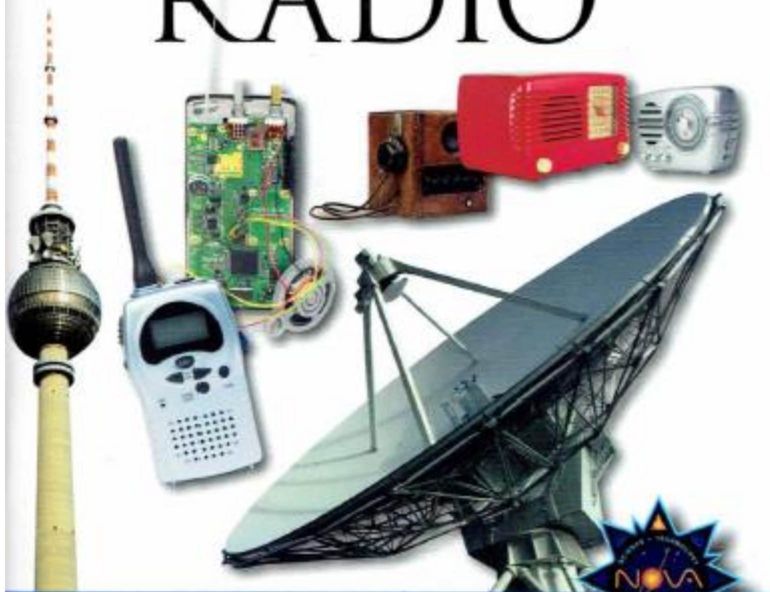
MERIT BADGE SERIES

RADIO



BOY SCOUTS OF AMERICA®

STEM-Based

How to Use This Pamphlet

The secret to successfully earning a merit badge is for you to use both the pamphlet and the suggestions of your counselor.

Your counselor can be as important to you as a coach is to an athlete. Use all of the resources your counselor can make available to you. This may be the best chance you will have to learn about this particular subject. Make it count.

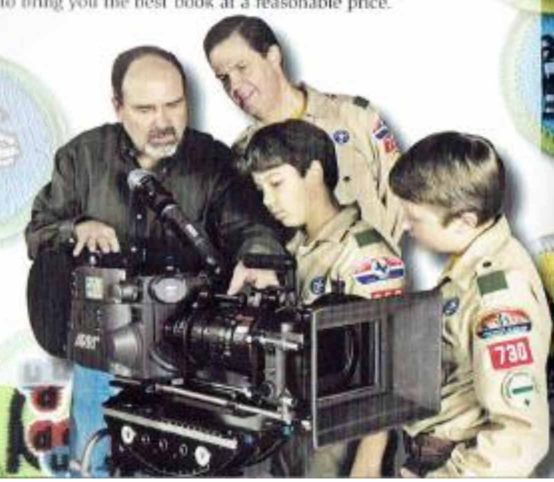
If you or your counselor feels that any information in this pamphlet is incorrect, please let us know. Please state your source of information.

Merit badge pamphlets are reprinted annually and requirements updated regularly. Your suggestions for improvement are welcome.

Send comments along with a brief statement about yourself to National Advancement Committee, S209 • Boy Scouts of America • 1325 West Walnut Hill Lane • P.O. Box 152079 • Irving, TX 75015-2079 • merit.badge@Scouting.org.

Who Pays for This Pamphlet?

This merit badge pamphlet is one in a series of more than 100 covering all kinds of hobby and career subjects. It is made available for you to buy as a service of the national and local councils, Boy Scouts of America. The costs of the development, writing, and editing of the merit badge pamphlets are paid for by the Boy Scouts of America in order to bring you the best book at a reasonable price.



BOY SCOUTS OF AMERICA
MERIT BADGE SERIES

RADIO

"Enhancing our youths' competitive edge through merit badges"

BOY SCOUTS OF AMERICA®

Requirements

1. Explain what radio is. Then discuss the following:
   a. The differences between broadcast radio and hobby radio
   b. The differences between broadcasting and two-way communications
   c. Radio station call signs and how they are used in broadcast radio and amateur radio
   d. The phonetic alphabet and how it is used to communicate clearly
2. Do the following:
   a. Sketch a diagram showing how radio waves travel locally and around the world. Explain how the broadcast radio stations WWV and WWVH can be used to help determine what you will hear when you listen to a shortwave radio.
   b. Explain the difference between a DX and a local station. Discuss what the Federal Communications Commission (FCC) does and how it is different from the International Telecommunication Union.
3. Do the following:
   a. Draw a chart of the electromagnetic spectrum covering 100 kilohertz (kHz) to 1,000 megahertz (MHz).
   b. Label the MF, HF, VHF, UHF, and microwave portions of the spectrum on your diagram.
   c. Locate on your chart at least eight radio services, such as AM and FM commercial broadcast, citizens band (CB), television, amateur radio (at least four amateur radio bands), and public service (police and fire).

