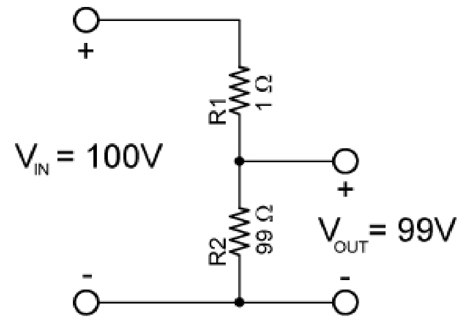
  - Two Resistor Voltage Divider Circuit:
    - The resistors in a voltage divider do not have to be of equal value. An input voltage can be divided to any lesser voltage using two resistors. In the circuit below, the higher the resistance of R2, the higher the output voltage.



$V_{OUT} = V_{IN} * R_2 / (R_1 + R_2)$ (No load on output)

    - If a load is added to the output terminals, the resistive load must be taken into consideration as a parallel resistor to R2.

- Examples of Two Resistor Voltage Divider:



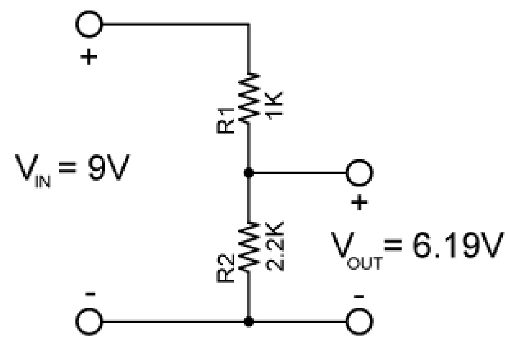
Example 1

$V_{OUT} = V_{IN} * R_2 / (R_1 + R_2)$

$V_{OUT} = 100V * 99\ \Omega / (1\ \Omega + 99\ \Omega)$

$V_{OUT} = 100V * 99\ \Omega / 100\ \Omega$

$V_{OUT} = 99V$



Example 2

$V_{OUT} = V_{IN} * R_2 / (R_1 + R_2)$

$V_{OUT} = 9V * 2200\ \Omega / (1000\ \Omega + 2200\ \Omega)$

$V_{OUT} = 9V * 2200\ \Omega / 3200\ \Omega$

$V_{OUT} = 6.19V$

- See applets:
    - http://www.falstad.com/circuit/e-voltdivide.html
    - http://www.raltron.com/cust/tools/voltage_divider.asp
    - http://hyperphysics.phy-astr.gsu.edu/hbase/electric/voldiv.html
- Related web sites:
    - http://openbookproject.net//electricCircuits/DC/DC_5.html

- **Fundamental equations for electrical circuits according to Darren Ashby, *Electrical Engineering 101*:**
    - *Ohm's Law*
    - *Voltage divider rule*
    - Capacitors impede changes in voltage
    - Inductors impede changes in current
    - *Series and parallel resistors*
    - Thevenin's theorem

Electronics Technology and Robotics I Week 7
Series Circuits Lab 1 – Series Resistors

- **Purpose:** The purpose of this lab is to verify, by experiment, the formula for total resistance for resistors in series.

- **Apparatus and Materials:**

    - 1 – Solderless Breadboard with 9 V Supply
    - 1 – Digital Multimeter
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor
    - 1 – 470 Ohm Resistor
    - 1 – 1 K Ohm Resistor
    - 1 – 2.2 K Ohm Resistor

- **Procedure:**
    - Total Resistance of Series Resistors Using Ohm Meter:
        - Measure the resistance of each resistor and record.
        - Wire the series resistor network in Figure 1.
        - Add the individual resistances to determine the total resistance of the network.
        - Now measure the total resistance of the resistor network and record.

Figure 1

- Total Resistance of Series Resistors Using Ohm's Law:
    - Connect a 9 V battery to the resistor network as shown in Figure 2.

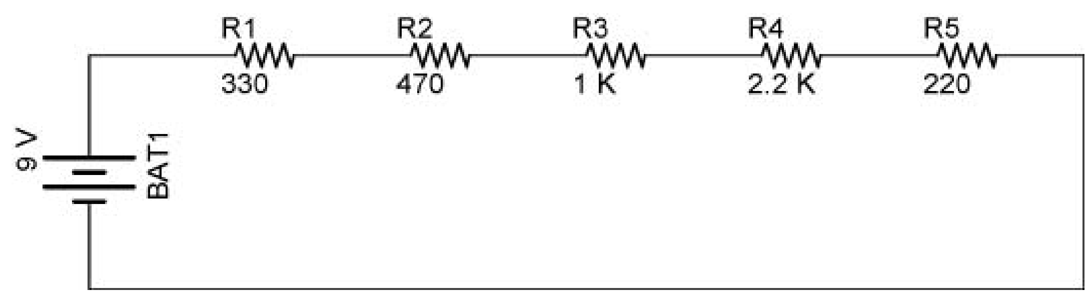


Figure 2

- Measure the source voltage V_T and the current I_T through the series resistor network.
- Knowing V_T and I_T, calculate the total resistance R_T using Ohm's Law.

