



Section 2: Telepresence for Volume 2: How Do We Explore?



NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration.
Image credit: NOAA. For more information, see the following
Web site:
<http://oceanexplorer.noaa.gov/okeanos/welcome.html>



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.

Wow, That Hertz!

Focus

Wireless communications physics

Grade Level

9-12 (Physical Science/Physics)

Focus Question

How does wireless communications technology contribute to human communication, and how is this technology used aboard the NOAA Ship *Okeanos Explorer* to investigate unknown areas in Earth's ocean?

Learning Objectives

- Students will explain the concept of energy transfer through wave propagation, and how this process is used to support telepresence and scientific communications aboard the *Okeanos Explorer*.
- Students will define an electric current, and describe the relationship between current, voltage and resistance using Ohm's Law.
- Students will identify and describe the function of five basic electronic building blocks that make radios work.

Materials

- Copies of *Review of Basic Concepts About Electricity and Electromagnetic Waves*, *Wave Propagation Research Guide*, and *Ohm's Law* Worksheets and (optionally) *Hands-On Activity Guide Wireless Communications: Listen to Satellites*; one for each student or student group
- Materials required for one *Ohm's Law Verification Activity* (see Learning Procedure, Step 1g and Step 5):
 - 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 that may be shared by several groups:
 - Soldering iron (25 - 40 watts)
 - Wire cutters
 - Needle-nose pliers
 - Phillips screwdriver
 - Wire strippers or sharp knife

(Optional) Materials for *Hands-On Activity: Listening to Satellites*

- UHF FM radio, such as a police scanner (e.g., Uniden BC72XLT) or an amateur radio UHF transceiver
- 1 - Square wood dowel, 1 x 1 x 30 inches
- 3 - Brass rods, 1/8-inch diameter x 30 inches
- 3 ft Coaxial cable, RG-58 with appropriate connector for radio antenna jack
- 2 - Nylon cable ties, approximately 6 inches long
- Tools:
 - Hacksaw
 - Metal file
 - Glue gun with glue
 - Ruler
 - Marker
 - Vise
 - Drill or drill press with 1/8-inch drill bit
 - Round dowel, approximately 3/4-inch diameter

Audio Visual Materials

Optional – Images of exploration technologies (see Learning Procedure, Step 1c)

Teaching Time

Two to four 45-minute class periods, depending upon the availability of resources and activities assigned for out-of-class completion (see Learning Procedure, Step 1g)

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Telepresence
Satellite communication
Wireless communication
Ohm's Law
Propagation

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.



NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration.
Image credit: NOAA. For more information, see the following Web site:
<http://oceanexplorer.noaa.gov/okeanos/welcome.html>

Okeanos Explorer Vital Statistics:

Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit <http://oceanexplorer.noaa.gov/okeanos/welcome.html>.
Follow voyages of America's ship for ocean exploration with the *Okeanos Explorer* Atlas at http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm



On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as “America’s Ship for Ocean Exploration;” the only U.S. ship whose sole assignment is to systematically explore Earth’s largely unknown ocean. The strategy for accomplishing this mission is to use state-of-the-art technologies to search the ocean for anomalies; things that are unusual and unexpected. When an anomaly is found, the exploration strategy shifts to obtaining more detailed information about the anomaly and the surrounding area. An important concept underlying this strategy is the distinction between exploration and research. As a ship of discovery, the role of *Okeanos Explorer* is to locate new features in the deep ocean, and conduct preliminary investigations that provide enough data to justify follow-up by future expeditions.

The *Okeanos Explorer* strategy involves three major activities:

- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties “from top to bottom” while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

In addition to state-of-the-art navigation and ship operation equipment, this strategy depends upon four types of technology:

- Telepresence;
- Multibeam sonar mapping;
- CTD (an instrument that measures conductivity, temperature, and depth) and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters.

In many ways, telepresence is the key to the *Okeanos Explorer*’s exploration strategy. This technology allows people to observe and interact with events at a remote location. The *Okeanos Explorer*’s telepresence capability is based on advanced broadband satellite communication through which live images can be transmitted from the seafloor to scientists ashore, classrooms, and newsrooms, and opens new educational opportunities that are a major part of *Okeanos Explorer*’s mission for advancement of knowledge.

In the summer of 2010, years of planning, field trials, and state-of-the-art technology came together for the first time on the the ship’s maiden voyage as part of the INDEX-SATAL 2010 Expedition. This expedition was an international collaboration between scientists from the United States and Indonesia to explore the deep ocean in the Sangehe Talaud Region. This region is located in the ‘Coral Triangle’, which is the global heart of shallow-water marine biodiversity. A major objective of the expedition was to advance our understanding of undersea ecosystems, particularly





Map showing the Coral Triangle region – the most diverse and biologically complex marine ecosystem on the planet. The Coral Triangle covers 5.7 million square km, and matches the species richness and diversity of the Amazon rainforest. Although much of the diversity within the Coral Triangle is known, most still remains unknown and undocumented. Image courtesy of www.reefbase.org.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/coral_triangle_hires.jpg

those associated with submarine volcanoes and hydrothermal vents. Among the Expedition's many "firsts," this was the first time scientists have been able to use an underwater robot to get a first-hand look at deepwater biodiversity in the waters of the Sangihe Talaud Region. For more information about the INDEX-SATAL 2010 Expedition, see <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>.