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4. Explain how radio waves carry information. Include in your explanation: transceiver, transmitter, receiver, amplifier, and antenna.
5. Do the following:
   a. Explain the differences between a block diagram and a schematic diagram.
   b. Draw a block diagram for a radio station that includes a transceiver, amplifier, microphone, antenna, and feed line.
   c. Explain the differences between an open circuit, a closed circuit, and a short circuit.
   d. Draw eight schematic symbols. Explain what three of the represented parts do. Find three electrical components to match to three of these symbols.
6. Explain the safety precautions for working with radio gear, including the concept of grounding for direct current circuits, power outlets, and antenna systems.
7. Visit a radio installation (an amateur radio station, broadcast station, or public service communications center, for example) approved in advance by your counselor. Discuss what types of equipment you saw in use, how it was used, what types of licenses are required to operate and maintain the equipment, and the purpose of the station.

8. Find out about three career opportunities in radio. Pick one and find out the education, training, and experience required for this profession. Discuss this with your counselor, and explain why this profession might interest you.

9. Do ONE of the following (a OR b OR c):

a. AMATEUR RADIO

(1) Tell why the FCC has an amateur radio service. Describe some of the activities that amateur radio operators can do on the air, once they have earned an amateur radio license.

(2) Using proper call signs, Q signals, and abbreviations, carry on a 10-minute real or simulated amateur radio contact using voice, Morse code, or digital mode. (Licensed amateur radio operators may substitute five QSL cards as evidence of contacts with amateur radio operators from at least three different call districts.) Properly log the real or simulated ham radio contact and record the signal report.

(3) Explain at least five Q signals or amateur radio terms you hear while listening.

(4) Explain some of the differences between the Technician, General, and Extra Class license requirements and privileges. Explain who administers amateur radio exams.

(5) Explain how you would make an emergency call on voice or Morse code.

(6) Explain the differences between handheld transceivers and home "base" transceivers. Explain the uses of mobile amateur radio transceivers and amateur radio repeaters.

b. BROADCAST RADIO

(1) Prepare a program schedule for radio station "KBSA" of exactly one-half hour, including music, news, commercials, and proper station identification. Record your program on audiotape or in a digital audio format, using proper techniques.

(2) Listen to and properly log 15 broadcast stations. Determine the program format and target audience for five of these stations.

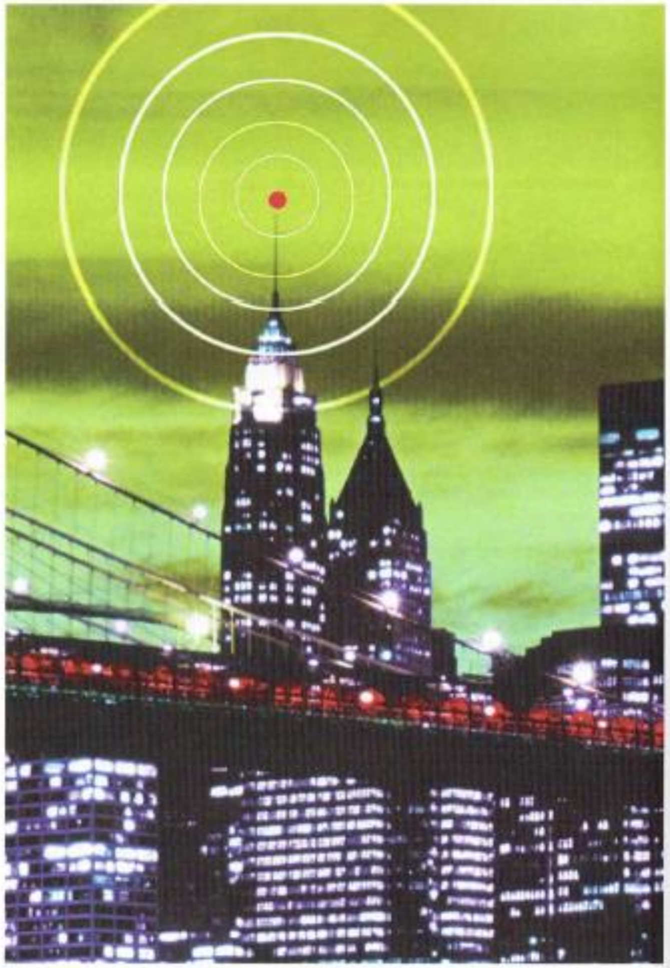
(3) Explain at least eight terms used in commercial broadcasting, such as segue, cut, fade, continuity, remote, Emergency Alert System, network, cue, dead air, PSA, and playlist.

