Additional Technology Activities

Okeanos Explorer's prominent VSAT (Very Small Aperture Terminal) dome enables satellite communications between explorers ashore and at sea and provides multiple high-definition video streams for widespread dissemination. Image credit: NOAA.

Telepresence/Wireless Communication

Thanks to telepresence, the experience of discovery is not confined to a few scientists aboard the *Okeanos Explorer*. Video from the underwater robot is transmitted to a satellite orbiting in a fixed position above Earth, then relayed to the University of Rhode Island's Inner Space Center. From there, video and audio from the ship are sent to Exploration Command Centers (ECCs) in places such as Seattle, New Hampshire, Maryland, Connecticut, and Indonesia. Observers in these ECCs are able to communicate with the *Okeanos Explorer's* Control Room via the Internet. During the ship's maiden voyage to Indonesia in 2010, only computers connected to the advanced academic network called Internet2 were able to view the video,

> "...but as the excitement built up around the *Okeanos Explorer* and the INDEX-SATAL Expedition, participants began using increasingly creative solutions for developing ad-hoc viewing stations and in some cases mini-ECCs utilizing the standard Internet. These solutions extended telepresence capabilities to smaller academic institutions, public venues, hotel rooms, the cafeteria at the U.S. Embassy in Jakarta, and even at one scientist's private residence."

This quotation is from "Implementing Telepresence: Technology Knows No Bounds," INDEX-SATAL 2010 daily log for July 9, 2010 by Webb Pinner and Kelley Elliott; *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html*.

These activities provide an introduction to some of the fundamental concepts of wireless communication technology that support telepresence aboard the *Okeanos Explorer*.

For additional information see the Telepresence section of *The Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?* starting on page 33 (*http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-TPbkgnd.pdf*).

Satellite Communications

The most prominent piece of communications equipment aboard *Okeanos Explorer* is the 4.2 m diameter dome that houses the ship's 3.7 meter Very Small Aperture Terminal (VSAT) dish antenna. This antenna is the critical link between the *Okeanos Explorer* and the satellites that relay information between the ship and shore-based Exploration Command Centers, as well as NOAA's Network Operations Center.

Computers and hardware included in the antenna system make constant adjustments that compensate for the ship's heave, roll and pitch to keep the antenna pointed toward the appropriate communications satellite. Radio transmitters and receivers connected to the VSAT antenna operate in the global C-band, using frequencies between 3.7 to 4.2 GHz for downlinks, and frequencies between 5.925 GHz to 6.425 GHz for uplinks (signals received from a satellite are downlinks; signals sent to a satellite are uplinks). These frequencies are in the microwave region of the electromagnetic spectrum.

The satellites used by the *Okeanos Explorer*'s telepresence system are 22,753.2 statute miles ("normal" miles, not nautical miles) above Earth's surface. At this altitude, the satellites' rotational speed matches the speed of Earth's rotation so they appear to remain in a fixed position when viewed from Earth's surface. For this reason, these satellites are called "geo-synchronous" or "geo-stationary."

Wireless Communication Worksheet

Learning Procedure

1. Ask students why telepresence is important to ocean exploration. In addition to making it possible for more people to interact in real time with events aboard the *Okeanos Explorer*, students should realize that communication is essential to the scientific process, which is based on the idea of testing hypotheses, then reporting the results to others who can verify those results or find additional information that builds on them. For this reason, it is critical for scientific communications to convey accurate information.

   Show students the well-known statement: "I know you believe you understood what you think I said, but I'm not sure you realize that what you heard is not what I meant to say." This statement is often used to highlight the difficulties of human communication. Ask students to describe the basic process of human communication, beginning with an idea that one person wishes to convey to another. Students should recognize that the person with the idea (the sender) translates the idea into words, symbols, pictures, or some other form outside the sender's brain; then the sender gives this translation to the person intended to receive the idea; and finally the receiver translates the words, symbols, or other information received back into an idea. If all goes well, the idea that ends up in the receiver's brain is the same as the idea that originated in the sender's brain; but there are many things that can go wrong.

   An obvious possible problem is that the sender and receiver may not attach exactly the same meaning to the symbols used to convey the idea. The potential for this problem increases when different languages are involved. Ask students what could be done to find out whether the idea has been successfully communicated. An obvious solution is to have the receiver repeat the idea back to the sender, who can then compare the receiver's version with the original. This is a feedback process; simple and effective, but often unused in human communications. Air traffic controllers, on the other hand, are required to use a feedback mechanism called a readback/hearback loop to verify that information has been accurately communicated.

   Briefly discuss other factors that can influence the effectiveness of human communication. These factors include distractions, moods, prejudice, experience, physical well-being, and many others. A major influence is that humans communicate in multiple ways at the same time. In fact, it is almost impossible NOT to communicate, whether we want to or not; gestures, appearance, tone of voice, and even absence can all send signals to others that may conflict with our conscious efforts to directly communicate ideas. The importance of "body language" is often mentioned in this context, and may be much more significant than verbal communication in determining the message that is actually received. In many cases, it seems that we listen best through our eyes.

   Return to the question of how telepresence contributes to scientific communication. Students should recognize that:
   - Telepresence makes visual communication possible, which greatly enhances the transfer of information and ideas;
   - Telepresence provides the opportunity for feedback, to verify the accuracy of information received; and
   - Telepresence greatly shortens the time required for the "scientific feedback" process to occur by allowing more people to interact with exploration activities in real time.

2. Tell students that their assignment is to investigate the basic technology that makes telepresence possible. Provide each student or student group with a copy of the Wireless Communications Worksheet. When students have finished answering Worksheet questions, lead a discussion of their results using the answer sheet on page 4.

Student Worksheet: Wireless Communication

1. What is wireless communication?

2. What did the following people contribute to the development of wireless communication technology?
   - Hans Christian Ørsted
   - Michael Faraday
   - James Clerk Maxwell
   - Heinrich Rudolf Hertz
   - Nikola Tesla
   - Guglielmo Marconi
   - Reginald Fessenden

3. List at least five wireless communication devices that you have used within the past month.

4. In 1858, the first transatlantic cable was completed. An editorial in the *Times of London* commented:

   > "Tomorrow the hearts of the civilized world will beat in a single pulse, and from that time forth forevermore the continental divisions of the earth will, in a measure, lose those conditions of time and distance which now mark their relations."

   Later the same year, Charles Briggs and Augustus Maverick wrote:

   > "Of all the marvelous achievements of modern science the electric telegraph is transcendentally the greatest and most serviceable to mankind. . . The whole earth will be belted with the electric current, palpitating with human thoughts and emotions. . . How potent a power, then, is the telegraphic destined to become in the civilization of the world! This binds together by a vital cord all the nations of the earth. It is impossible that old prejudices and hostilities should longer exist, while such an instrument has been created for an exchange of thought between all the nations of the earth."

   Do you think the electric telegraph and its successor, wireless communications, have produced the benefits forecast by these writers? What other factors may have been involved?

5. Draw a block diagram showing the major components needed to send a wireless voice message between two points on Earth that are 100 miles apart (you only need to show the components needed to send a message in one direction).

Wireless Communication Answer Sheet

1. Wireless communication literally means communicating without wires. This definition could include smoke signals, drums, and ordinary human speech. Normally, however, this term refers to techniques for communicating over long distances using electromagnetic waves, as opposed to techniques that require wires to connect a sender with a receiver.

2. Contributions to the developement of wireless communication technology:
   - Hans Christian Ørsted demonstrated that an electric current produces a magnetic field as it flows through a wire.
   - Michael Faraday created the first electric motor based on Ørsted's observation. He also showed that a magnet moving through a loop of wire caused an electric current to flow in the wire, and that a current also flowed if the loop was moved over a stationary magnet.
   - In 1864, James Clerk Maxwell predicted the existence of electromagnetic fields, and that these fields are responsible for electricity, magnetism and light. He also predicted that electric and magnetic fields travel through space in the form of waves at the speed of light.
   - Heinrich Rudolf Hertz validated Maxwell's predictions with experiments between 1886 and 1888, but saw no practical use for his discoveries.
   - Nikola Tesla began researching electromagnetic fields in 1891, and demonstrated numerous inventions that could be considered the forerunners of wireless communications. Between 1895 and 1898, he received wireless signals transmitted via short distances and demonstrated a radio controlled boat.
   - Guglielmo Marconi built on the discoveries of Hertz and possibly Tesla to develop wireless communications systems. In 1897 he received a British patent for a radio based on designs and techniques of several other experimenters, including Tesla. By 1899, Marconi had demonstrated the effectiveness of wireless telegraph communications between ships and shore stations, and in 1899 transmitted the first wireless message across the English Channel, and later established the first transatlantic radio service.
   - Reginald Fessenden began working with Thomas Edison in 1886, and developed a wireless telephone communication system that was operating between Pittsburgh and Allegheny City by 1899. A year later, he made the first successful wireless voice transmission.

   The key point is that the development of wireless communication took place in many steps, and involved many individuals who advanced understanding so that others could build on their results. Students may also note that it is quite possible that some individuals (*e.g.*, Tesla) may deserve more credit than is commonly understood.

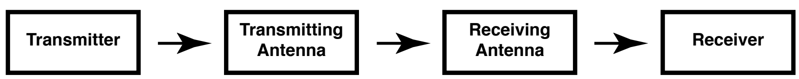
3. Some wireless communication devices that are commonly used by students include:
   - Cell phones;
   - Wireless Internet;
   - Remote controls for televisions, media players, and other appliances;
   - Satellite television;
   - Car radios;
   - Global positioning systems;
   - Garage door openers;

- Keyless locks and entry systems (also called RFID systems, which stands for radio frequency identification).

4. Students should realize that neither the transatlantic cable nor modern wireless technology have caused "old prejudices and hostilities" to cease to exist. Building on earlier discussions about human communication (Step 2) students should understand that the ability to exchange signals does not necessarily mean that these signals will be understood, nor that the signals will convey the same meaning to sender and receiver. Many of the same factors that interfere with one-on-one human communication (prejudice, mood, external influences, etc.) also interfere with cultural communications that might lessen old prejudices and hostilities.

