Using Ohm's Law to Build a Voltage Divider

Provided by TryEngineering - www.tryengineering.org

Lesson Focus
Students will design, build, and characterize one of the basic circuits of electrical engineering, the voltage divider. These circuits produce a wide range of output voltages and are building blocks for more complex circuits. Circuit design will emphasize the concepts of Ohm's Law and students will explore mathematical relationships of parallel and series resistors. Students will demonstrate their design efforts by building prototype circuits and using test measurement tools to confirm their predictions.

Lesson Synopsis


Voltage dividers are a building block circuit used by Electrical Engineers to analyze resistance and optimize electronic devices. In this lesson students apply Ohm's Law to construct voltage divider circuits. Students learn how to read resistor codes and calculate resistor values. Using breadboards, students build voltage dividers and predict and measure output voltage values. Students are given the electrical requirements for an LED, and are then challenged to design and verify a voltage divider circuit to illuminate it.

Age Levels
14-18.

Objectives

- Understand and demonstrate the engineering design process
- Use Ohm's Law as a tool for engineering design.
- Use a digital multimeter to collect data.
- Analyze the electrical requirements of light emitting diodes (LED's).

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:
- The engineering design process
- The relationship between voltage, current, and resistance in an electrical circuit
- basic breadboard and measurement techniques

Prerequisites (Recommended)
Students should have a basic working knowledge of these related TryEngineering lessons (available from www.tryengineering.org/lesson.php)
- Get Connected With Ohm's Law
- Series and Parallel Circuits

Lesson Activities

The activity consists of using a nine-volt battery to:

- Predict the output voltage of a simple voltage divider using Ohm's Law and derived equations.
- Design, build, and demonstrate a simple voltage divider circuit.
- Measure and record the voltage produced and compare to the predicted value.
- Use the concepts and techniques to design a circuit for a high intensity light emitting diode.

Resources/Materials

Four teacher handouts are provided:

- Step By Step Guide
- Appendix 1: Equations for Series and Parallel Resistance
- Appendix 2: Matrix of Possible Voltage Outputs
- Appendix 3: Advanced Equations for Voltage Divider Ratios

Three student handouts are provided for advance review:

- Voltage Divider Information Sheet
- Resistor Color Codes
- Step By Step Procedures

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- TryEngineering (www.tryengineering.org)
- IEEE Global History Network (www.ieeeghn.org)
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/)
- National Council of Teachers of Mathematics Principles and Standards for School Mathematics (www.nctm.org/standards)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)

Supplemental Reading

- Ohm's Law, Electrical Math and Voltage Drop Calculations by Tom Henry. (ISBN: 978-0945495260)
- Teach Yourself Electricity and Electronics, Fourth Edition (Paperback) by Stan Gibilisco. (ISBN: 978-0071459334)
- Electrical Engineering 101: Everything You Should Have Learned in School but Probably Didn't by Darren Ashby. (ISBN: 978-1856175067)

Extension Ideas

- Create an Excel spreadsheet that predicts all possible output voltages given a selection of resistors and batteries.
- Remove R2 from the circuit. Replace R1 with the largest available value. Connect the multimeter to measure V2, using the multimeter's internal resistance instead of R2. Use the voltage measured to calculate the internal resistance of the multimeter.

Optional Writing Activity

- Research the life and work of Georg Ohm and write a page on how his discoveries have impacted modern electronics.

References

- Brad Snodgrass
  Central Indiana Section of IEEE
  URL: www.cis-ieee.org

Using Ohm's Law to Build a Voltage Divider

For Teachers:
Step by Step Guide

◆ Lesson Goal

This lesson encourages students to use Ohm's Law to design and build a voltage divider circuit. The voltage divider is one of the first circuits Electrical Engineering students learn and it is very useful for the study of Ohm's law and associated concepts. During this lesson students derive and apply mathematical equations to build voltage divider circuits, including a circuit that will power a light emitting diode (LED).

◆ Lesson Objectives

- Learn about Ohm's Law.
- Use a digital multimeter to collect data.
- Explore the concepts of voltage and current.
- Analyze the electrical requirements of light emitting diodes (LED's).

◆ Materials

- Student handouts
- One set of materials for each group of students:

  Note: The following materials list can be adapted for material on hand or for obtaining other voltage outputs. All materials can be reused.