c. SHORTWAVE LISTENING

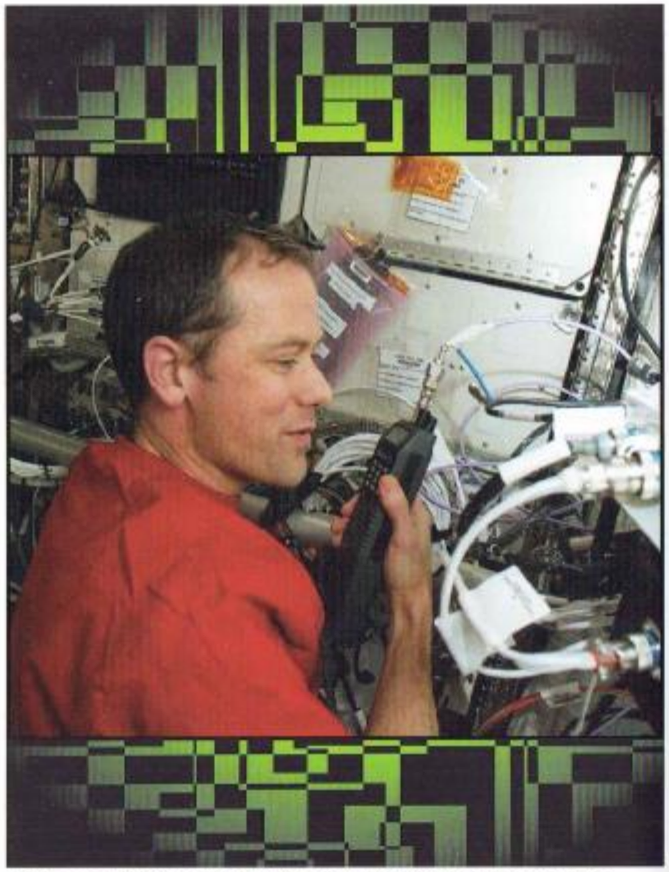
(1) Listen across several shortwave bands for four one-hour periods—at least one period during daylight hours and at least one period at night. Log the stations properly and locate them geographically on a globe.

(2) For several major foreign stations (BBC in Great Britain or HCJB in Ecuador, for example), list several frequency bands used by each.

(3) Compare your daytime and nighttime logs; note the frequencies on which your selected stations were loudest during each session. Explain differences in the signal strength from one period to the next.



Contents



While in orbit, NASA astronaut Tom Marshburn (KE5HOC) used the radios of the International Space Station to communicate with Johnson Space Center in Houston. As an amateur or "ham" radio operator, he also used ham radios to connect with students across the United States through the ARISS (Amateur Radio on the International Space Station) program.

Adventure on the Airwaves

Picture yourself as an astronaut on the International Space Station, talking by radio to Mission Control. Or as a radio news reporter or a police officer racing to a crime scene. Or as a storm chaser monitoring weather-spotter reports on ham radio. All these images share one thing: your interest in radio, either as part of work or as a hobby.

The World of Radio

LORAN stands for **LO**ng-**RA**nge **N**avigation. **VOR** is short for **V**ery-high-frequency (VHF) **O**mnidirectional **R**ange, a short-range navigation system.

With a ham radio license, you might talk to country music singer Patty Loveless (KD4WUJ), or to a licensed astronaut aboard the International Space Station. You might talk to an Israeli Scout during Scouting's Jamboree-on-the-Air. As a short-wave listener, you can eavesdrop on Coast Guard helicopters shadowing a drug runner in the Caribbean. You can listen to Voice of America, the international radio network of the United States, and compare it to Radio Beijing's version. You can get the exact time from the National Institute of Standards and Technology's radio station WWV, or find out the weather in France by listening in on airliners flying 40,000 feet over Europe.