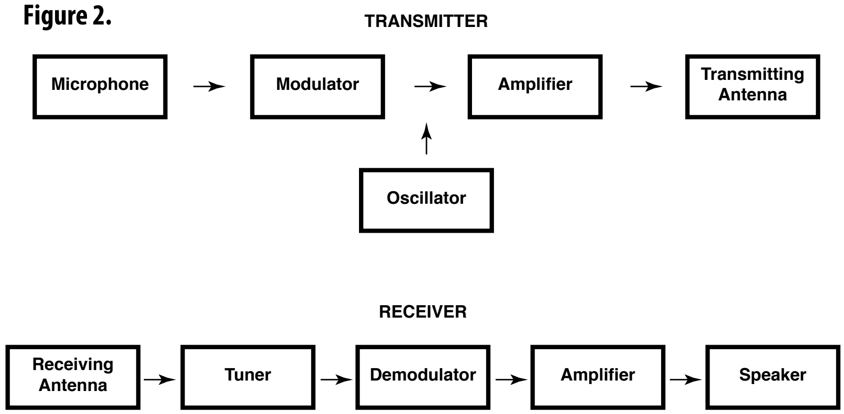
5. The simplest acceptable block diagram of a wireless system should include a transmitter, transmitting antenna, receiving antenna, and receiver (Figure 1).

Figure 1.



A satellite is not needed to cover a distance of 100 miles, though a satellite might improve the quality of the communication. A better diagram will include some more details about the transmitter and receiver (Figure 2):

Figure 2.



In Figure 2, the modulator in the transmitter encodes the audio signal from the microphone onto the radio frequency wave produced by the oscillator (modulation can be done several ways; see "A Day in the Life of an Ocean Explorer for a demonstration). The strength of the radio frequency wave is boosted by the amplifier. The amplified signal is sent to the antenna, which radiates the radio frequency energy. The antenna may radiate the energy in all directions, or it may radiate in a narrower direction so that more energy is sent toward the receiver. At the receiver, the tuner is set to match the frequency of the radio wave sent by the transmitter. The antenna receives some of the energy from the transmitted wave, and sends the signal through a demodulator that extracts the audio signal from the radio frequency wave. The audio signal is amplified, and sent to a speaker which makes the signal audible to humans. For more information, see the American Radio Relay League's "Radio Lab Handbook;" *http://www.arrl.org/radio-lab-handbook*.

Ask students what modifications would be needed to make this a two-way system. Students should realize the the entire system in Figure 1 would have to be duplicated, so that each station includes a transmitter as well as a receiver. Usually, the same antenna can be used to send and receive.

Tell students that communicating by wireless over 100 miles is one thing, but suppose the sending and receiving stations are thousands of miles apart. Students will probably identify the need for satellites that can relay signals between the two stations. This means that the satellite also must have a transmitter and a receiver. In each case, it is desirable for the transmitter to send the strongest signal possible, and for the receiver to be able to detect the weakest signal possible.

Wireless Communication: Making a Simple Radio

Learning Procedure

1. Provide students with the materials and directions to build a simple radio (see pg. 7) and have students complete the Making a Simple Radio Activity.

2. When students have finished building their radios, lead a discussion to summarize the relevance of this activity to telepresence aboard the *Okeanos Explorer*. Students should realize that crystal set radios are the most basic ("bare bones") demonstration of the principles that underlie wireless communication technology:
   - Radio waves strike an antenna and cause an electric current to flow in the antenna;
   - The antenna can be connected to a circuit that only allows current to flow when the radio waves have a certain frequency;
   - Radio waves that have been modulated can carry information such as audio signals;
   - The current produced by radio waves striking an antenna retains the effects of modulation, and this current also carries the information contained in the radio waves; and
   - Energy in the electric current from radio waves can be converted to sound energy that replicates the audio signals that were originally used to modulate the radio waves.

   Students should also realize that modern wireless communication technology and telepresence use these same principles, but the equipment is much more complex at every stage. Amplifiers are used to increase the strength of radio waves before they are transmitted, as well as after they are received. Different types of modulation are used that can carry more information and ensure that the signals that are received match those that were sent. Specially designed antennas are used to focus radio waves in a specific direction, and to receive radio waves from a specific source. The ability to send high-resolution images and large amounts of scientific data from the *Okeanos Explorer* to the other side of the world in a few seconds requires thousands of resistors, capacitors, coils, and many other components. Still, every phone call from crew members to friends ashore, every email, and every image received in an ECC is made possible by the basic principles seen in the crystal set radio.

Hands-On Activity: Making a Simple Radio

During World War II, some soldiers listened to news and entertainment using "Foxhole Radios" that they made with some wire, a razor blade, a safety pin, and a pair of earphones. These contraptions were a type of "crystal set," the simplest type of radio, and were the first widely-used type of radio receiver. Because they use very few parts, crystal set radios provide an effective "bare bones" demonstration of the basic principles that underlie wireless communication technology.

Many crystal set designs are available on the Internet, including an entire Web site devoted exclusively to building them (*http://www.midnightscience.com/index.html*). This Web site, operated by the Xtal Set Society, provides many relevant resources, including detailed instructions and kits of parts. The Society's Oat Box Crystal Set is easy to build and uses inexpensive and readily available parts (see *http://www.midnightscience.com/oat-box-project.html*). The following summary is adapted from the Oat Box Crystal Set manual.

Materials

150 ft - #24 insulated wire (twin-lead speaker wire may be less expensive than regular hookup wire)
1 - 1N4001 diode (*e.g.*, Radio Shack 276-1101)
1 - 100-pf disc capacitor (*e.g.*, Radio Shack 272-0123)
1 - Resistor, 47 K-ohm, 1/2- or 1/4-watt
2 - Alligator clips (*e.g.*, Radio Shack 270-380)
1 - High impedance ceramic earphone (or the amplified speaker used in the Light Beam Modulation activity)
5 - Machine screws, 6-32 x 3/4-inch
5 - Solder lugs, #6 hole (optional, if solder connections are desired)
5 - 6-32 nuts (10 nuts if solder lugs are not used)
10 - Flat washers, #6 hole (20 washers if solder lugs are not used)
1 - Empty round oatmeal box
3 ft - Masking tape
1 ft - Solder (optional, if solder connections are desired)

Tools

1 - Pair small wire cutters
1 - Awl or icepick
1 - Screwdriver to fit 6-32 machine screws
1 - Pair needle nose pliers
1 - Soldering iron; approximately 60 watts (size is not critical; optional, if solder connections are desired))

Procedure

1. If you are using the Oat Box Crystal Set manual, attach the paper template to the oat box. Otherwise, use Figures 1 and 2 as guides. Punch holes for the five machine screws using an icepick or awl.

2. Mount the five 6-32 machine screws. If you plan to use solder connections, place a flat washer on a machine screw, then push the screw through one of the holes from the

Figure 1.

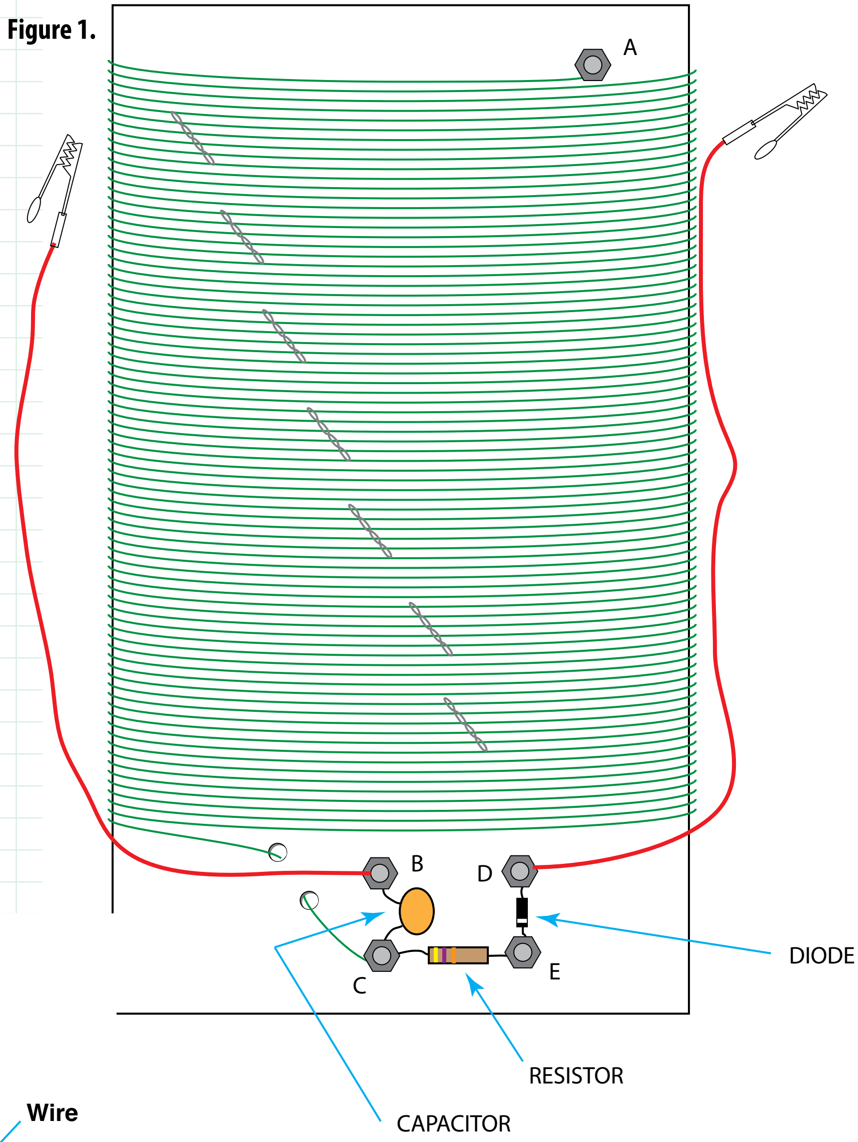
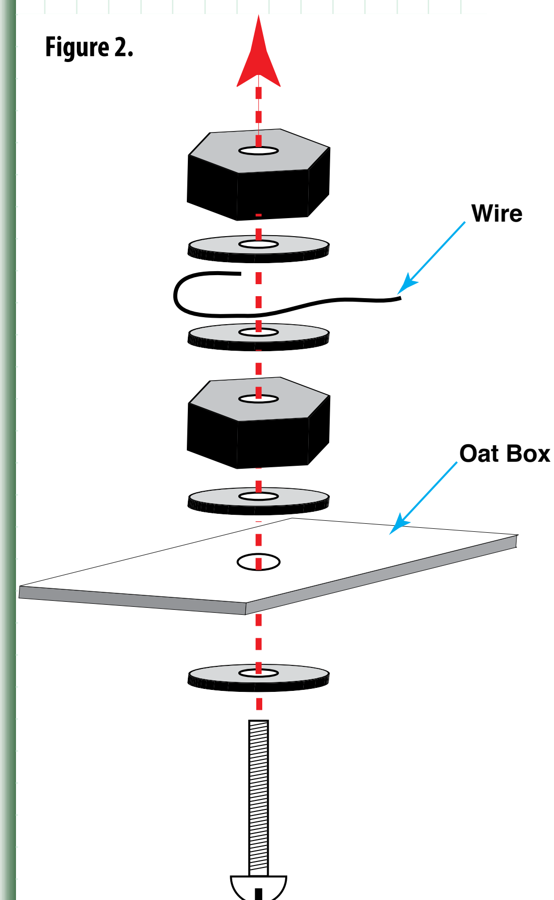


Figure 2.



inside of the oat box. Then place another washer onto the screw, followed by a solder lug, then fasten the assembly in place with a 6-32 nut.