Thanks to telepresence, these experiences were not confined to a few scientists aboard the *Okeanos Explorer*. Video from the underwater robot was transmitted to a satellite orbiting in a fixed position above Earth, then was relayed to the University of Rhode Island's Inner Space Center. From there, video and audio from the ship was sent to other Exploration Command Centers (ECCs) in Seattle, New Hampshire, Maryland, Connecticut, and Indonesia. Observers in these ECCs were able to communicate with the *Okeanos Explorer*'s Control Room via the Internet. At first, 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>.

This lesson guides an introduction to some of the fundamental concepts that provide the foundation for wireless communication technology that supports telepresence aboard the *Okeanos Explorer*.

Satellite Communications Aboard the *Okeanos Explorer*

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 “geosynchronous” or “geo-stationary”.



All communications with the shore are made possible by the *Okeanos Explorer*'s powerful satellite dome, which enables the ship to establish high-bandwidth connectivity with Exploration Command Centers throughout the world. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/okeanos_vsats_hires.jpg

Learning Procedure

NOTES:

This lesson offers a variety of opportunities to integrate technology and engineering content with core science and mathematics curricula. Depending upon curriculum mandates and the availability of time and resources, this introduction may be extended to include additional hands-on activities as described in unit 9 of the American Radio Relay League's *Education and Technology Curriculum Guide*, available as a free download from <http://www.arrl.org/curriculum-guide>.

1. To prepare for this lesson:

a) Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
- “Executing Telepresence: The Seattle ECC Comes Online!” by Kelley Elliott and David Butterfield (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>);
- “Implementing Telepresence: Technology Knows No Bounds” by Webb Pinner and Kelley Elliott (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>); and

b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.

(c) If desired, download images to accompany discussions in Step 2.

(d) Review content discussed in Step 3, which reviews basic concepts about electricity and electromagnetic waves. Many students will have had prior exposure to these concepts, as they are often covered in middle and high school textbooks for physics and physical science. Depending upon such exposure, you may choose to abbreviate or omit this step.

(e) Review procedures for Hands-On Activity Guides referenced in Step 7, and decide whether these will be included with this lesson.

(f) Make copies of student handouts as needed.

(g) Obtain materials needed for Part B of the *Ohm's Law Worksheet*. This activity is adapted from *Get Connected with Ohm's Law*, an activity from TryEngineering (www.tryengineering.org). In its original version, this activity uses dedicated continuity test jigs assembled in advance by the educator. The *Ohm's Law Worksheet* describes an alternative procedure using prototyping boards (also known as breadboards). This alternative has an advantage in that the supplies may be re-used for a variety of other activities. In addition, students must make the various connections themselves, adding to the manipulative experience as well as reinforcing students' understanding of series circuits and basic procedures for measuring voltage and current. Finally, if available resources are not adequate to provide a separate set of materials for each student group, one or two sets of materials can be used consecutively by one or two students groups, while the remaining students work on other activities.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

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.

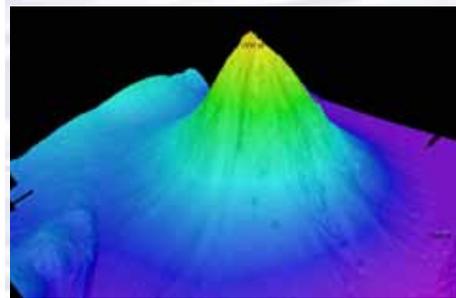
3. *Note: This step may be abbreviated or omitted, depending upon students' prior knowledge; see Step 1d.*

Provide each student or student group with a copy of *Review of Basic Concepts About Electricity and Electromagnetic Waves*. When students have answered questions on the worksheet, lead a discussion of their results. Key points include:

- 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.
- 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.
- The frequency of a wave is the number of crests that pass a given point in a certain amount of time, usually one second.
- 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; 1×10^3), megahertz (MHz; 1×10^6), or gigahertz (GHz; 1×10^9) are commonly used.