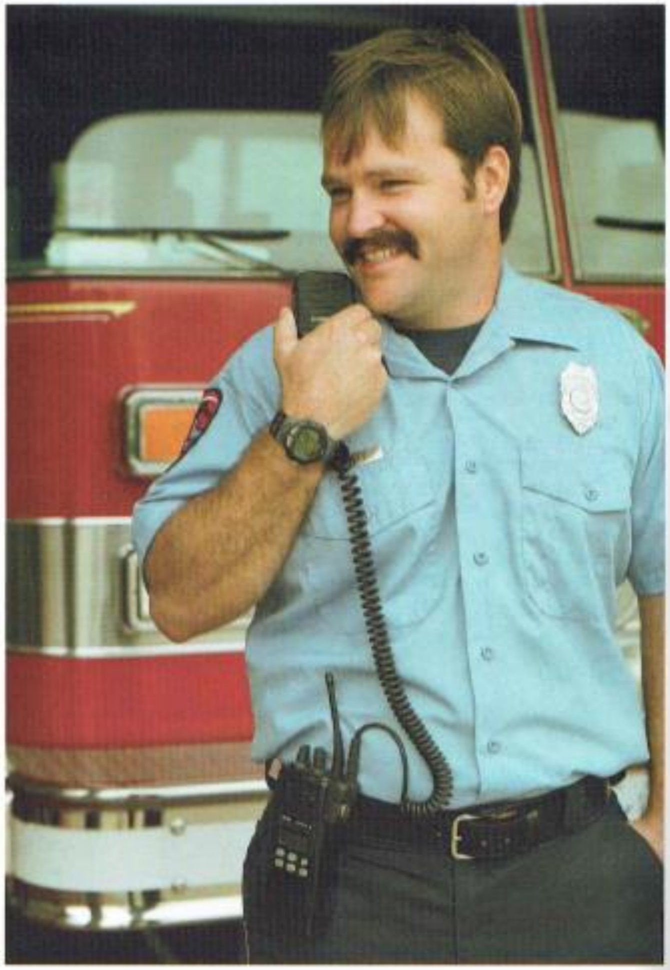
People use radio signals to control everyday items from model cars and airplanes to automatic garage door openers and the door locks on their cars. The U.S. Border Patrol and the Army use radio signals to control unmanned aerial vehicles (UAVs), which broadcast television pictures back to the ground. Pilots and sailors count on radio signals from the satellites of the Global Positioning System (GPS) and land-based LORAN and VOR transmitters to help them navigate safely through the air and oceans.

You use radio in some way every day. You might listen to satellite news from another country, ride in a bus equipped with a business-band radio, watch educational television at school, watch a police officer with a walkie-talkie at the scene of an accident, or text-message a friend on a cell phone.

When you have earned this merit badge, you will know a lot about radio. You may even have found a lifelong hobby or career. Let's get started.

Your Choice From Three Options

To complete the Radio merit badge requirements, you will choose one of these three options to learn more about: amateur radio, broadcast radio, or shortwave listening. This pamphlet gives details about each.



What Is Radio?

In England radio is called "wireless"—a good word for it. Radio is the use of electrical waves to send and receive information—"communications"—from the transmitter to the receiver, without wires connecting the two places. The places might be far apart (a TV transmitter on a satellite orbiting Earth, and a receiver in your living room) or quite close (a key fob on your key ring and the remote door-lock receiver in your car).

Broadcasting uses radio to send information to lots of people at the same time. The information might be just voices and music (as in AM or FM or shortwave broadcasting), or it might also include pictures transmitted along with the sound (television).

Hobby radio is the use of radio by ordinary people—ham radio operators "working DX" or citizens band operators with radios in their 18-wheelers, model aircraft or boat enthusiasts who control their craft by radio remote control, model-rocket builders who send television transmitters up on their rockets, even your Scout troop using Family Radio Service (FRS) portable radios to keep in touch while hiking.

Broadcasting is one-way radio—a transmitter sends transmissions to many receivers, but the receivers can't reply. With two-way radio, however, there is a transmitter and receiver at both ends so that messages can travel both ways.

Licenses

Some types of radios (garage door openers, wireless network cards in laptops)—usually those that are very low power—are not licensed at all.