If you do not plan to use solder connections, place a flat washer on a machine screw, then push the screw through one of the holes from the inside of the oat box. Then place another washer onto the screw, and fasten the assembly in place with a 6-32 nut. Place two more washers onto the machine screw followed by a second nut. Do not tighten the second nut until all of the wires and components are in place (see Figure 2).

3. Prepare eight lengths of #24 insulated wire, 128 inches long. If you are using twin-lead speaker wire, separate the two leads into single wires. Remove about 1-inch of insulation from both ends of each wire.

4. Attach one end of one wire to the machine screw near the top of the oat box, either by soldering or by wrapping the wire around the machine screw and then tightening the outside nut.

5. Wrap the wire around the oat box, keeping each coil snugly against the preceding coil. When most of the wire has been wrapped onto the oat box, tape the coil turns onto the box with masking tape. Twist the bare end of another wire together with the bare end of the first wire, and continue wrapping the second wire around the oat box. These twists are called "taps." Leave them sticking out, because they will be used to make connections later. Continue this procedure until all eight lengths of wire have been wrapped onto the box. ***TIP: Keeping the lid on the oat box will help the box keep its shape during wrapping.***

6. Punch two holes near the end of the last length of wire as shown in the manual or in Figure 1. Feed the end of the last length of wire through the nearest hole, then out of the other hole, and fasten to the machine screw labeled "C" in Figure 1. Do not solder the solder lug or tighten the second nut on this machine screw yet.

7. Prepare two 8-inch lengths of #24 insulated wire by removing about 1/2-inch of insulation from one end of each wire, and connecting each of these ends to an alligator clip. Remove machine screw labeled "D" in Figure 1. Do not solder the solder lugs or tighten the second nuts on these machine screws yet.

8. Connect one end of the 100-pf capacitor (it doesn't matter which end) to the machine screw labeled "B" in Figure 1. Solder the solder lug or tighten the second nut on the machine screw to complete the assembly on this machine screw.

9. Connect the other end of the 100-pf capacitor to the machine screw labeled "C" in Figure 1. Do not solder the solder lug or tighten the second nut on this machine screw yet.

10. Connect one end of the 47 K-ohm resistor (it doesn't matter which end) to the machine screw labeled "C" in Figure 1. Do not solder the solder lug or tighten the second nut on this machine screw yet.

11. Connect the other end of the 47 K-ohm resistor to the machine screw labeled "E" in Figure 1. Do not solder the solder lug or tighten the second nut on this machine screw yet.

12. Examine the diode and find the cathode end (usually, the end with a white band). Connect this end of the diode to the machine screw labeled "E" in Figure 1. Do not solder the solder lug or tighten the second nut on this machine screw yet.

13. Connect the other end of the diode to the machine screw labeled "D" in Figure 1. Solder the solder lug or tighten the second nut on the machine screw to complete the assembly on this machine screw.

14. Connect the earphone or leads from the amplified speaker to the machine screws labeled "C" and "E" in Figure 1. Solder the solder lugs or tighten the second nuts on the machine screws to complete the assembly on these machine screws. This completes construction of your radio!

15. Connect a wire from a cold water pipe (or other grounded object) to the machine screw labeled "C" in Figure 1. Connect about 50-feet of wire to the machine screw labeled "B" in Figure 1. The latter wire is your radio's antenna, and it should be as

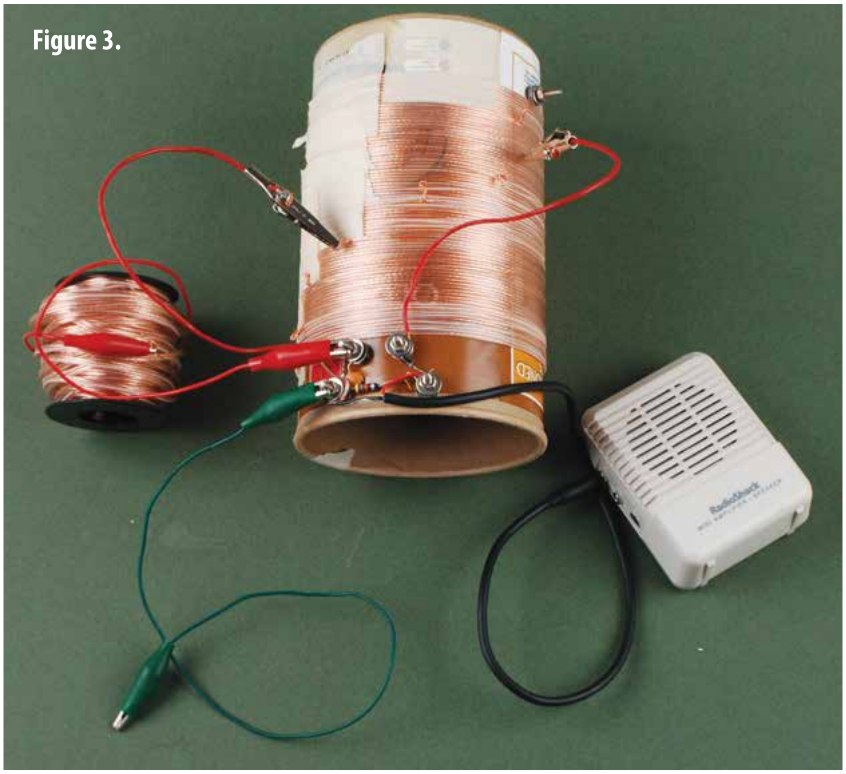


Figure 3. A crystal radio. Green jumper wire connects to cold water pipe (ground). Red jumper wire connects to 50-ft antenna (coiled on spool).

high as possible (but avoid getting near power lines, trying to stand on chairs, or unsafe use of ladders). You may use jumper cables for these connections as shown in Figure 3 to make it easy to disconnect your crystal set from the ground and antenna.

16. Attach the alligator clip from the machine screw labeled "B" in Figure 1 to the twist in the coil nearest the top of the oat box (these twists are called "taps"). Attach the alligator clip from the machine screw labeled "D" in Figure 1 to the twist in the coil to one of the taps near the center of the coil. Turn on the amplified speaker, or place the earphone in one ear.

17. Move the clip from the tap near the top of the oat box to other taps until you hear a radio station. When you have found one, move the other clip until the clearest signal is obtained.

What's Going On?

A capacitor is a device that consists of two conductors separated by an insulator. When a voltage is applied across the conductors, a static electric field develops in the insulator that stores energy. An inductor is a device that can store energy in a magnetic field created by the electric current passing through it. Inductors are usually coils of insulated wire.

When a capacitor is connected in parallel with an inductor and they are in a circuit connected to a source of alternating voltage, an alternating current will flow through the circuit. The amount of current that flows depends upon the values of capacitance and inductance in the circuit, and also upon the frequency of the applied voltage. At a certain frequency, called the resonant frequency, almost no current flows. If the frequency of the applied voltage is above or below the resonant frequency of the circuit, a much larger current will flow.

In the crystal set, the long antenna and ground act as a capacitor, and the coil is an inductor. The specific values of capacitance and inductance determine the resonant frequency of the circuit, and moving the clips from one tap to another tap changes the inductance of the coil, and consequently the resonant frequency of the circuit (because connecting to different taps essentially removes part of the coil from the circuit). This allows us to tune the radio.

We are surrounded by many electromagnetic waves of many different frequencies, including many radio waves. When radio waves strike the antenna, they causes alternating currents to flow in the radio circuit, at many different frequencies. If the frequency of a particular wave is different from the resonant frequency of the circuit, the current will flow through straight to ground, and this is what happens to most of the wave energy that enters the antenna. But if the frequency of a wave is close to the circuit's resonant frequency, most of the current will be blocked from flowing to ground, and will flow to the diode instead. Diodes are devices that allow current to flow in only one direction, so they change alternating current to direct current.

Many radio waves are modulated to contain audio information (such as music or voice communications). One way to modulate a radio wave is to vary the strength or amplitude of the wave in a pattern that matches the variations in the audio signal. This is called amplitude modulation (see the Light Modulation activity). When the current from an amplitude modulated radio wave flows through the diode, the diode changes the alternating current to a direct current whose amplitude (strength) varies because of the modulation. When this pulsing direct current flows into the earphone (or amplified speaker), the current is converted to sound energy that replicates the audio information that was originally used to modulate the radio wave before it was transmitted. In the years before diodes were invented, various mineral crystals were used instead, particularly the lead sulfide mineral known as galena.

Light Modulation

This activity introduces students to the concept of wave modulation for communication. The activity may be done as a demonstration or as a student activity, depending upon available time, resources, and student abilities.

This activity demonstrates how light (one type of electromagnetic wave) can be modulated to transmit music or vocal information. Other versions of this activity have been described and are available on the Internet (e.g., *http://www.exploratorium.edu/square_wheels/index.html*; *http://www.profbunsen.com.au/files/lightmodulation.pdf*). The procedure described below uses breadboards (also called prototyping boards) that can be re-used for many other activities involving electronic circuits. These boards are available in a variety of sizes, usually can be snapped together with other boards for larger circuits, and allow circuits to be assembled without soldering, making connections with #22 solid hookup wire. Typically, prototyping boards have many small holes that will hold a #22 solid wire. Some of these holes are joined together by connections built into the board. See Figure 1 on the *Light Modulation Student Guide* for an example.