The ROV Little Hercules descends through deep water to an undersea volcano in the Celebes Sea to search for hydrothermal vents and associated ecosystems. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/1june29_hires.jpg



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



Scientists in the Exploration Command Center at NOAA's Pacific Marine Environmental Laboratory in Seattle view live video from the *Okeanos Explorer*'s ROV. Image courtesy NOAA
<http://www.pmel.noaa.gov/images/headlines/ecc.jpg>



Senior Survey Technician Elaine Stuart holds onto the CTD as it comes aboard the *Okeanos Explorer*. Image courtesy NOAA
<http://www.moc.noaa.gov/visitor/photos/photospage-b/CAP%20015.jpg>



The impact of telepresence is marvelous: 10-20 scientists and thousands of public onlookers from three countries, five time zones, and distributed across thousands of miles, are able to witness, discuss and document the incredible life and habitats existing at the bottom of Indonesia's deep ocean. Here, participants view images sent from the bottom of the ocean off Indonesia to monitors at the Exploration Command Center in Seattle. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/seattle_command_center_hires.jpg

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

- 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.
- 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.
- 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 *Radio Lab Handbook* (see Other Resources).

4. Ask students how often they use radio communication technology. Some students may consider radio to be an old-fashioned or even out-dated 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.

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 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 *Radio Lab Handbook* (see Other Resources).

When students have answered questions on the worksheet, lead a discussion of their results. Key points include:

- **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.
- **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.
- **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.
- **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.
- 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.

5. Provide each student group with a copy of *Ohm’s Law Worksheet* and Ohm’s



Law Activity Supplies listed under “Materials” (see Step 1g). If you want to have students complete Part A of the *Worksheet* individually, provide each student with a copy. If resources are limited, materials may be provided to one or two student groups at a time, while other groups work on other activities. When students have answered questions on the worksheet, lead a discussion of their results. Key points include:

Part A

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

$$R = E \div I$$

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

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

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

$$\text{Power} = \text{Volts} \cdot \text{Amps},$$

$$\text{so Amps} = \text{Power} \div \text{Volts} = 60 \text{ watts} \div 12 \text{ volts} = 5 \text{ amps}$$

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

Part B

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

- 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.
6. 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 *Education and Technology Curriculum Guide*, (see Other Resources).

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 a select certain frequencies, and also to select a transmitting frequency that is not already being used by another operator.
- Mixers do pretty much 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 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!). The Yagi antenna described in the Listen to Satellites activity is another example that uses separate antenna elements for the same purpose. A short video describing some features of this antenna is available at <http://www.youtube.com/watch?v=IsHtCUSfN4>.

7. Optional – Have students complete one or more of the *Hands-On Activity Guides for Wireless Communications*:

- *Light Beam Modulation* (included with the *A Day in the Life of an Ocean Explorer* lesson)
- *Make the Simplest Radio* (included with the *Please Pass the Remote* lesson)
- *Listen to Satellites* (included with this lesson)

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Human Activities,” then click on “Technology” for activities and links about satellite communications and other ocean exploration technologies.

The “Me” Connection

Have students write a short essay discussing how knowledge about fundamentals of wireless communication might be personally useful in finding new ways to use this technology.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Class discussions and students’ answers to worksheet questions provide opportunities for assessment.

Extensions

Find out more about wireless communications and amateur radio: The American Radio Relay League (the national association for amateur radio) has extensive resources about wireless technology including curricula, lesson plans, free downloads, kits, and projects; see <http://www.arrl.org/etp-classroom-resources>.

Other Resources

Anonymous. 2010. Web site for the INDEX-SATAL 2010 Expedition [Internet]. Office of Ocean Exploration and Research, NOAA [cited January 7, 2011]. Available from <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html> – Includes links to lesson plans, career connections, and other resources

Anonymous. Ocean Explorer [Internet]. NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. Available from: <http://oceanexplorer.noaa.gov>.

Anonymous. ARRL Education and Technology Program Curriculum Guide [Internet]. American Radio Relay League. [cited January 7, 2011]. Available from <http://www.arrl.org/curriculum-guide>.

Anonymous. Radio Lab Handbook [Internet]. American Radio Relay League. [cited January 7, 2011]. Available from <http://www.arrl.org/radio-lab-handbook>.

Anonymous. Satellite Radio Frequencies [Internet]. [cited January 14, 2011]. Available from <http://www.zarya.info/Frequencies/FrequenciesISS.php>; Web site listing frequencies of radio transmissions from the International Space Station



Anonymous. Documents for New Satellite Users. The Radio Amateur Satellite Corporation [Internet]. [cited January 14, 2011]. Available from <http://www.amsat.org/amsat-new/information/faqs>; collection of articles introducing amateur satellites and related topics from AMSAT.org

Elliott, K. and D. Butterfield 2010. Executing Telepresence: The Seattle ECC Comes Online! [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>

Eng, D. 2010. Listening to Satellites. Make 24:48-53; pdf may be purchased online from: <http://www.makershed.com/ProductDetails.asp?ProductCode=EMKV24>.