In the United States, radio transmitters are regulated by an agency of the federal government called the Federal Communications Commission, or FCC. Other countries have agencies that serve the same purpose. These agencies issue permission for the use of radio waves. The legal paper granting this permission is called a *license*.

In some types of radio ("services"), every transmitter has a license. For example, all broadcasting stations are required to be licensed. An organization might have a license to cover all of its transmitters. Your local police department would have one license for its base station and all of the radios in its cars and handheld radios used by its officers.

In other types of radio, some central transmitters are licensed, but others are not. For example, phone companies need licenses for their cell phone sites, but individual cell phone users are not licensed. In the amateur radio service, the radios themselves are not licensed, but the operators ("hams") have licenses to operate any ham radio within the limits of their license class.

Call Signs

Licensed transmitters (or, in the amateur radio service, operators) are assigned a "name" by the FCC when they are issued their license. This name is usually a combination of letters, or letters and numbers, called a *call sign*. Each radio service has different rules for what call signs look like and how often they must be transmitted.

Call signs for U.S. broadcasting stations have either three or four letters—for example, WOR in New York City, or KABC in Los Angeles. Call signs for broadcasters east of the Mississippi River start with the letter *W*, and broadcasters

west of the Mississippi River start with *K*. There are a few exceptions, such as Pittsburgh's KDKA or WFAA in Dallas, but most follow the rule. Broadcast stations in the United States are required to identify themselves with their call signs on the hour; most will do so several times each hour.

A broadcaster may have several stations in different broadcasting services using the same call sign, in which case the letters *AM*, *FM*, or *TV* follow the call sign. WSKG-FM is used by public radio in Binghamton, New York, and WSKG-TV is the public television station. Some radio stations networks may have related call signs, as in WJIV, WBIV, WSIV, and a few others that once made up the "ivy" network in central New York.

Canadian broadcasting stations have call signs starting with **C**, as in CFAX in Vancouver or CBN in St. John's, Newfoundland.

Ham Call Signs

In the amateur radio service, each set of calls is unique. The beginning *(prefix)* of the call sign indicates the country: W, K, N, or A for the United States; VE for Canada; XE for Mexico, for example. In the United States the first letter may be followed by another letter, then always by a number, which tells you where the ham was first licensed (the *call district*). These numbers are assigned roughly clockwise around the country, starting with 1 for New England, 2 for New York or New Jersey, 3 for the mid-Atlantic states, and so on, to 9 and 0 in the Midwest. Canadian ham call signs use a similar system, going from east to west with VE1 in Nova Scotia and VE7 in British Columbia.

If a ham moves to another call district, his call sign does not change. So if you hear a "W6" he might be in California, or he might have received his call letters when he lived there but is now living in Maine.

The last one to three letters are usually assigned alphabetically from the unused combinations at the time the call sign was issued. In most cases the *suffix* letters following the number are meaningless. In the past, some organizations were able to get special call signs, like the Boy Scouts of America's ham radio station K2BSA, or the Smithsonian's NN3SI. The FCC now has a "vanity call sign" procedure. For a fee, a ham may request a specific call sign if it is not assigned to someone else. Many Scouters have calls with "BSA" suffixes. Many hams have come up with sayings to make their call signs easier to remember, such as "K two little furry bunnies" for K2LFB.

Here are some common prefixes:

W, K, N, A—United States
VE, VO, XJ—Canada
XE—Mexico
PY—Brazil
G—Great Britain
F—France
I—Italy
4X, 4Z—Israel
JA—Japan
ZL—New Zealand

This map shows what number will be in your amateur radio call sign, depending on where you live when you first get your license. For example, if you live in California, your call sign will contain a 6. You will keep that call sign even if you move to another call district.

Phonetic Alphabet

Many letters sound similar. Over the radio it can be hard to make out the differences between *C, E, V,* and *Z,* or *B, P,* and *T,* or S and *F,* and so on, especially when a radio station is weak or there is static. Things can get even more confusing when one of the operators is more familiar with the alphabet the way it is pronounced in another language. In Spanish, for instance, the letter *E* is pronounced like a long *A*, as in *day*. So if you hear a ham in Mexico say a long *A*, which letter does he mean?

To help make themselves understood, radio operators use a *phonetic alphabet*. A phonetic alphabet uses a word to stand for each letter the operator is trying to get across. If your name is Ted, you would spell your name as "Tango Echo Delta." If it is Dan, you would say "Delta Alfa November." If there is static and you spelled out your name only as "D-A-N" instead of saying "Delta Alpha November," the listener might hear "B-E-N." Many letters sound alike when the signal is hard to hear.