A note about soldering: If you (or your students) have never soldered before, you may want to visit *http://www.instructables.com/id/How-to-solder/*. Be sure to wear safety glasses or goggles when soldering, and work in a well-ventilated space (you can set up a small fan if necessary to blow away soldering fumes).

Materials

- 5 ft - Insulated solid copper wire, 20- or 22-gauge
- 3 ft - Audio cable with 3.5 mm phone plug on both ends; mono (not stereo)
- 1 - 470-ohm resistor
- 1 - Light emitting diode, white, high brightness (*e.g.*, Radio Shack 276-0017)
- 1 - Solar cell (*e.g.*, Edmund Scientific 3039808; most solar cells will work)
- 1 - 9-volt battery
- 1 - 9-volt battery snap connector
- 1 - Piece of hook-and-loop fastener material, approximately 1-inch square
- 1 - Amplified speaker (*e.g.*, Radio Shack 277-1008, or battery-powered speaker for computer sound or MP3 player) with 3.5 mm input jack
- 1 - Small radio or CD player with 3.5 mm headphone jack (be sure this jack is used ONLY for headphones; if it is used for battery charging or other functions, find another music source!)
- 1 - Breadboard approximately 2 x 3 in (*e.g.,* Radio Shack 276-003 or Mouser Electronics 383-A360)
- *Light Modulation Student Guide*, one copy for each student group (if students will be doing the activity
- Engineering Design Journal (composition book), for each student

Tools

- 1 - Pair needle nose pliers
- 1 - Sharp knife or wire strippers
- 1 - Soldering iron

Note: Mention of commercial names does not imply endorsement by NOAA.

Procedure

a. Instructor Preparation

If students will be doing this activity, make copies of *Light Modulation Student Guide*, one copy for each student group. You may also want to complete steps that involve soldering (Steps 1, 2, and 3) in advance.

b. Pre-activity

If you have not already done so, discuss how radio waves differ from ocean waves. Be sure students recognize that ocean waves require a medium (water) through which they can transfer energy, while radio waves do not require a medium. Radio waves and light waves are two types of electromagnetic waves that are composed of an electric field and a magnetic field that are oscillating (moving back and forth) together. These waves may also be described as the movement of particles called photons, which are massless packets of energy that travel at the speed of light.

Ask students how radio waves are sent from one place to another. Students should identify that a device (technically called a transmitter, but students may suggest other names) is used to send radio waves, and may also identify an antenna as a necessary component of the system. Some students may have had experience with walkie-talkies, which should suggest these answers. Students may also identify satellites as a necessary component of the communications system. For telepresence as it is implemented aboard the *Okeanos Explorer*, satellites are definitely needed. Radio waves were transmitted without satellites for many years before satellites became available, and often are still transmitted this way; but satellite communications are much more reliable, particularly when the transmitting and receiving stations are thousands of miles apart. Satellites used for this kind of communication are sometimes called repeaters, because they receive signals that are transmitted to them, and then re-send these signals to receivers.

Knowing that radio waves transport energy and that those waves can be sent from one place to another, ask students, "How can we use this process to send a message?" Some students may know that in the early days of radio, messages were sent by basically turning the transmitter on and off in a pattern that formed a code, and this code was used to send messages (in fact, this is also how messages were sent on radio's predecessor: the wire telegraph). Some students also may be familiar with Morse code, which is still used to send messages this way. Point out that this process doesn't allow us to send voice, music, or visual messages, and describe modulation as a way to change radio waves when they are sent so that the changes incorporate the desired message. When modulated messages are received, the changes can be used to recreate the original sound.

c. Activity

(1) If students will be performing this activity independently, provide each student group with materials and a copy of the *Student Guide*. If you have not already completed Steps 1, 2, and 3, review soldering procedures.

If you plan to do this activity as a demonstration, complete Steps 4 through 12, explaining each step to students.

(2) Discuss how the modulated light beam can transmit music or vocal information. The battery provides a steady current to the LED, and when the radio is disconnected the LED shines steadily. The resistor limits the current to avoid damaging the LED. When the radio or media player is turned on, the audio signal from the radio is added to the current from the battery. This causes the LED to flicker. Light from the flickering LED causes the solar cell to generate an electrical signal that varies in strength corresponding to the audio signal. The varying electrical signal is amplified and fed to the speaker, which produces a sound that replicates the audio signal from the radio or media player.

(3) Ask students to design a light modulation system that will allow a message to be transmitted over a longer distance. Emphasize that the Engineering Design Process described in the *Student Guide* should be used, and that each step in the process should be documented in each student's Engineering Design Journal. You may also want to introduce students to the common ground rules for brainstorming described in the sidebar at right to assist with this aspect of the Engineering Design Process. Unless additional resources are available, students will not be able to test their ideas, so the entire design cycle cannot be completed for this activity. The proposed design, however, should be based on students' experience with the light modulation activity, as well as additional research.

Common Ground Rules for Brainstorming

- The more ideas, the better! Groups should try to generate as many ideas as possible in a set amount of time.
- There are no bad ideas! No ideas should be criticized during a brainstorming session, so that people can offer ideas without worrying about what others may think. Unworkable or less satisfactory ideas will be weeded out later on.
- Weird is welcome! Unusual ideas are fine, and new ways of looking at a problem can provide better solutions.
- Make it better! Sometimes one good idea stimulates others. Ideas that are combinations or modifications of previous ideas are completely acceptable.

In some brainstorming sessions, participants write their ideas on separate "sticky notes." These can then be posted on a wall or marker board and re-arranged, discussed, combined, and modified to select the most promising approaches for solving the problem.

d. Post-activity

Have each student group present their solution to the design problem, then lead a discussion about their ideas. Potential design solutions include:

- Increasing the intensity of the LED;
- Using a laser instead of the LED;
- Using a lens to focus the LED output on the solar cell;
- Using a larger solar cell; and
- Using fiber optic cable to conduct modulated light to the solar cell.

This list is not all-inclusive, and other approaches are acceptable, as long as students can explain why their chosen approach is the best of several possible solutions that they considered. During this discussion, reinforce the following concepts:

- For many design problems, the Engineering Design Process may include more steps than students used for this activity. In particular, many problems require designers to select materials from which technological solutions will be created. This selection requires considering the physical properties of potential materials, their cost, and whether there are other consequences associated with using certain materials such as toxicity or ease of recycling.

- Systems are a combination of components (including machines, processes, and/or people) that are designed to work together to accomplish certain tasks. Ask students to identify components in the light modulation system used for this activity. Students should identify the sound source, battery, LED, solar cell, and amplified speaker; but may also recognize that the sound source and amplified speaker are also systems that include many different components.

- Constraints are requirements that must be met by satisfactory design solutions. Most problems include constraints that are not necessarily specified in the problem statement, such as environmental conditions (*e.g.*, conditions in the deep ocean), cost, and size.

- Trade-offs are often necessary in design solutions to meet the requirements imposed by constraints.

- Optimization is identifying a solution that meets all of the constraints with the best combination of trade-offs.

- Models are used to help visualize possible solutions, and may be two-dimensional, three-dimensional, or mathematical.

- Analysis is a systematic examination of information needed to proceed through each step of the Engineering Design Process.

Resources

Anonymous. Light Modulation [Internet]. Prof. Bunsen Science [cited January 10, 2011]. Available from: *http://www.profbunsen.com.au/files/lightmodulation.pdf*

Rathjen, D. and P. Doherty. Modulated LED [Internet]. Exploratorium [cited January 10, 2011]. Available from: *www.exploratorium.edu/square_wheels/modulated_led.pdf* – Part of the "Square Wheels ...and Other Easy-To-Build, Hands-On Science Activities" collection (*http://www.exploratorium.edu/square_wheels/index.html*)

Light Modulation Student Guide

Figure 1. Prototyping Board

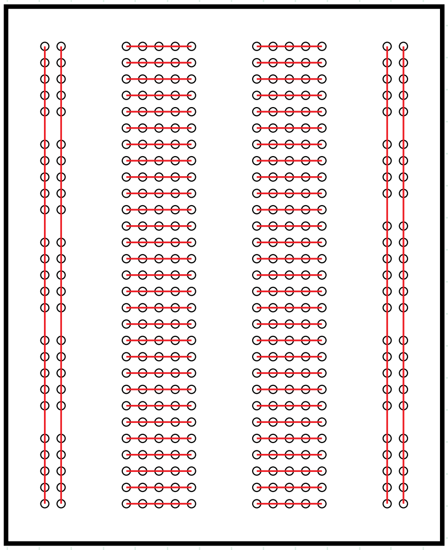
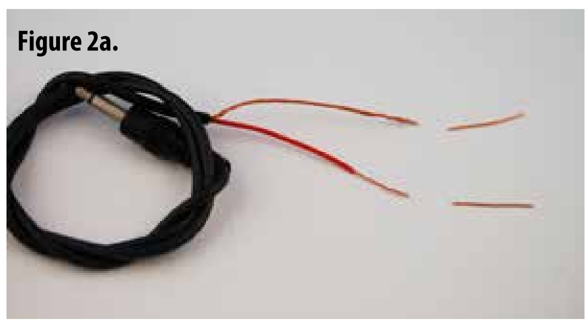


Figure 1. Layout of a typical prototyping board. The red lines show holes that are electrically joined by connections inside the board. On this board, there are two vertically-oriented sets of 25 connected holes on the left and right sides of the board. These holes are often used for connections to a battery, to make it easy to supply power to any spot on the board. In the middle part of the board, there are 58 horizontally-oriented sets of 5 connected holes; 29 on the right side of center, and 29 on the left side of center. These middle sets of holes are used to connect the components of various circuits. Since there are 58 separate sets of holes, this board can hold a lot of components!

Figure 2. Audio cable ends prepared for connecting to prototype board. Note that this was a stereo cable; the red wire connects to the tip of the plug, the black and uninsulated wires are twisted together. a. Insulation removed from ends of insulated wires; short lengths of bare #22 wire ready to attach; b. Bare ends of wires in audio cable twisted around short lengths of #22 wire; c. Twisted wires soldered.

1. Cut the audio cable in half, and remove about 2-inches of the outer plastic jacket from each of the cut ends. Be careful not to cut into the insulation of the wire inside the cable. If you have a mono cable, you should find one insulated wire and one uninsulated wire inside the cable. If there are two insulated wires instead of one, then you have a stereo cable (see the next paragraph). Remove about 1/2-inch of the insulation from the end of the wire inside the cable. Twist the strands of the insulated wire together, and then twist them around a short length (about 3/4-inch) of bare #22 wire, and solder the connection (the short length of solid wire makes it easier to connect the wire to the prototyping board.) Twist the strands of the uninsulated wire together, and solder another short length of bare #22 wire onto this wire as well (Figure 2). Prepare both halves of the audio cable this way.