Multimeter
Breadboard with Wire Set
Calculator
LED – Super Red, Clear Lens
9V Alkaline Battery
9V Battery Holder with Wire Leads
Resistor: 100 ohm, Carbon Film, 1/2W, 5%
Resistor: 150 ohm, Carbon Film, 1/2W, 5%
Resistor: 220 ohm, Carbon Film, 1/2W, 5%
Resistor: 330 ohm, Carbon Film, 1/2W, 5%
Resistor: 470 ohm, Carbon Film, 1/2W, 5%
Resistor: 560 ohm, Carbon Film, 1/2W, 5%
Resistor: 680 ohm, Carbon Film, 1/2W, 5%
Resistor: 820 ohm, Carbon Film, 1/2W, 5%
Resistor: 910 ohm, Carbon Film, 1/2W, 5%
Resistor: 1000 ohm, Carbon Film, 1/2W, 5%

◆ Time Needed

Three to four 45 minute sessions

For Teachers:
Step by Step Guide (continued)

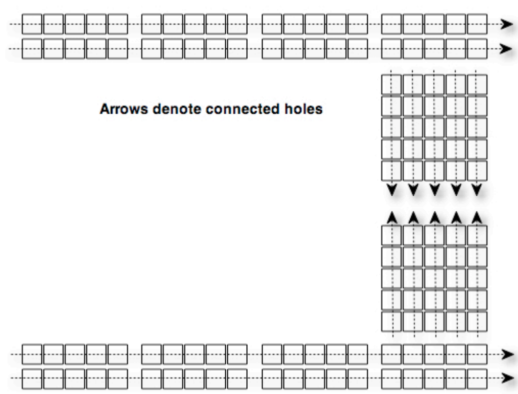
◆ **Procedure**
Divide students into groups of two. Show students the various Student Resource Sheets. These may be read in class, or provided as reading material for the prior night's homework.

Step 1: Reading Resistor Values
Students will find each of the following resistors in their lesson kit. They can review the handout on Resistor Color Codes and then determine the color codes for the following resistors. After finding each resistor in the lesson kit students can measure and record the resistance and determine whether the value is within the tolerance.

Resistor	First Band	Second Band	Multiplier	Tolerance	Highest Resistance	Lowest Resistance	Measured	Within Tolerance?
820 ohm	Gray	Red	Brown	5%	861	779		
470 ohm	Yellow	Violet	Brown	5%	494	446		
1K ohm	Brown	Black	Red	5%	1050	950		

Step 2: Understanding Breadboards
Breadboards normally have rows of holes along each edge that are connected together. Then, running perpendicular to the edge holes, there are shorter rows with holes connected together. Oftentimes, the breadboards are split into two halves so that an integrated circuit can be placed in the middle of the board. For these boards, there will be a set of holes on each side of the split that are connected to each other, but are not connected across the split.

Invite students to explore the breadboards found in their kits. In the spaces provided on their worksheets, encourage students to draw diagrams of some of the connections on the breadboards and how the breadboards may be used to build a voltage divider circuit.



Using Ohm's Law to Build a Voltage Divider

For Teachers:
Step by Step Guide (continued)

Step 3: Building a Voltage Divider
Using the diagram and the resistors in the lesson kit, invite students to build a voltage divider using the 9V battery, R1=820ohm, and R2=470ohm. Students can then predict and measure output voltages for their voltage dividers and record the information on their worksheets.

Assuming the 9V battery, R1=820ohm, and R2=470ohm.

What voltage would you expect?

$$\underbrace{\boxed{3.3V}}_{V_2} \quad \underbrace{\boxed{= 9V}}_{V_{battery}} \quad * \quad \frac{\overset{\boxed{470}}{R2}}{\underset{(R1+R2)}{\boxed{(820} + \boxed{470)}}}$$

What voltage did you measure?

Remember that the resistors have tolerances!!