Pinner, W. and K. Elliott. 2010. Implementing Telepresence: Technology Knows No Bounds [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure of atoms
- Interactions of energy and matter

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor

Ocean Literacy Essential Principles and Fundamental Concepts

Because most Fundamental Concepts are broad in scope, some aspects of some Concepts may not be explicitly addressed in this lesson. Such aspects, however, can be easily included at the discretion of the individual educator.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.



Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy”. Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Fundamental Concept g. There are deep-ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth’s oxygen. It moderates the Earth’s climate, influences our weather, and affects human health.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation’s economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation’s explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings. Please send your comments to: oceaneducation@noaa.gov

For More Information

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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?

Student Worksheet

Wave Propagation 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*?



Student Worksheet:

Ohm's Law

Part A – Theory Review

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?
4. What does Ohm's Law say about the relationship between current, voltage, and resistance?
5. If 100 volts flows through a circuit having a resistance of 10 ohms, how much current flows through this circuit?
6. If a 60-watt light bulb is connected to a 12-volt battery, how much current flows through the light bulb?

Part B – Experimental Verification

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

Figure 1. Prototyping Board

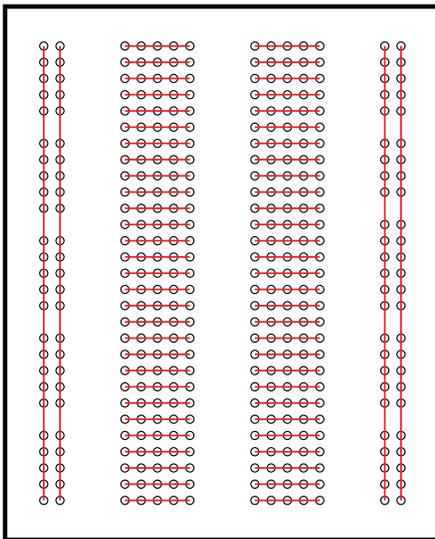


Figure 1. Layout of a typical prototyping board. The red lines show holes that are electrically joined by connections inside the board. On this board, there are two vertically-oriented sets of 25 connected holes on the left and right sides of the board. These holes are often used for connections to a 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!

Tools

Soldering iron (25 - 40 watts)

Wire cutters

Needle-nose pliers

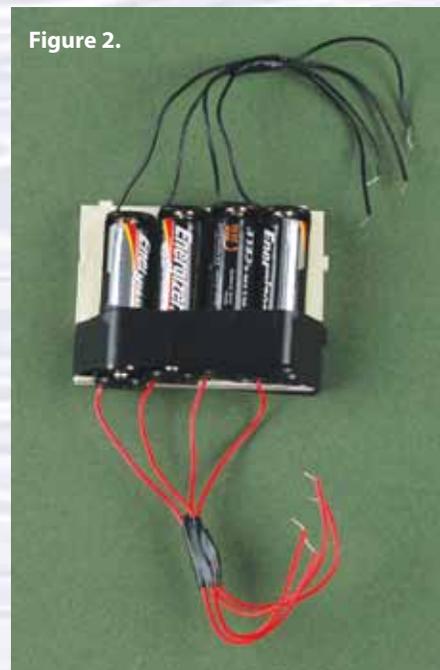
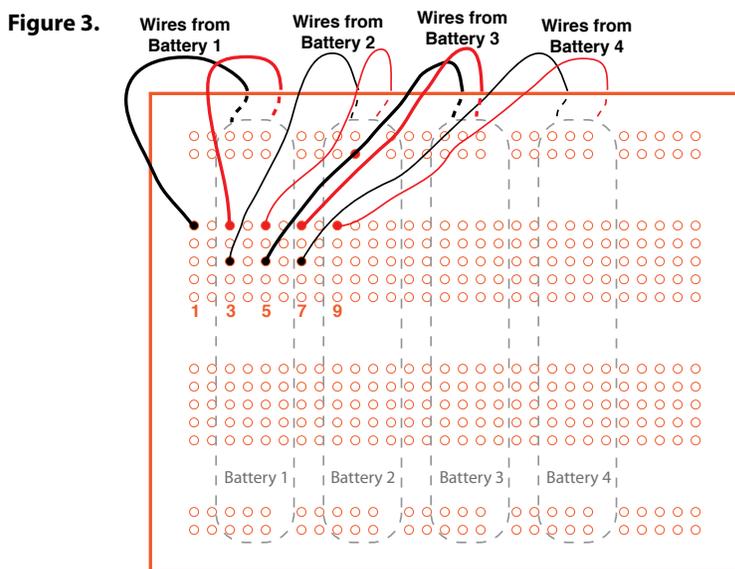
Phillips screwdriver

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.