   Note: If you have a stereo cable instead of a mono cable, you will have two insulated wires instead of one. If your radio or media player uses stereo earphones, remove about 1/2-inch of the insulation from both wires, twist them together, and solder a short length of bare #22 wire onto the two wires. If your radio or media player does not use stereo earphones, you will need to identify which of the insulated wires in the stereo cable goes to the very tip of the plug on the other end of the cable (usually it will be the red or white wire; you can use the "ohms" setting on a multimeter or a continuity tester to check). Remove about 1/2-inch of the insulation from the OTHER wire, and twist it together with the uninsulated wire, then solder a short length of bare #22 wire onto the two wires.



2. Remove about 1/2-inch of the insulation from the ends of the two wires attached to the battery snap connector. Twist one of these wires around a short length (about 3/4-inch) of bare #22 wire, and solder the connection. Repeat with the other wire attached to the snap connector (Figure 3).

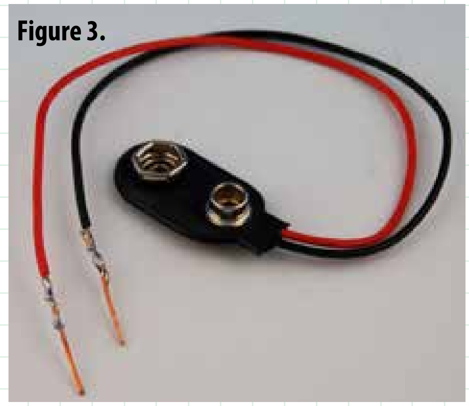


Figure 3.

3. Examine your breadboard, and determine which holes are connected together (if the package containing your prototyping board does not have this information, you can use the "ohms" setting on a multimeter or a continuity tester to find out which holes are connected). Plug the wires from the solar cell into two sets of holes that are NOT connected near one end of the breadboard. Use one of the other holes in each set to connect the wires from one of the audio cables (Figure 4).

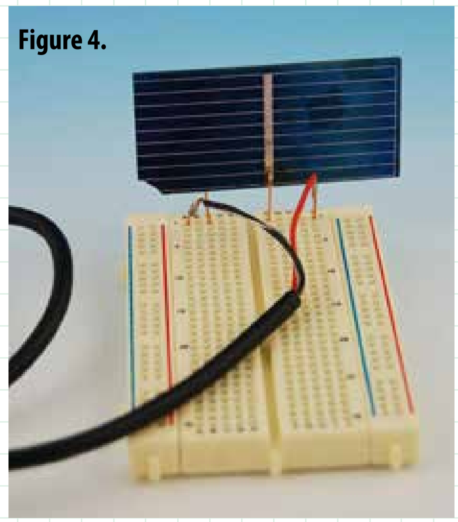


Figure 4.

4. Connect the plug on the audio cable used in Step 3 to the input jack of the amplified speaker, and turn the speaker on. If you shine a light onto the solar cell, you should hear static in the speaker (Figure 5).


Figure 5.

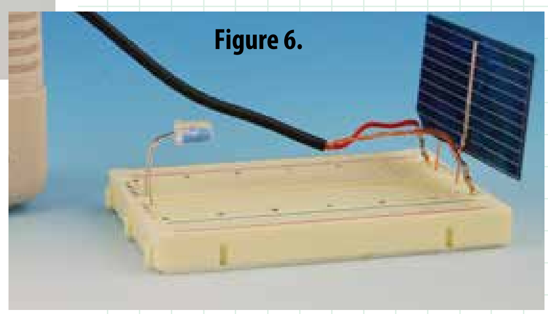


Figure 6.

5. Examine the LED, and notice that one side is flattened. This is the cathode (negative side) of the LED. Plug the cathode into one set of holes near the end of the breadboard opposite to the end where the solar cell is connected. Plug the anode (positive side) of the LED into another set of holes that is NOT connected to the first set (Figure 6). Bend the wires from the LED at right angles so that the top of the LED will point to the opposite end of the breadboard.

6. Plug one end of the 470-ohm resistor (it doesn't matter which end) into one of the other holes in the set to which the anode of the LED is connected. Plug the other end of the resistor into a third set of holes that is NOT connected to either of the sets already used (Figure 7).

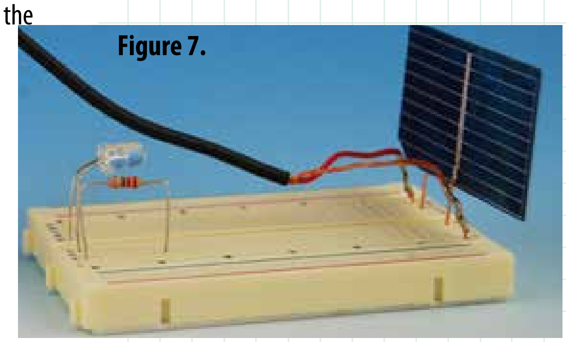
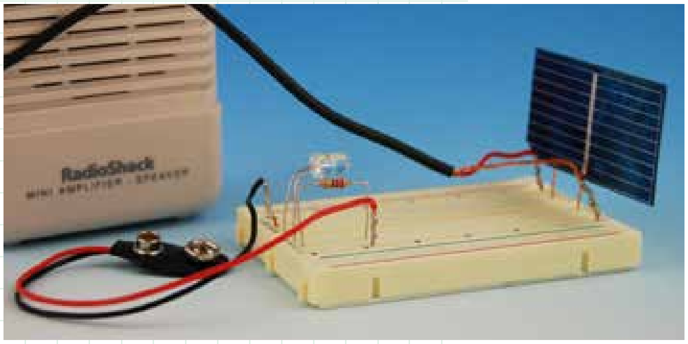


Figure 7.

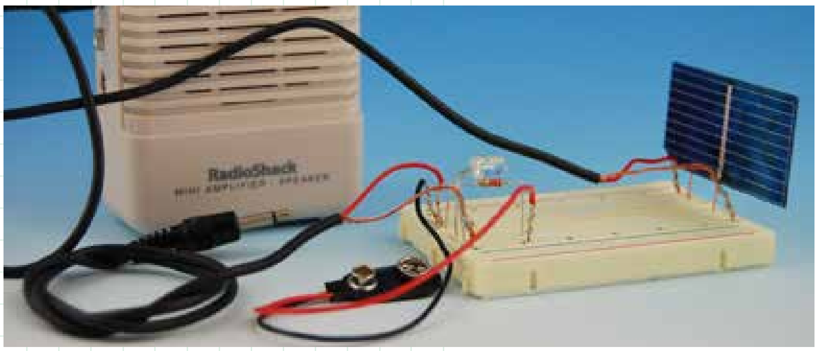
Figure 8.



7. Connect the negative (black) wire attached to the battery snap connector to one of the other holes in the set to which the cathode of the LED is connected. Connect the positive (red) wire from the snap connector to one of the other holes in the set to which the end of the resistor is connected (connect the battery to the end of the resistor that is NOT connected to the LED) (Figure 8).

8. Attach the battery to the battery snap connector. The LED should turn on and glow steadily. Disconnect the battery from the snap connector.

Figure 9.



9. Connect one of the wires (it doesn't matter which one) from the remaining audio cable to one of the other holes in the set to which the anode of the LED is connected. Connect the other wire from the same audio cable to one of the other holes in the set to which the cathode of the LED is connected (Figure 9).

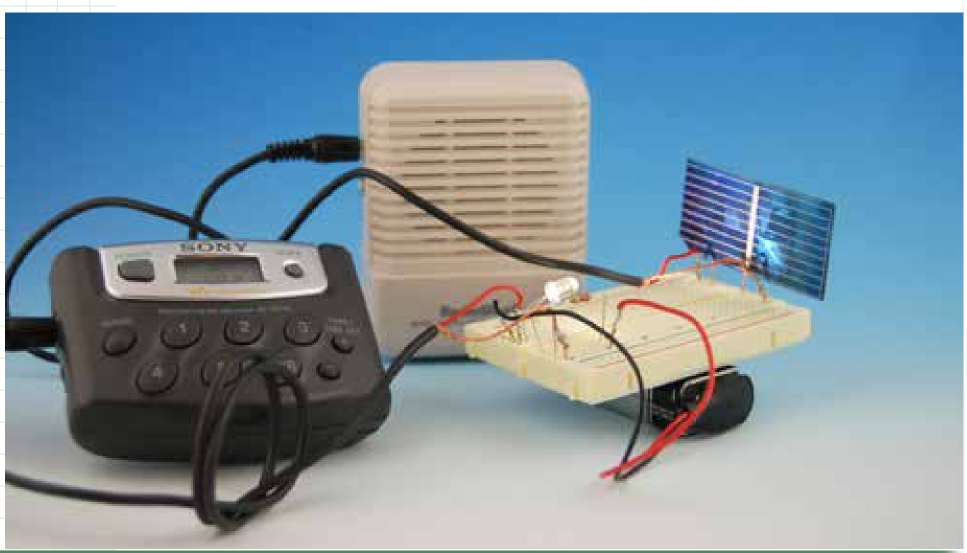
10. Turn on the radio or media player, and check to be sure a strong sound is coming from the speaker. If the radio or media player does not have a built-in speaker, use a pair of headphones to be sure a strong sound is being produced.

11. Connect the plug on the end of the audio cable used in Step 9 to the headphone jack on the radio or media player. This will disconnect the speaker (if there is one), so you won't hear anything.

12. Attach the battery to the battery snap connector. The LED should turn on, and you may see it flickering. Attach the battery to the bottom of the breadboard with a piece of hook and loop fastener.

13. Place the LED so that it shines on the solar cell, and turn on the amplified speaker (Figure 10). You should hear sound from the radio or media player coming from the amplified speaker. If you place an opaque object between the LED and the solar cell, the sound should stop.

Figure 10.



14. **Engineering Design Challenge:** Design a light modulation system that will allow a message to be transmitted over a longer distance. Use the Engineering Design Process described in Box 1, and document each step of the process in your Engineering Design Journal. If you don't have resources to test your ideas, you won't be able to complete the entire design cycle shown in Box 1, but you should be able to justify your proposed design based on your experience with the light modulation activity and additional research.