Step 4: Building a Voltage Divider for a Desired Output
Using the voltage divider circuit, challenge students to select R1 and R2 from the lesson kit to produce the following output voltages:

V_2	$V_{battery}$	R1	R2	V_2 calculated	V_2 measured
2.0V	9V	330 820	100 220	2.09 1.90	
3.0V	9V	680 910	330 470	2.94 3.07	
5.0V	9V	470 560 680	560 680 820	4.89 4.94 4.92	
7.0V	9V	150 150 220 220	470 560 680 910	6.82 7.10 6.80 7.25	

For Teachers:
Step by Step Guide (continued)

Step 5: Building a Light Emitting Diode circuit
A circuit to illuminate a Light Emitting Diode (LED) is very similar to a Voltage Divider circuit. An LED circuit replaces R1 with the LED. For an LED in this configuration, V_1 will be a constant voltage, regardless of the total current. Therefore, for these circuits, V_2 is also known. LED's require a certain amount of current for optimal operation. This is called the bias current. Therefore, if V_2 and bias current are known, students can calculate a value for R2.

As the name implies, LED's are diodes. This means that they will only illuminate when installed with the proper polarity. In most cases, the flatted side of the LED needs to face towards the lower voltage. For this circuit, the flatted side should point towards R2

If R1 is replaced with an LED that has a voltage V_1 of 2.0V and requiring a bias current of 20mA, (0.020A) determine the following:

What is the value of V2?

7.0V	=	9.0V	-	2.0
V_2		$V_{battery}$		V_1

What is the value of I_{total}

0.020	=	0.020	=	0.020
I_{total}		I_1		I_2

What is the resistor required for proper bias.

350	=	7.0V	/	0.020
R_2		V_2		I_2

Try a few resistors near the required resistor value. Measure V2 and compute the bias current.

V_2 measured	**$V_{battery}$**	**R2**	**I_2 calculated**
7.0	9.0	220	32mA
7.0	9.0	330	21mA
7.0	9.0	470	15mA

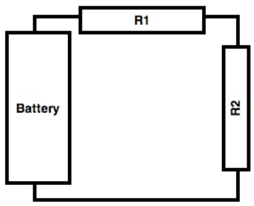
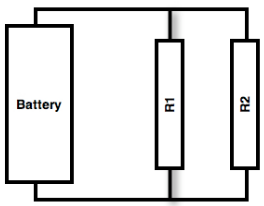
Which resistor is the best choice? Why?

Many correct answers are possible, depending on the actual resistor value and the parameters for the particular LED. Students should be encouraged to try different resistors to find a pleasing LED brightness, without being out of specified parameters.

Using Ohm's Law to Build a Voltage Divider

For Teachers:
Appendix 1: Equations for Series and Parallel Resistance

By applying basic concepts and Ohm's Law, the equations for series and parallel resistance can be derived.

	For a series circuit, R1 is said to be in series with R2. For these circuits, the *current* flowing through each device in series is the same. Adding the *voltages* across each element in series is equal to the total (battery) voltage.
	For a parallel circuit, R1 is said to be in parallel with R2. For these circuits, the *voltage* across each device in parallel is the same. Adding the *current* through each element in parallel is equal to the total (battery) current.

These concepts can be used to derive the equations for series and parallel resistors.

Series Resistors

$$I_1 = I_2 = I_{total}$$
$$V_{battery} = V_1 + V_2$$
$$V_1 = I_1 * R1$$
$$V_2 = I_2 * R2$$
$$V_{battery} = I_{total} * R_{total}$$

Substituting, and dividing by I_{total}

$$I_{total} * R_{total} = I_1 * R1 + I_2 * R2$$
$$R_{total} = R1 + R2$$

Parallel Resistors

$$V_{battery} = V_1 = V_2$$
$$I_{total} = I_1 + I_2$$

Substituting, and dividing by $V_{battery}$

$$V_{battery}/R_{total} = V_1/R1 + V_2/R2$$
$$1/R_{total} = 1/R1 + 1/R2$$

Solving for R_{total}

$$R_{total} = (R1*R2)/(R1+R2)$$

Using Ohm's Law to Build a Voltage Divider

For Teachers:
Appendix 2: Matrix of Possible Voltage Outputs

For the specified list of resistors and a 9V battery, the following output voltages are possible:

R1

R2	Output Voltage	100	150	220	330	470	560	680	820	910	1000
	100	4.50	3.60	2.81	2.09	1.58	1.36	1.15	0.98	0.89	0.82
	150	5.40	4.50	3.65	2.81	2.18	1.90	1.63	1.39	1.27	1.17
	220	6.19	5.35	4.50	3.60	2.87	2.54	2.20	1.90	1.75	1.62
	330	6.91	6.19	5.40	4.50	3.71	3.34	2.94	2.58	2.40	2.23
	470	7.42	6.82	6.13	5.29	4.50	4.11	3.68	3.28	3.07	2.88
	560	7.64	7.10	6.46	5.66	4.89	4.50	4.06	3.65	3.43	3.23
	680	7.85	7.37	6.80	6.06	5.32	4.94	4.50	4.08	3.85	3.64
	820	8.02	7.61	7.10	6.42	5.72	5.35	4.92	4.50	4.27	4.05
	910	8.11	7.73	7.25	6.60	5.93	5.57	5.15	4.73	4.50	4.29
	1000	8.18	7.83	7.38	6.77	6.12	5.77	5.36	4.95	4.71	4.50

Using Ohm's Law to Build a Voltage Divider

For Teachers:

Appendix 3: Advanced Equations for Voltage Divider Ratios

The ratio of the battery voltage and the desired voltage can be used to determine the goal ratio of the two resistors. Knowing this ratio is very helpful when choosing from a limited selection of resistors.

Starting with the Voltage Divider Equation

$$V_2 = V_{battery} * (R2)/(R1 + R2)$$

The ratio of the voltage is represented by

$$V_2/V_{battery} = R2/(R1 + R2)$$

Invert the terms and solve for a simpler ratio of resistors

$$V_{battery}/V_2 = (R1 + R2)/R2$$
$$V_{battery}/V_2 = (R1/R2) + (R2/R2)$$
$$V_{battery}/V_2 = R1/R2 + 1$$
$$(V_{battery}/V_2) - 1 = R1/R2$$
$$R1/R2 = (V_{battery}/V_2) - 1$$

Consider the requirement for a 5V supply, using a 9V battery. Search for two resistors that obey the following proportion.

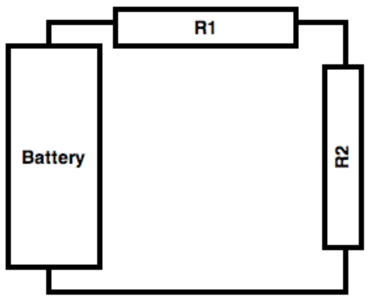
$$R1/R2 = (V_{battery}/V_2) - 1$$
$$R1/R2 = (9/5) - 1$$
$$R1/R2 = 0.8$$

Using this ratio, it is immediately clear that R1=820 and R2=1000 will produce the desired voltage.

Using Ohm's Law to Build a Voltage Divider

For Teachers:
Voltage Divider Information Sheet

A Voltage Divider is used to produce a desired output voltage, using resistors in series. The output voltage (voltage across R2) is proportional to the ratio of R1 and R2



Using Ohm's Law, compute the Voltage across R1 and R2 and the total resistance

$V_1 = I_1 * R1$ -- where V_1 is the voltage across R1, and I_1 is the current through R1
$V_2 = I_2 * R2$ -- where V_2 is the voltage across R2, and I_2 is the current through R2
$V_{battery} = I_{total} * R_{total}$ -- where $V_{battery}$ is the battery voltage and R_{total} is the total resistance

Since R1 and R2 are in series, the total resistance is known.

$$R_{total} = R_1 + R_2$$

Since R1 and R2 are in series, the current through each resistor is the same as the total current

$$I_{total} = I_1 = I_2$$

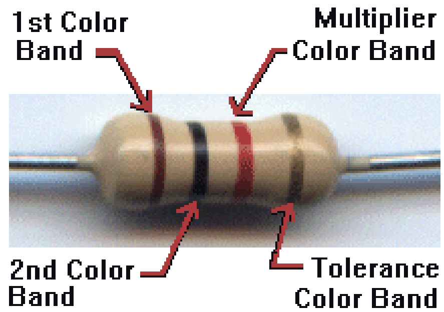
Solving for V_2

$$I_2 = V_2/R2$$
$$I_{total} = V_{battery}/R_{total} = V_{battery}/(R1+R2)$$
$$I_2 = I_{total}$$
$$V_2/R2 = V_{battery}/(R1+R2)$$
$$V_2 = V_{battery}(R2/(R1+R2))$$

Therefore, the voltage across R2 can be determined by controlling the ratio of R2 to the total resistance, R1 + R2.