- **Results:**

Resistor	Resistors Nominal Value (?)	Resistors Measured Value (?)	Total Resistance Ohm's Law (?)
R1	220		
R2	330		
R3	470		
R4	1K		
R5	2.2K	______	
	R_T = 4,220	R_T =	R_T =

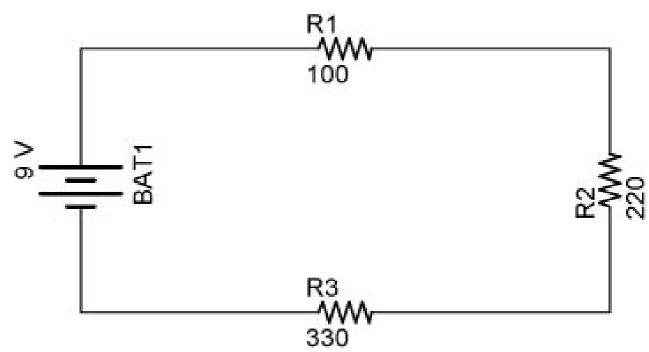
- **Conclusions:**
  - Do the four values of R_T equal one another? Explain any discrepancies.
  - If a 1 M Ohm resistor is in series with a 100 Ohm resistor, which resistor affects the total resistance more?

Electronics Technology and Robotics I Week 7
Series Circuits Lab 2 – Kirchhoff's Voltage Law

- **Purpose:** The purpose of this lab is to experimentally verify Kirchhoff's Voltage Law for a series resistor circuit.

- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – 100 Ohm Resistor
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor

- **Procedure:**
    - Wire the following series circuit and measure the voltage drop across each resistor.
    - Compare the sum of the voltage drops with the voltage source:



- **Results:**

	Voltage (V)
V_1	
V_2	
V_3	______
$V_1 + V_2 + V_3$	
V_{SOURCE}	

- **Conclusions:**
    - Does $V_{SOURCE} = V_1+V_2+V_3$?
    - Or put another way, does $V_{SOURCE} - V_1 - V_2 - V_3 = 0$? Explain any discrepancies.

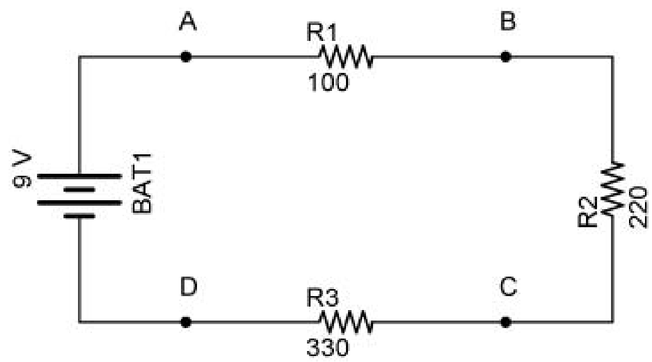
Electronics Technology and Robotics I Week 7
Series Circuits Lab 3 – Current in Series Circuits

- **Purpose:** The purpose of this lab is to verify, by experiment, the formula for total current for resistors in series.

- **Apparatus and Materials:**

    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – 100 Ohm Resistor
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor

- **Procedure:**
    - Using the same circuit from Lab 2, measure and record the current at each Point A - D.



- **Results:**

	Current (mA)
I_A	
I_B	
I_C	
I_D	

- **Conclusions:**
    - How do the 4 current readings relate to one another?

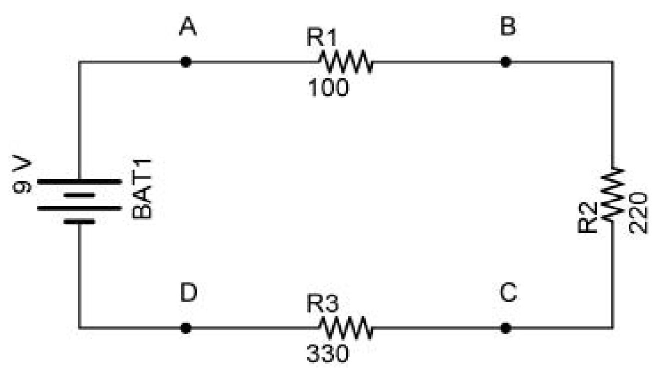
Electronics Technology and Robotics I Week 7
Series Circuits Lab 4 – Power in Series Circuits

- **Purpose:** The purpose of this lab is to verify, by experiment, that the total power consumed in series circuit is equal to the sum of the power consumed by each resistor.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – 100 Ohm Resistor
  - 1 – 220 Ohm Resistor
  - 1 – 330 Ohm Resistor

- **Procedure:**
  - Copy the voltages from Lab 2 and currents from Lab 3.
  - Calculate the power for each resistor and then the total power consumed for the following circuit:



- **Results:**

Resistor	Resistance (Ω)	Voltage (V)	Current (A)	Power (W) P = V * I
R1	100	V1 =	I1 =	P1 =
R2	220	V2 =	I2 =	P2 =
R3	330	V3 =	I3 =	P3 =
				$P_1 + P_2 + P_3 =$
		$V_T =$	$I_T =$	$P_T =$

- **Conclusions:** Does $P_T = P_1 + P_2 + P_3$?