Box 1: Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:

- Define the problem
- Gather relevant information
- Brainstorm possible solutions
- Analyze possible solutions and select the most promising
- Test the solution by building a prototype
- Revise and improve the solution
- Repeat previous steps until results are acceptable
- Report the design process and results

These steps involve several key skills:

- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

Student Worksheet:
Review of Basic Concepts
About Electricity and Electromagnetic Waves

You should understand the meaning of the following:

Compression wave
Transverse wave
Electromagnetic wave
Electric current
Conductor
Insulator
Frequency
Wavelength
Wave trough
Wave crest
Hertz

1. When we see a wave, something appears to be moving. What is moving?

2. What are the trough and crest of a wave?

3. What is meant by "frequency of a wave"?

4. Frequency is measured in units called hertz. What does hertz mean?

5. What is meant by "wavelength of a wave"?

6. What is the relationship between frequency and wavelength?

7. What is an electric current?

8. What happens when an electric current flows through a conductor?

9. What is the difference between a sound wave and an electromagnetic wave?

Review of Basic Concepts about Electricity and Electromagnetic Waves Answer Sheet

1. Waves are energy transport phenomena. When a wave appears to move, we are seeing a disturbance moving through a solid, liquid, or gaseous medium. The only thing that is actually transported from one place to another is the energy of the wave.

   Electromagnetic waves are formed when an electric field is coupled with a magnetic field. The magnetic and electric fields of an electromagnetic wave are perpendicular to each other and to the direction of the wave.

2. Crest and trough are terms that identify the extremes of displacement experienced by a particle moving in a wave. The crest is maximum upward or positive displacement of a particle compared to its resting position. The trough is the maximum downward or negative displacement of a particle compared to its resting position.

3. The frequency of a wave is the number of crests that pass a given point in a certain amount of time, usually one second.

4. One hertz is a frequency of one complete cycle per second. In other words, one crest of a wave passes a given point in one second. Electromagnetic waves usually have much higher frequencies, so units of kilohertz (kHz; 1 x 103), megahertz (MHz; 1 x 106), or gigahertz (GHz; 1 x 109) are commonly used.

5. The wavelength of a wave is the distance over which a wave's shape repeats. That is, the distance between two adjacent crests.

6. Frequency and wavelength of electromagnetic waves are related by the formula:

   $$W = C \div F$$

   where W is wavelength in meters, C is the velocity of the wave, and F is frequency in hertz (cycles per second). The velocity of electromagnetic waves is the velocity of light, which is 300,000,000 meters per second.

7. An electric current is the movement of electrons through a conductor. A conductor is a substance through which electrons may move. An insulator is a substance through which electrons cannot move.

8. An electric current flowing through a conductor produces a magnetic field. The direction of the magnetic field is perpendicular to the direction of the electric current.

9. A sound wave is an example of a compression or mechanical wave, while an electromagnetic wave is an example of a transverse wave. A compression wave requires a medium through which energy can be transferred. An electromagnetic wave does not require a medium, because its energy is transferred as electric and magnetic fields. These fields are perpendicular to each other. This is called a transverse wave because the electric and magnetic fields are also perpendicular to the direction in which the wave moves. Electromagnetic waves can also be thought of as the motion of massless packets of energy called photons which move at the speed of light.

   If students require additional explanation of these topics, you may wish to refer them to Unit 2 of the American Radio Relay League *Radio Lab Handbook* (see Other Resources).

Wave Propagation Research Guide

Learning Procedure

1. Ask students how often they use radio communication technology. Some students may consider radio to be an old-fashioned or even outdated technology, but the basic principles of radio communication are the foundation of modern wireless communication that includes cell phones, satellite television, wireless Internet, satellite television, global positioning systems, keyless locks and entry systems, and remote controls for televisions, media players, and other appliances.

2. Tell students that their assignment is to find out how electromagnetic waves are used in wireless communication systems, and then to explore some of the "building blocks" that make this technology work. Provide each student or student group with a copy of the Wave Propagation Student Research Guide. Answers to questions on the Guide can be found in many books and Web sites, but you may also wish to refer students to Unit 2 of the American Radio Relay League *Radio Lab Handbook* (see Other Resources, page 33).

3. When students have answered questions on the worksheet, lead a discussion of their results using the answer sheet on page 23.

Wave Propagation Student Research Guide

Electromagnetic waves are fields of energy that travel at the speed of light and can move over very long distances. These waves can also be thought of as movements of massless packets of energy called photons. In the mid- to late-1800's scientists discovered ways to use electromagnetic waves to send messages over long distances, and these discoveries were the foundation of radio, television, and modern wireless technologies; including the telepresence technology aboard the *Okeanos Explorer*.

These technologies make use of a group of electromagnetic waves called radio waves whose frequencies range from around 30 kHz to over 300 GHz (frequencies below 30 kHz are also used for avalanche beacons and communications in mines and submarines). This very large frequency range is often divided into:

Low Frequencies (LF): 30 - 300 kHz
Medium Frequencies (MF): 300 - 3000 kHz
High Frequencies (HF): 3 - 30 MHz
Very High Frequencies (VHF): 30 - 300 MHz
Ultra High Frequencies (UHF): 300 - 3000 MHz
Microwaves: 3 - 300 GHz

Wireless communication is based on various types of wave propagation, which refers to the four ways that radio waves travel from one place to another. Describe each of the following types of wave propagation, and which frequencies are used for communications with each propagation type:

1. Line-of-Sight Propagation
2. Ground Wave Propagation
3. Sky Wave Propagation
4. Tropospheric Ducting
5. Which of these types of propagation do you think is used for satellite communications and telepresence aboard the *Okeanos Explorer*?

Wave Propagation Research Guide
Answer Sheet

1. **Line-of-Sight Propagation** occurs when radio waves travel in a straight line from a transmitting antenna to a receiving antenna. Obstructions such as buildings and landforms can interfere with these signals, and the Earth's curvature limits the distance over which line-of-sight propagation can be used for communications. This type of propagation is most often used for Very High Frequencies (VHF): 30 to 300 MHz, Ultra High Frequencies (UHF): 300 to 3,000 MHz, and microwave frequencies: 3 to 300 GHz.

2. **Ground Wave Propagation** involves radio waves travelling along Earth's surface. These waves may follow Earth's curvature up to about 100 miles. This type of propagation works best at Low Frequencies (LF): 30 to 300 kHz, Medium Frequencies (MF): 300 to 3,000 kHz, and High Frequencies (HF): 3 to 30 MHz.

3. **Sky Wave Propagation** takes place in the ionosphere, a layer in Earth's atmosphere that contains particles with an electric charge called ions. The ionosphere is 35 to 300 miles above Earth's surface. Under some conditions, radio waves can be reflected from the ionosphere, so a signal from a transmitting antenna is bounced off of the ionosphere to a receiving antenna that may be far away. The distance between the two antennas may be as much as 2,500 miles with a single bounce. Sometimes, several bounces are possible, which can make it possible for signals to travel around the world. Sky wave propagation (also called skip) can affect communications at frequencies from LF to VHF, but the effect is less on higher frequency waves, so communications over the longest distance tend to involve lower frequencies.

4. **Tropospheric Ducting** happens when a warm air mass forms on top of a cooler air mass in the troposphere, which is another atmospheric layer seven to ten miles above Earth's surface. This is called a temperature inversion, since upper layers of the atmosphere are normally cooler than lower layers. Radio waves may be bounced back and forth between the two air masses so that the temperature inversion acts like a duct, and radio waves may travel long distances through the duct before they are reflected back to Earth's surface. This usually involves VHF or UHF frequencies. The troposphere may also reflect radio waves, and cause a skip similar to sky wave propagation; but since the troposphere is much lower than the ionosphere, the distance gained is usually much shorter.

5. **Line-of-sight propagation** is used for satellite communications and telepresence aboard the *Okeanos Explorer*. Communication frequencies are in the microwave region (3.7 – 6.5 GHz), which minimizes interference as the radio waves pass through the troposphere and ionosphere.

Ohm's Law Theory Review

Learning Procedure

1. Provide each student or student group with a copy of *Ohm's Law Theory Review Student Worksheet*.

2. When students have answered questions on the worksheet, lead a discussion of their results using the answer sheet provided on page 25.

Ohm's Law Theory Review
Student Worksheet

1. An electric current is the movement of electrons through a conductor. The word "current" also refers to a property of an electric current that can be measured with an ammeter. What does this measurement mean? What are the units of current as measured by an ammeter?

2. What is the voltage of an electric current? What are the units of voltage?

3. What is resistance in an electric circuit? What are the units of resistance?

4. How can you use voltage and current to calculate power? What are the units of power?

5. What does Ohm's Law say about the relationship between current, voltage, and resistance?

6. If 100 volts flows through a circuit having a resistance of 10 ohms, how much current flows through this circuit?

7. If a 60-watt light bulb is connected to a 12-volt battery, how much current flows through the light bulb?

Ohm's Law Theory Review Answer Sheet

1. The word "current" refers to the quantity of electricity in an electric current, and is measured in amperes (or amps for short). It may be helpful to use water as an analogy: the term "current" is analogous to the quantity of water, measured in liters or gallons, that flows through a pipe.

2. Voltage refers to the force with which an electric current moves, and is measured in volts. Continuing the water analogy, voltage is analogous to the pressure of water flowing through a pipe.

3. Resistance is a measure of the opposition to the flow of electricity in an electric circuit, and is measured in ohms. In the water analogy, a valve or obstruction in the pipe would create resistance to the flow of water.

4. Electric power is defined as the product of voltage and current, and is measured in watts (1 volt x 1 amp = 1 watt)

5. Ohm's Law states that the current flowing through an electric circuit is equal to the voltage divided by the resistance. This is usually written:

   $$I = E \div R$$

   where I is current, E is voltage, and R is resistance. Equivalent forms are:

   $$E = I \cdot R$$

   and

   $$R = E \div I$$

6. If 100 volts flows through a circuit having a resistance of 10 ohms, 10 amps of current flow through this circuit:

   $I = E \div R$, so $I = 100$ volts $\div$ 10 ohms $= 10$ amps

7. If a 60 watt light bulb is connected to a 12 volt battery, 5 amps of current flow through the light bulb:

   Power = Volts • Amps, so
   Amps = Power ÷ Volts = 60 watts ÷ 12 volts = 5 amps

If students require additional explanation, you may wish to refer them to Section 3.2 of the Radio Lab Handbook (see Wireless Communication Resources).