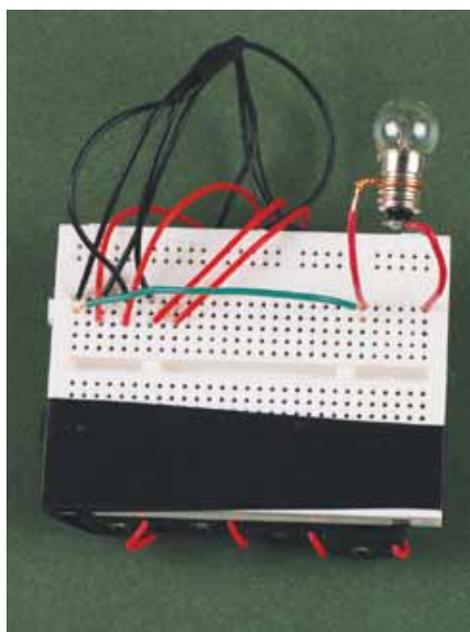
2. Cut two 2-inch lengths of insulated solid copper wire, and remove about 1/2-inch of the insulation from each end. Attach an alligator clip to one end of each wire (Figure 4).

Figure 4.

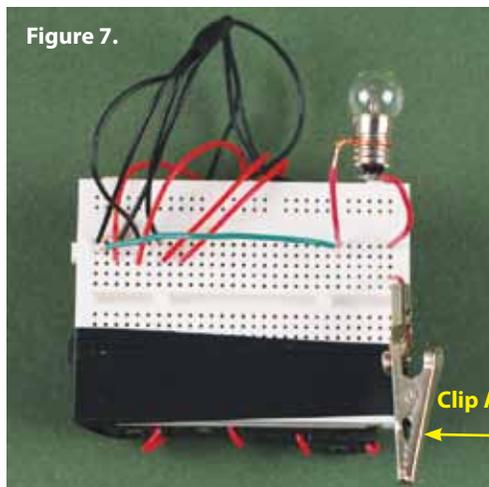


Figure 5.

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).

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.

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.

Figure 8.

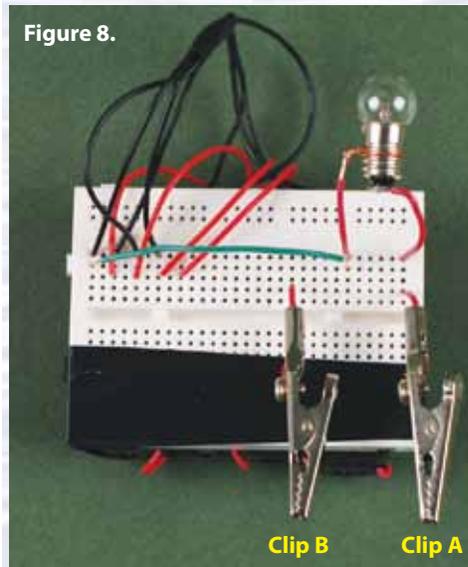


Figure 9.

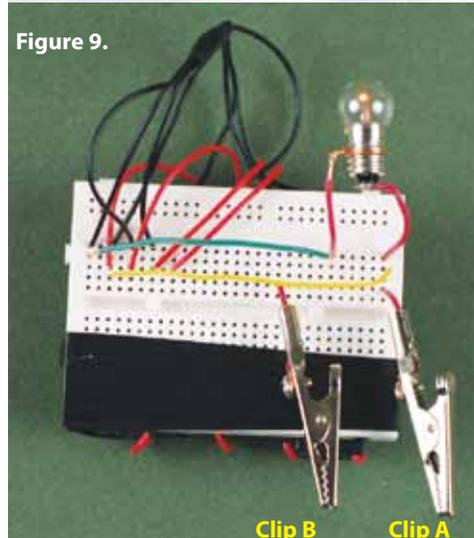
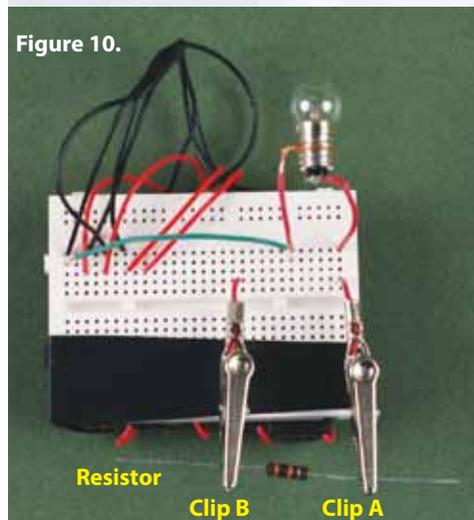


Figure 10.





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?

Hands-On Activity Guide

Wireless Communications: Listen to Satellites

Telepresence communication equipment aboard *Okeanos Explorer* sends and receives signals via satellites that relay transmissions to and from a ground station in California that is connected to the NOAANet Multiprotocol Label Switching network. This network connects with Exploration Command Centers (ECCs) via Internet2, the United States' high-performance research and education network. The Inner Space Center at the University of Rhode Island acts as the hub for the ECC system.