Many phonetic alphabets have been used over the years, and the military uses its own system. Most civilian radio users now use the following standard set by the International Telecommunication Union (ITU) and International Civil Aviation Organization (ICAO).

Standard ITU/ICAO Phonetics

This list of words is used for the phonetic alphabet.

A—Alfa (AL-fah)
B—Bravo (BRAH-voh)
C—Charlie (CHAR-lee or SHAR-lee)
D—Delta (DELL-tah)
E—Echo (ECK-oh)
F—Foxtrot (FOKS-trot)
G—Golf (GOLF)
H—Hotel (hoh-TELL)
I—India (IN-dee-ah)
J—Juliet (JEW-lee-ett)
K—Kilo (KEY-loh)
L—Lima (LEE-mah)
M—Mike (MIKE)
N—November (no-VEM-ber)
O—Oscar (OSS-cah)
P—Papa (PAH-pah)
Q—Quebec (keh-BECK)
R—Romeo (ROW-me-oh)
S—Sierra (see-AIR-rah)
T—Tango (TANG-go)
U—Uniform (YOU-nee-form or OO-nee-form)
V—Victor (VIK-tah)
W—Whiskey (WISS-key)
X—Xray (ECKS-ray)
Y—Yankee (YANG-key)
Z—Zulu (ZOO-loo)

How Radio Waves Travel

Radios use AC, or alternating current, like the electricity that comes from the outlets in your house. (You may also be familiar with DC, or direct current, as is produced by batteries.) The AC electric power that lights your room reverses or *alternates* from positive to negative and back, 60 times each second. We can say its frequency of alternating is 60 times (cycles) per second, or 60 hertz.

As the frequency of alternating current gets higher than about 10,000 hertz, the signal no longer wants to stay in the wire. Thus, at frequencies above 10,000 Hz, alternating current becomes *radio frequencies*, or RF. If the length of the wire is right, the signal leaves the wire (now an *antenna*) and goes through the air, like the light from a lightbulb. As you read this, millions of those signals are zipping through your body (luckily they don't tickle).

Think about that lightbulb for a minute. If you are standing close enough, you see the glow of the bulb. Even if you can't see the bulb itself, you might see its light shining on the walls of the room. What if the bulb were behind your house? You could still see its light reflected off the picture window in the house next door.

One hertz (Hz) equals one cycle per second. One kilohertz (kHz) equals 1,000 hertz. One megahertz (MHz) equals 1,000,000 hertz, or 1,000 kHZ.

Radio signals travel the same way as the light from the bulb. If your receiving antenna can actually "see" the transmitting antenna, you will receive the signal directly. This is called *line-of-sight reception*, and that is how very high frequency (VHF) and ultra high frequency (UHF) signals are most often received.

Most local radio reception, especially on the AM radio broadcast *band* during the day, is like seeing the bulb scattering light from the walls of the room. This is called *ground wave* because the signal hugs the ground, traveling along Earth's surface.

A *band* is a range of frequencies. AM radio stations transmit within the medium-wave band from 535 to 1605 kHz. The shortwave band ranges from 3 to 30 MHz. FM stations transmit within a very high frequency (VHF) band from 88 to 108 MHz.

How can you explain being able to hear a distant station when your receiving antenna is too far away to "see" the transmitting antenna? Just as the lightbulb reflects from the window next door, so radio waves seem to reflect from a "mirror" in the sky—the layers of air between 40 and 300 miles up called the *ionosphere*. Radio waves may bounce ("skip") from the ionosphere back to Earth, and up again, all the way around the world.

The ionosphere is made up of air that is electrically charged by the sun and shaped by Earth's magnetic field. Radio waves entering the layers of the ionosphere can be bent and reflected back to Earth, or they can be absorbed by the ionosphere, or they may pass through the ionosphere, depending on the radio frequency and the height and thickness of the ionosphere's layers. The height and thickness of the layers will change as the angle and amount of sunlight changes over the day and the seasons of the year.

The layers are also affected by variations in the sun's light caused by sunspots and other effects. This is why the distance a radio transmitter may be heard (propagation) varies with the time of day, season, and the 11-year sunspot cycle.

When you transmit a radio wave, it goes toward the ionosphere and skips back to Earth.