Figure 1. Prototyping Board

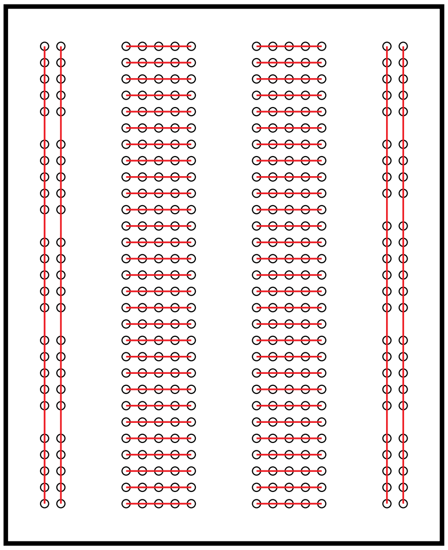
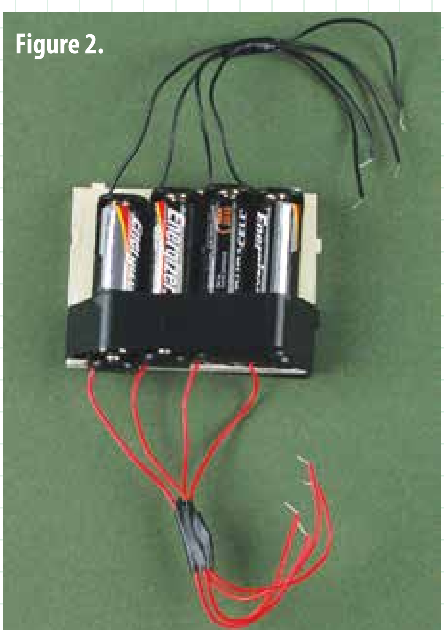


Figure 1. Layout of a typical prototyping board. The red lines show holes that are electrically joined by connections inside the board. On this board, there are two vertically-oriented sets of 25 connected holes on the left and right sides of the board. These holes are often used for connections to a battery, to make it easy to supply power to any spot on the board. In the middle part of the board, there are 58 horizontally-oriented sets of 5 connected holes; 29 on the right side of center, and 29 on the left side of center. These middle sets of holes are used to connect the components of various circuits. Since there are 58 separate sets of holes, this board can hold a lot of components!

Figure 2.



Experimental Verification of Ohm's Law

The purpose of this activity is to measure the relationship between voltage and current in several electric circuits.

This activity uses a prototyping board (also called a "breadboard") which simplifies the process of connecting components to make electric circuits. Prototyping boards are available in a variety of sizes, and usually can be snapped together with other boards for larger circuits. Connections are made with #22 solid hookup wire, so circuits can be assembled without soldering (although some soldering may be necessary to prepare components prior to assembly). Typically, prototyping boards have many small holes that will hold a #22 solid wire. Some of these holes are joined together by connections built into the board. See Figure 1 for an example.

Materials

1 - Prototyping board ("breadboard") approximately 2 x 3 inch (*e.g.*, Radio Shack 276-003 or Mouser Electronics 383-A360)
2 - Alligator clips (*e.g.*, Radio Shack 270-380)
5 ft - Insulated solid copper wire, 22-gauge
4 - Single battery holders, size AA (*e.g.*, Mouser Electronics 12BH311A-GR)
4 - Batteries, size AA
2 ft - Vinyl electrical tape
1 - 6-volt flashlight bulb (one with threads is easier to work with, but the threadless style will also work)
1 - 47-ohm resistor
1 - 100-ohm resistor
1- multimeter capable of measuring volts, milliamps, and ohms (*e.g.*, Extech MN16A; Maker Shed model MKSF6 is an inexpensive kit)
1 ft - Rosin-core solder

Tools

Soldering iron (25 - 40 watts)
Wire cutters
Needle-nose pliers
Phillips screwdriver
Wire strippers or sharp knife
Note: Mention of commercial names does not imply endorsement by NOAA.

Procedure

1. Examine your prototyping boards, and determine which holes are connected together. Wire the four battery holders in series using the prototyping board. An easy way to keep things neat and together is to put the batteries in the battery holders, then fasten the battery holders to the back of the prototyping board using vinyl electrical tape (Figure 2; be sure not to cover too many holes on the front of the prototyping board!). Figure 3 shows one way to make the connections on the prototyping board, but other layouts are fine too.

2. Cut two 2-inch lengths of insulated solid copper wire, and remove about 1/2-inch of the insulation from each end. Attach an alligator clip to one end of each wire (Figure 4).

Figure 3.

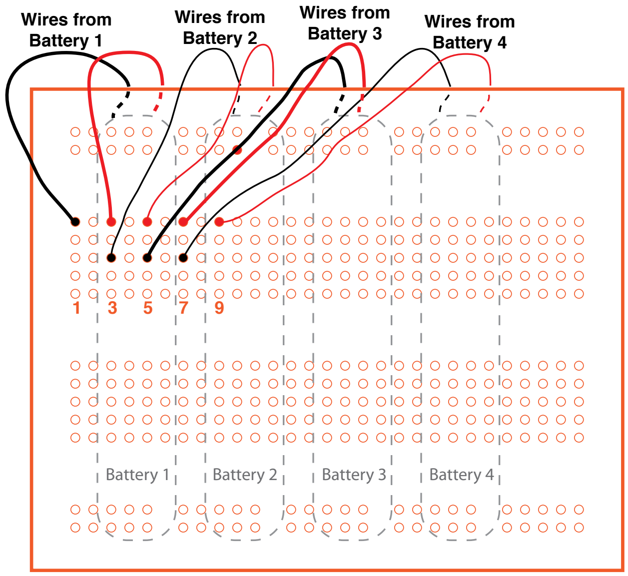
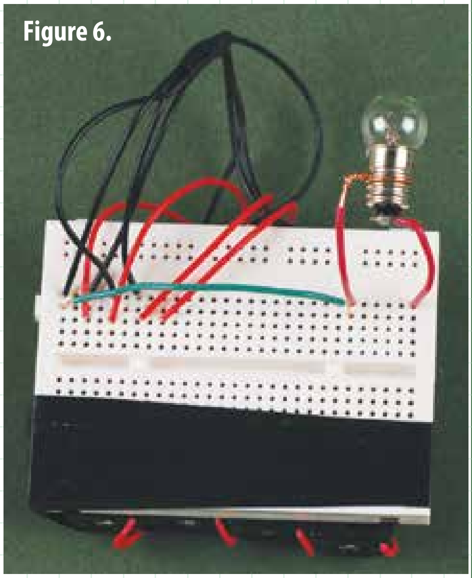


Figure 4.

Figure 5.

Figure 6.



3. Cut two 3-inch lengths of insulated solid copper wire, and remove about 1/2-inch of the insulation from each end. These wires will be used as jumpers to make circuits by connecting sets of holes on the prototyping board.

4. Cut two 3-inch lengths of insulated solid copper wire, and remove about 1/2-inch of the insulation from one end of each wire. Remove about 1.5-inches of the insulation from the other end of one wire, and wrap this tightly around the threaded portion of the flashlight bulb. Remove about 1/4-inch of the insulation from the end of the remaining wire, and solder this to the tip of the flashlight bulb's base (Figure 5). This is much easier if you have a helper hold the bulb using the wire wrapped around the base as a handle while you solder.

5. Plug the wires from the bulb into two sets of holes on the prototyping board that are NOT connected (Figure 6).

6. Use one of the jumpers prepared in Step 3 to connect the negative lead from Battery #1 to one of the leads from the flashlight bulb (it doesn't matter which one). Plug one of the alligator clips into one of the unoccupied holes in the set to which the other lead of the bulb is connected (Figure 7). This will be called "Clip A."

Figure 7.

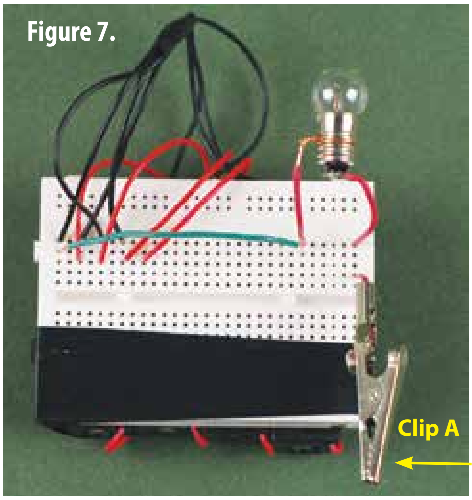


Figure 8.

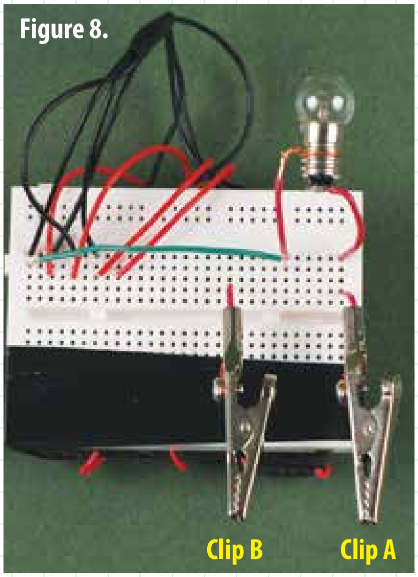


Figure 9.

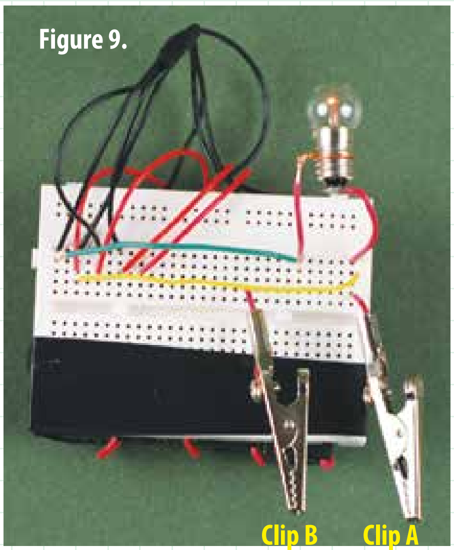
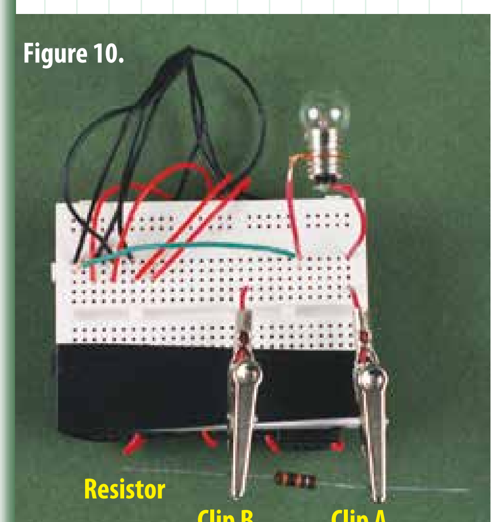


Figure 10.