Using Ohm's Law to Build a Voltage Divider

Student Resource: Resistor Color Codes



All resistors are color coded for quicker reading of their values. To determine the value of a resistor, first look for a gold or silver band at one end of the color code. This is the tolerance band. Rotate the resistor so that the tolerance band is on your right.

Now, the value of the resistor is read from left to right. The first two bands represent the first two digits in the resistor value. The third band is a multiplier. Use the chart below to decode the colors.

The example above has a first color band of Brown and second color band of Black. The multiplier band is Red. The tolerance band is Gold.

The value of the resistor is computed as follows:

Brown = 1	Black = 0	Red = 2	Gold = 5%

Resistance = 10 * 10^2
= 1000 Ohm (Ω) or 1KΩ

Tolerance = 5% of 1000Ω = 50Ω.

The tolerance band specifies that these resistors may have any value between 950Ω and 1050Ω

COLOR	DIGIT	MULTIPLIER
Black	0	10^0 = 1
Brown	1	10^1 = 10
Red	2	10^2 = 100
Orange	3	10^3 = 1000 (1K)
Yellow	4	10^4 = 10,000 (10K)
Green	5	10^5 = 100,000 (100K)
Blue	6	10^6 = 1,000,000 (1M)
Violet	7	10^7 = 10,000,000 (10M)
Gray	8	10^8 = 100,000,000 (100M)

Tolerance
- Gold= 5%
- Silver=10%
- None=20%

Student Worksheet:
Step by Step Procedures

Step 1: Reading Resistor Values
Before the appropriate resistors can be chosen, their values must be determined. One way, of course, is to measure every resistor. Obviously, this is not practical. Fortunately, every resistor comes with a color-coded value printed on it.

Review the handout on Resistor Color Codes.

Determine the color codes for the following resistors. Find the resistor in the lesson kit. Measure and record the resistance. Is the value within the tolerance?

Resistor	First Band	Second Band	Multiplier	Tolerance	Highest Resistance	Lowest Resistance	Measured	Within Tolerance?
820 ohm								
470 ohm								
1K ohm								

Step 2: Understanding Breadboards
Engineers often use a tool called a Breadboard to build prototype circuits. Find a white plastic board full of holes and a box of pre-cut wires in the lesson kit. This is the breadboard.

Breadboards are made so that some of the holes are electrically connected, so that circuits can be built. Using the multimeter and wires from the kit of pre-cut wires, draw a diagram of some of the connections on the breadboard.

Next, draw a diagram showing how a voltage divider circuit might be built with the breadboard.

Step 3: Building a Voltage Divider
Using the diagram and the resistors in the lesson kit, build a voltage divider using the 9V battery, R1=820ohm, and R2=470ohm.

What voltage would you expect?

	=	*			
			R2		
			(	+	)
V_2	$V_{battery}$			(R1+R2)	

What voltage did you measure?

Step 4: Building a Voltage Divider for a Desired Output
Using the voltage divider circuit, select R1 and R2 from the lesson kit to produce the following output voltages

V_2	$V_{battery}$	R1	R2	V_2 calculated	V_2 measured
2.0V					
3.0V					
5.0V					
7.0V					

Step 5: Building a Light Emitting Diode circuit
A circuit to illuminate a Light Emitting Diode (LED) is very similar to a Voltage Divider circuit. An LED circuit replaces R1 with the LED. For an LED in this configuration, V_1 will be a constant voltage, regardless of the total current. Therefore, for these circuits, V_2 is also known. LED's require a certain amount of current for optimal operation. This is called the bias current. Therefore, if V_2 and bias current are known, a value for R2 can be calculated.

As the name implies, LED's are diodes and they will only illuminate when installed with the proper polarity. For this circuit, the flatted side should point towards R2

If R1 is replaced with an LED that has a voltage V_1 of 2.0V and requiring a bias current of 20mA, (0.020A) determine the following

What is the value of V_2?

$\boxed{}$	=	$\boxed{}$	-	2.0
V_2		$V_{battery}$		V_1

What is the value of I_{total}

$\boxed{}$	=	0.020	=	$\boxed{}$
I_{total}		I_1		I_2

What is the resistor required for proper bias.

$\boxed{}$	=	$\boxed{}$	/	0.020
R_2		V_2		I_2

Try a few resistors near the calculated value to find an optimal LED brightness. Measure V_2 and compute the bias current.