As a rule, signals in the AM broadcast band (535 kHz to 1605 kHz) are limited to the relatively short distances of ground-wave propagation during the day, since this is when the lower layers of the ionosphere are thickest and absorb the signals. At night, these layers become thinner, and the AM signals can pass through and be bent to "skip" down much farther away.

On the other hand, signals in the range of about 10 MHz to 30 MHz are bent by this thicker daytime layer, so they are useful for worldwide communications during the day. But at night, as the layer thins, it becomes too thin to bend the waves, and these signals are no longer capable of long-distance "skip."

Knowing the Propagation

A good check of radio propagation (the ability of radio signals to travel from one place to another) is to listen to radio station WWV in Colorado, or its sister station WWVH in Hawaii, operated by the National Institute of Standards and Technology (NIST). These stations broadcast on exact frequencies of 2.5, 5, 10, 15, and 20 MHz—frequencies in the *shortwave* radio spectrum.

The stations transmit a continuous "beep-beep" at one-second intervals, with a voice identification of each station's call sign each minute, sometimes with additional information including time corrections, "space weather" reports such as solar storms that affect radio communications, marine storm warnings, and Global Positioning System (GPS) status reports. WWVH identifies at 15 seconds before the minute, WWV immediately afterward. By tuning to each of the WWVH and WWV frequencies, a listener can get a good idea of how loud signals on these radio frequencies will be from ham radio stations or other radio services located in the West and the Pacific areas.

International time stations like CHU in Ottawa, Canada, and WWV in Fort Collins, Colorado, *below*, are scattered around the world. By knowing the propagation, you can choose the band to listen to that is best for the distance that interests you.

What Is DX?

Radio stations that are not local to your area are called *DX*, the Morse code abbreviation for "distance." It isn't possible to provide a definition of DX as a number of miles, so that you could measure on a map when a station becomes DX. In some ham radio bands, like the 20-meter band at 14.0 to 14.35 MHz, where normal propagation is in the thousands of miles, a DX station usually is considered to be anyone outside your home country. In other bands like the 2-meter band at 144 to 148 MHz, where normal propagation is very short range, a station in the next state might be "DX." In any case, you can tell the DX station because it is the one everyone is likely trying to reach.

The FCC and the ITU

When radio began, the radio frequency spectrum was not regulated. Each user built a station and got on the air. The result was a mess. Even worse, the earliest "spark gap" radio transmitters simply used a big spark to create static, which was turned on and off to form the dots and dashes of Morse code characters. Each transmitter's "frequency" depended on its antenna's length, but basically every transmitter's signal was heard everywhere up and down the bands. Two Scouts talking across town on homemade transmitters could interfere with ships at sea—and anyone else trying to communicate.

Spark was outlawed in the 1920s, which helped some. At the same time, radio broadcasting became popular and broadcast stations began to multiply like weeds. Everyone wanted to start a radio station. Without regulation, that is just what they did.

Finally, the world's countries got together to divide the radio spectrum into bands or groups of frequencies. Each band is assigned to one or more services or types of users, such as military or government use, broadcasting, amateur (ham) radio, etc. In this country, a U.S. government agency, the Federal Communications Commission (FCC), was formed in 1927 (it was called the Federal Radio Commission back then). The commission became responsible for regulating the use of these bands by users in the various radio services within the United States.

Today, the FCC regulates who gets to use what frequencies, and issues licenses to radio stations, transmitters, and operators. In each service, the FCC decides which users require licensing. For example, amateur service operators must take an FCC test to get their "ham" licenses, while in the broadcasting service each transmitter is licensed, but the on-the-air personality at the microphone does not need a license.

The FCC is responsible for setting and enforcing technical standards for anything that generates radio frequencies. Look at your CD player or garage door remote control; you may find a label saying it complies with FCC rules.

The FCC does not have authority outside the United States. Global telecommunications networks and services are coordinated by the International Telecommunication Union (ITU), headquartered in Geneva, Switzerland.

"The ITU Radiocommunication Sector (ITU-R) plays a vital role in the global management of the radio-frequency spectrum and satellite orbits—limited natural resources which are increasingly in demand from a large and growing number of services such as fixed, mobile, broadcasting, amateur, space research, emergency telecommunications, meteorology, global positioning systems, environmental monitoring, and communication services—that ensure safety of life on land, at sea, and in the skies."
—http://www.itu.int/ITU-R

How Radio Waves Carry Information

A pure radio signal does not convey any information; it's just there. While a continuous radio signal might be of some use as a homing beacon, if you want to communicate using radio you must find a way to put information onto the signal.