Telepresence communications via satellites uses frequencies in the microwave range (3.7 - 6.5 GHz). While special equipment is needed to operate at these frequencies, anyone can listen to other satellite communications with much simpler (and much less expensive) equipment. The key to this activity is an antenna that can concentrate satellite signals and send them to a receiver tuned to the frequency of the satellite transmissions. The *Okeanos Explorer* uses a large dish antenna to concentrate signals to and from the relay satellite. Another type of antenna that accomplishes the same thing (but not as effectively as a 3.7 m dish!) is called a Yagi antenna after one of its inventors, Hidetsugu Yagi. This antenna is made of a series of rods called elements. One element, called the driven element, is connected to the transmitter or receiver, and is oriented so that it is perpendicular to the direction of the signal being received or transmitted. Another element, called the reflector, is oriented the same way, and is placed so that the driven element is between the reflector and the desired "target" for the radio signal (in other words, the reflector is placed so that it can reflect radio waves from the driven element in the desired direction of the signal being received or transmitted). Other elements, called directors, are placed between the director and the desired "target" for the radio signal. Figure 1 shows a Yagi antenna with three elements (the Yagi antenna is mounted on the tower: the tower is NOT part of the antenna). The driven element is in the middle, the reflector is the longest element (closest to the viewer), and the director is the shortest element. The length and placement of the elements is very important, and depends upon the frequency of radio waves to be sent or received.

Diana Eng, a fashion designer and amateur radio operator, shows one type of Yagi antenna here: http://blog.makezine.com/archive/2009/07/catching_satellites_on_ham_radio.html. She (Eng, 2010) provides detailed instructions for constructing and using a similar antenna in volume 24 of Make magazine. The following activity is based on this article.

Materials

- UHF FM radio, such as a police scanner (e.g., Uniden BC72XLT) or an amateur radio UHF transceiver
- 1 - Square wood dowel, 1 x 1 x 30 inches
- 3 - Brass rods, 1/8-inch diameter x 30 inches
- 3 ft Coaxial cable, RG-58 with appropriate connector for radio antenna jack
- 2 - Nylon cable ties, approximately 6 inches long
- Additional tools:
 - Hacksaw
 - Metal file
 - Glue gun with glue
 - Ruler

Figure 1. A Yagi antenna



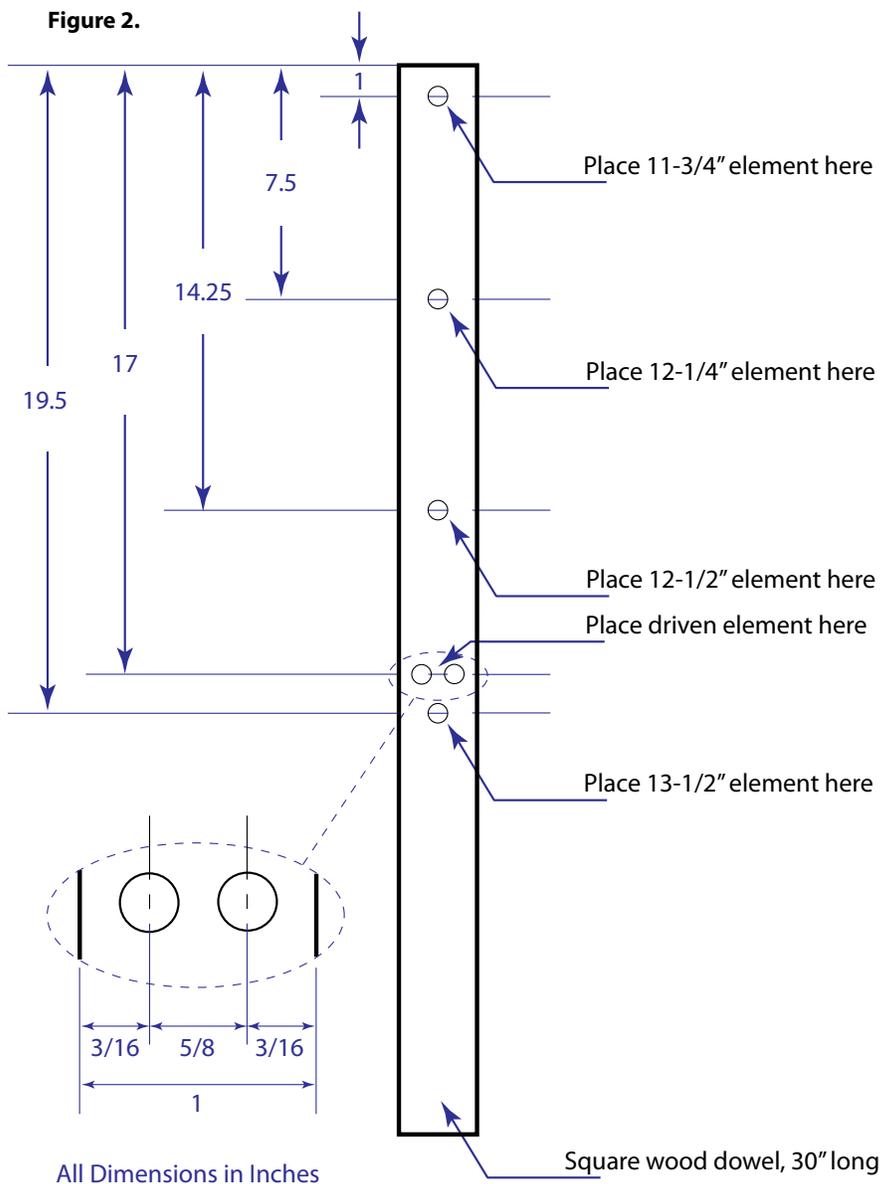
Note that the antenna is mounted on TOP of the tower. Image credit: NOAA.