7. Plug the other alligator clip into an unoccupied set of holes approximately 1-inch away from Clip A (Figure 8). This second alligator clip will be called "Clip B."

8. Now you can begin your investigation. First, measure the voltage and current in the circuit when the battery voltage supplied to the circuit is 1.5 volts, 3 volts, 4.5 volts, and 6 volts. Start by connecting a jumper (Step 3) from Clip A to the positive lead from Battery #1 (Figure 9). The bulb should light dimly.

9. Set the multimeter to measure volts, and if your meter has manual range settings, select a range around 10 or 20 volts. You want a range that is above the maximum voltage in the circuit (6 volts), but is close enough to this voltage to get accurate readings as the voltage changes.

   BE SURE THE MULTIMETER IS SET ON THE PROPER MEASUREMENT AND RANGE BEFORE TOUCHING THE PROBES TO THE CIRCUIT!

   Measure the voltage in the circuit by then touching the negative test probe from the multimeter to the base of the flashlight bulb, and the positive test probe to Clip A. Record this measurement.

10. Now measure the current in the circuit by setting the multimeter to amps, and selecting a range (if your meter has manual range settings) around 1 amp. To measure current, the meter must be in series with the circuit (in contrast to voltage measurements, in which the meter is connected in parallel with the circuit). An easy way to do this is to disconnect the jumper from Clip A (the other end of the jumper should still be connected to the positive lead from Battery #1), then connect the negative test probe from the multimeter to Clip A, and touch the positive test probe to the end of the jumper you just disconnected. Record this measurement next to the voltage measurement made in Step 9.

11. Connect the jumper from Clip A to the positive lead from Battery #2, and repeat Steps 9 and 10. Repeat this procedure twice more, with the jumper connected to the positive lead from Battery #3, and then with the jumper connected to the positive lead from Battery #4. You should now have four pairs of voltage and current measurements. Plot these points on a graph, with current on the x-axis and voltage on the y-axis. Since no current would flow if there were no voltage in the circuit, you may assume that zero voltage, zero current may be plotted as a fifth point on your graph. Connect these points with a straight line that is as close as possible to all of the points.

12. Now let's add some resistors to the circuit and see how that affects the voltage: current relationship. Put a 100-ohm resistor between Clip A and Clip B (Figure 10). The colored bands on many resistors show what the resistance is. One of the bands (usually silver or gold) indicates what the tolerance is. If you hold the resistor so that this band is on the right, the remaining bands show the resistance; the bands for a 100-ohm resistor are brown-black-brown.

13. Connect a jumper from one of the unoccupied holes in the set to which Clip B is connected to the positive lead from Battery #1 (Figure 11). Measure the voltage as described in Step 9. Then measure the current: disconnect the jumper from Clip B (the other end of the jumper should still be connected to the positive lead from Battery #1), touch the negative test probe from the multimeter to Clip B, and touch the positive test probe to the end of the jumper you just disconnected. Record the voltage and current measurements.

14. Repeat Step 13 three more times, with the jumper connected to the positive lead from Battery #2, then with the jumper connected to the positive lead from Battery #3, and finally with the jumper connected to the positive lead from Battery #4. You should now have four pairs of voltage and current measurements for the circuit that includes a 100-ohm resistor. Add these points to the graph from Step 11, and connect them with another straight line.

15. Repeat Steps 12 through 14, using a 47-ohm resistor (the color bands for a 47-ohm resistor are yellow-violet-black).

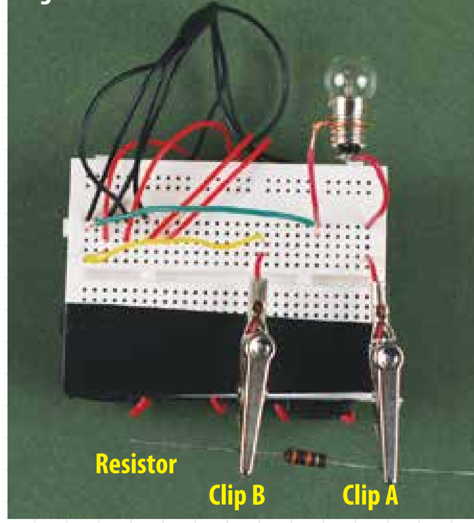
16. According to Ohm's Law, what is the formula for resistance if voltage and current are known?

17. Calculate the slopes of the three lines on your graph. What is the relationship between these slopes and the formula described in Step 16?

18. How do the experimentally-derived values for resistance in the circuits you investigated compare with the stated values of the resistors you used?

19. What did you observe about the flashlight bulb when the resistors were in the circuit? Do your measurements help explain this observation?

Figure 11.



Experimental Verification of Ohm's Law
Answer Sheet

Discussion should include:

16. According to Ohm's Law, resistance in a circuit is equal to voltage divided by current.

17. The slope of plots of voltage (y-axis) vs current (x-axis) are equivalent to the Ohm's Law formula for resistance, so these slopes should equal the resistance in their respective circuits.

18. Experimentally-derived values for resistance in the second and third groups of circuits should approximate the stated values of the resistors used. Factors that might account for variability include:
    – Variation between actual resistance and stated values of resistors;
    – Additional resistance in circuit components that was not accounted for in students' calculations;
    – Measurement errors due to inaccuracies in multimeters; and
    – Errors in reading measurements on multimeters.

    In the first circuit, resistance was not zero, since a current was present as evidenced by the flashlight bulb, as well as measurements with the multimeter. This resistance should have been quite low, however (less than 10 ohms) compared to the resistance in the other two circuits.

19. The flashlight bulb probably did not light when resistors were added to the circuits. Current measurements should show that current flow was much less (on the order of one-tenth) when resistors were present, and it is reasonable for students to infer that this amount of current was insufficient to cause the filament in the bulb to glow.

Components of Radio Communication

Learning Procedure:

1. Tell students that most radio communication systems use certain "building block" circuits that are almost always present, regardless of the frequencies used for communication. Assign one of the following components to each student group, and say that their assignment is to provide a brief description of what the component does, and how this function contributes to a radio communication system:

   Rectifier
   Oscillator
   Mixer
   Filter
   Amplifier
   Modulator/Demodulator
   Antenna

   This information can be found in many books and Web sites, but you may also wish to refer students to Unit 9 of the American Radio Relay League Education and Technology Curriculum Guide, (see Other Resources, page 33).

2. When students have completed their research, lead a discussion of their results. The following points should be included:
   - **Rectifiers** convert alternating current (AC) to direct current (DC). The incoming power to most communications systems is AC, because it is easier to distribute this type of electricity over long distances; but many radio communication circuits require DC.

   - Students should understand that when something oscillates, it moves back and forth. In radio circuits, oscillators generate alternating currents of various frequencies that can range from very low frequencies beneath the detection level of human hearing to very high frequencies in the microwave range. **Oscillators** are the circuit that produce the radio frequency wave that eventually carries information from the transmitter to a receiver. Some oscillators produce signals at only one frequency, while others are capable of generating signals over a range of frequencies. A variable frequency oscillator (VFO) allows a radio operator to tune a receiver to select certain frequencies, and also to select a transmitting frequency that is not already being used by another operator.

   - **Mixers** essentially do what the name implies: they mix two or more signals. In receivers, mixers are used to combine a signal from the antenna with a signal from a VFO, and this allows the operator to select specific frequencies for reception. Mixers add and subtract the input frequencies, so the output of a mixer is the sum and the difference of the input frequencies.

   - **Filters** are used to remove unwanted frequencies from a signal as it is being processed in a transmitter or receiver. Receiving antennas often are bombarded with signals from many different transmitters as well as from other devices that produce electromagnetic waves (such as electric motors and automobile engines). Filters are used at many points in receiving as well as transmitting circuits to eliminate this type of interference. High-pass filters allow signals above a certain frequency to pass through the filter; low-pass filters allow signals below a certain frequency to pass; and band-pass filters allow signals between two frequencies to pass.

- Many students will be familiar with **amplifiers** as they are used in music entertainment systems. In general, electromagnetic waves lose energy at a rate that is roughly inversely proportional to the square of the distance travelled. This means that even powerful signals from commercial broadcast stations are often reduced to thousandths or even millionths of a volt by the time they reach a receiving antenna. Amplifiers are used in transmitters to increase the strength of signals before they are sent to the antenna; and in receivers to increase the strength of received signals so they can be processed by other circuits, as well as to increase the volume so the processed signals can be heard by humans. The amount that a signal is strengthened by an amplifier is called the amplifier's gain.

- **Modulators** are used to change radio frequency waves so that they contain information that is to be communicated. Some students may know that in the early days of radio, messages were sent by basically turning the transmitter on and off in a pattern that formed a code, and this code was used to send messages. Today, radio waves are changed by modulators so that the changes incorporate the desired message. When these waves are detected by a receiver, a demodulator in the receiver "reads" the changes and reproduces the message.

- **Antennas** are often the most conspicuous component of a wireless communication system, and compared to other components, may be the simplest. The physical size of an antenna is critical, though; the dimensions of efficient antennas (those that absorb very little of a signal's energy) are determined by the frequency of the signals they are expected to transmit or receive. The orientation of antennas is also important, and in line-of-sight propagation if the transmitting antenna is oriented horizontally, the receiving antenna must have the same orientation; otherwise, the strength of the received signal will be greatly reduced. The simplest antenna consists of a length of wire that is about one-half the wavelength of the signal being transmitted. More complex antennas are used to detect low-energy signals (for example, from satellites) and may use parabolic reflectors or other types of construction to capture and concentrate received signals onto a specific part of the antenna. The VSAT (Very Small Aperture Terminal) antenna on the *Okeanos Explorer* is an example that uses a large parabolic reflector (more than 13 m in diameter!).

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Other Resources

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