V_2 measured	$V_{battery}$	R2	I_2 calculated

Student Worksheet (continued)

Which resistor is the best choice? Why? What happens if the LED is installed backwards?

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For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:
- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop
- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of activities in grades 5-8, all students should develop understanding of
- ✦ Transfer of energy
- ✦ Understandings about science and technology

◆National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop
- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of activities, all students should develop
- ✦ Interactions of energy and matter

◆Next Generation Science Standards Grades 3-5 (Ages 8-11)

Energy

Students who demonstrate understanding can:
- ✦ 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

◆Next Generation Science Standards Grades 6-8 (Ages 11-14)

Motion and Stability: Forces and Interactions
- ✦ MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

◆Next Generation Science Standards Grades 9-12 (Ages 14-18)

Energy
- ✦ HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- ✦ HS-PS3-3. Design, build, and refine a device that works within given constraint s to convert one form of energy into another form of energy.

Using Ohm's Law to Build a Voltage Divider

For Teachers: Alignment to Curriculum Frameworks (continued)

◆ **Principles and Standards for School Mathematics (ages 10 - 14)**

Number and Operations Standards

- Compute fluently and make reasonable estimates
  - ✦ Develop, analyze, and explain methods for solving problems involving proportions, such as scaling and finding equivalent ratios.

Algebra Standards

- Use mathematical models to represent and understand quantitative relationships
  - ✦ Model and solve contextualized problems using various representations, such as graphs, tables, and equations.

Measurement Standards

- Apply appropriate techniques, tools, and formulas to determine measurements.
  - ✦ use common benchmarks to select appropriate methods for estimating measurements.

Problem Solving Standards

- Solve problems that arise in mathematics and in other contexts

◆ **Principles and Standards for School Mathematics (ages 14 - 18)**

Number and Operations Standards

- Compute fluently and make reasonable estimates
  - ✦ develop fluency in operations with real numbers, vectors, and matrices, using mental computation or paper-and-pencil calculations for simple cases and technology for more-complicated cases

Algebra Standards

- Represent and analyze mathematical situations and structures using algebraic symbols
  - ✦ understand the meaning of equivalent forms of expressions, equations, inequalities, and relations

Measurement Standards

- Apply appropriate techniques, tools, and formulas to determine measurements.
  - ✦ analyze precision, accuracy, and approximate error in measurement situations.

Problem Solving Standards

- build new mathematical knowledge through problem solving

◆ **Common Core State Standards for School Mathematics Grades 3-8 (ages 8-14)**

Ratios and Proportional Relationships

- Understand ratio concepts and use ratio reasoning to solve problems.
  - ✦ CCSS.Math.Content.6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.
  - ✦ CCSS.Math.Content.7.RP.A.2c Represent proportional relationships by equations. For example, if total cost t is proportional to the number n of items purchased at a constant price p, the relationship between the total cost and the number of items can be expressed as t = pn.

Using Ohm's Law to Build a Voltage Divider

For Teachers:
Alignment to Curriculum Frameworks (continued)

◆Common Core State Standards for School Mathematics Grades 3-8 (ages 8-14)

Expressions & Equations

- Apply and extend previous understandings of arithmetic to algebraic expressions.
  - ✦ CCSS.Math.Content.6.EE.A.2 Write, read, and evaluate expressions in which letters stand for numbers.
- Reason about and solve one-variable equations and inequalities.
  - ✦ CCSS.Math.Content.6.EE.B.6 Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.
  - ✦ CCSS.Math.Content.6.EE.B.7 Solve real-world and mathematical problems by writing and solving equations of the form $x + p = q$ and $px = q$ for cases in which p, q and x are all nonnegative rational numbers.

◆Common Core State Standards for School Mathematics Grades 9-12 (ages 14-18)

Algebra

- Create equations that describe numbers or relationships
  - ✦ CCSS.Math.Content.HSA-CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law $V = IR$ to highlight resistance R.
- Solve equations and inequalities in one variable.
  - ✦ CCSS.Math.Content.HSA-REI.B.3 Solve linear equations and inequalities in one variable, including equations with coefficients represented by letters.

◆ Standards for Technological Literacy - All Ages

Design

- ✦ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

The Designed World

- ✦ Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.