<http://www.srh.noaa.gov/images/mlb/032v2.JPG>

- Marker
- Vise
- Drill or drill press with 1/8-inch drill bit
- Round dowel, approximately 3/4-inch diameter

Procedure

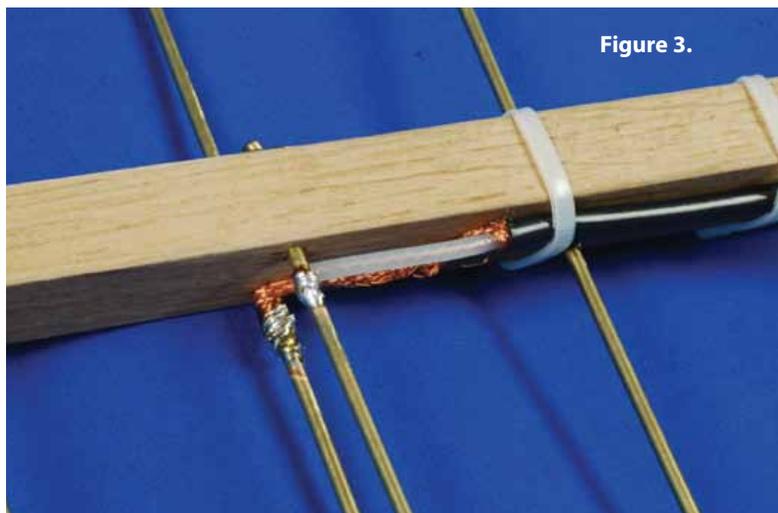
1. Measure and drill holes in the square wood dowel as illustrated in Figure 2.



2. Mark and cut the brass rods into the following lengths by holding each rod in the vise and cutting with the hacksaw:
 - 22 inches
 - 13-1/2 inches
 - 12-1/2 inches
 - 12-1/4 inches
 - 11-3/4 inches

Be sure to smooth cut edges with the metal file. [NOTE: The longest rod is 22-inches rather than 21 inches as specified in the original article.]

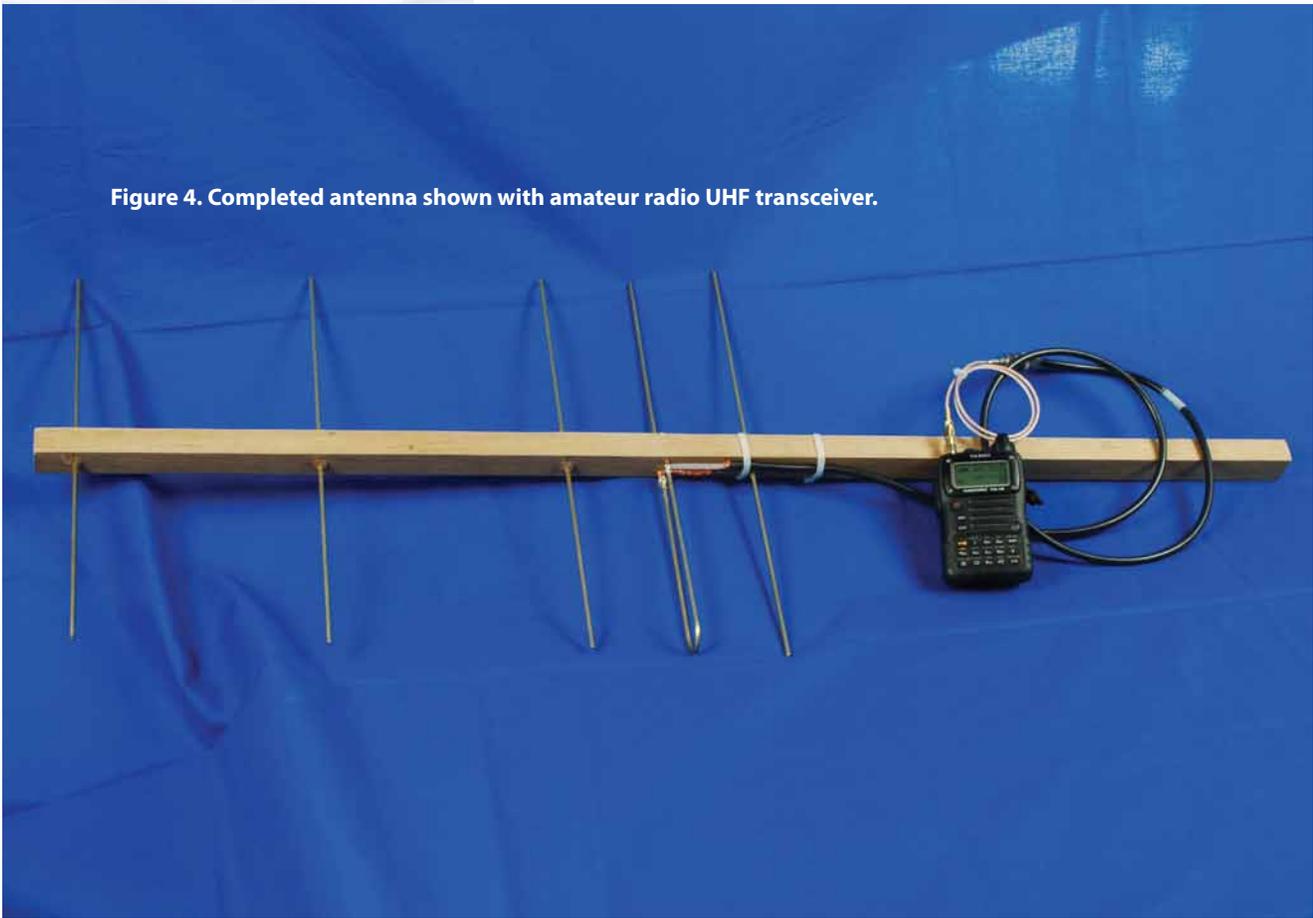
3. To make the driven element, mark the 22-inch rod 14 inches from one end. Hold the rod in the vise, place the 1/2-inch diameter round dowel on the 14-inch mark, then bend the rod around the dowel so that it forms a J shape. [NOTE: A 1/2-inch diameter dowel is used instead of the 3/4-inch diameter dowel specified in the original article, because this will make it easier to produce the required radius in the J bend.] Trim the ends of the rod so that the longer side is 13 inches from the bottom of the J, and the shorter side is 7 inches from the bottom of the J.
4. Insert the elements into the holes in the square dowel as indicated in Figure 1. Center the elements so that an equal length of each element extends on either side of the dowel, then glue the elements in place with hot glue.
5. Prepare the coaxial cable by cutting the connector off of one end, and trimming 3 inches of the outer insulation from this end. Separate the inner wire from the outer uninsulated shield, and trim 2 inches of insulation from the end of the inner wire. Wrap the bare portion of the inner wire around the short leg of the driven element, and wrap the uninsulated shield around the longer leg of the same element. Solder both connections. See Figure 3 below.



6. Fasten the coaxial cable to the square wood dowel with the nylon cable ties. Your antenna is finished! See Figure 4.
7. Follow Diana Eng's instructions for receiving signals from space. From the opening page on the <http://heavens-above.com> Web site, enter your location under the "Configuration" heading on the left side of the page, then select "Radio Amateur Satellites" under the "Satellites" heading. A new page will open listing all of the amateur radio satellites that will pass over your location during the next several days. Select satellites that have an altitude of at least 45 degrees above the horizon, and note the starting and ending times of the pass, as well as the frequency of transmissions (downlinks). Tune your scanner or radio to the appropriate frequencies, step outside at the appropriate time, point to the correct location in the sky, and listen up!



Figure 4. Completed antenna shown with amateur radio UHF transceiver.



Note that the <http://heavens-above.com> Web site also includes a great deal of other useful information about satellites and astronomy, including star charts for any location on Earth at any time of any year.

Resources

Anonymous. Satellite Radio Frequencies [Internet]. [cited January 14, 2011]. Available from <http://www.zarya.info/Frequencies/FrequenciesISS.php>; Web site listing frequencies of radio transmissions from the International Space Station

Anonymous. Documents for New Satellite Users. The Radio Amateur Satellite Corporation [Internet]. [cited January 14, 2011]. Available from <http://www.amsat.org/amsat-new/information/faqs>; collection of articles introducing amateur satellites and related topics from *AMSAT.org*

Eng, D. 2010. Listening to Satellites. *Make* 24:48-53; pdf may be purchased online from: <http://www.makershed.com/ProductDetails.asp?ProductCode=EMKV24>.

Eng, D. 2009. Catching Satellites on Ham Radio. [Internet]. [cited January 22, 2011]. Available from http://blog.makezine.com/archive/2009/07/catching_satellites_on_ham_radio.html.