Morse Code

Spelling out words by Morse code is fun and useful. The simplest way to put information on the signal is to turn it on and off in a recognizable pattern or code. That is exactly what ham operators do when using Morse code—they turn a simple continuous wave (CW) produced by a transmitter on and off in a series of long and short transmissions. Then, someone using a receiver detects whether the signal is there or not, and figures out from the pattern what was said.

Hams use the words *dit* and *dah* to represent the short and long sounds of the Morse code. The letter *A* is "di-dah," *B* is "dah-di-di-dit," *C* is "dah-di-dah-dit," and so on. Morse code works well under poor conditions for listening and hearing. The human ear is good at translating faint beeps amid static into letters. However, Morse code is a slow means of communication (15 to 20 words per minute is typical of on-the-air conversations), and machines have trouble interpreting the varying-length letters and spaces.

Modulation

Before long, people wanted to transmit sounds (audio) over the radio—that is, voices and music. To do that, you must combine the audio with the continuous radio signal (the *carrier*). This combination of audio and carrier is called *modulation*.

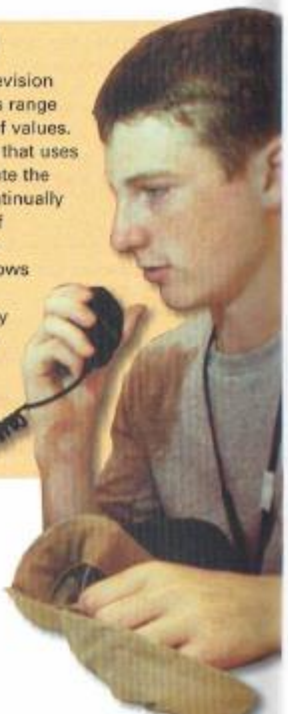
There are basically two ways to modulate a carrier with sounds or other signals. You can change the strength (amplitude) of the signal, which is called *amplitude modulation* or AM. Or you can change the frequency of the signal, which is called *frequency modulation* or FM. (Now you know what the AM and FM on your clock radio mean.) Television is a combination of AM (for the picture) and FM (for the sound).

Ham radio operators use a variety of amplitude modulation called *single sideband* (SSB) on the shortwave bands, and mostly FM on the VHF and UHF bands. *Citizens band* radios are mostly AM (although some use SSB, too). *Family Radio Service* (FRS) handheld radios use FM, as do most police and fire radios.

Today, more and more communications signals are being sent digitally. Digital satellite radio and television have been around for some time, and digital broadcast radio and TV are starting to replace the older AM and FM systems. Digital mobile phones have completely replaced the original analog cell phone system. All of these digital radio and TV systems, whether the signals are sent by satellites or earthly transmitters, use a system of shifting transmit frequency to send binary numbers—"ones" or "zeroes." They shift very quickly. Computers on each end can translate sound and pictures to digital numbers and back again without interrupting the show you are watching or listening to.

Analog vs. Digital

Ordinary voice, radio, and television signals are analog; the signals range over a continuous spectrum of values. Think of a glass thermometer that uses a column of mercury to indicate the temperature. The mercury continually rises and falls with changes of temperature. Compare that to a digital thermometer that shows the temperature in distinct numerical digits rather than by a continuously moving liquid. Analog communications signals can be digitized to be transmitted as the binary digits ("bits") 1 and 0.



Radio Communications: Basic Equipment

Let's look at a ham operator talking to a friend on the other side of the world, and see what parts are required. He talks into a microphone, which turns his voice into electrical energy, which the transmitter part of his transceiver uses to modulate the radio-frequency carrier. The modulated signal is sent to the antenna along a feed line and leaves the antenna as a radio signal. If the operator wants a more powerful signal, he can amplify it by using an amplifier between the transceiver and the antenna.

At the receiving station, the process happens in reverse. The receiving antenna picks up the radio signal. The signal goes down a feed line to another transceiver, where a radio frequency (RF) amplifier in the receiver part makes it strong enough to hear (the signal at the antenna can be very weak—maybe several millionths of a watt). Then, a detector extracts the audio part of the signal. The audio frequency (AF) energy is amplified by another amplifier, and a speaker reproduces the sound for the receiving operator to hear.

A transmitter and receiver combined in one box is called a *transceiver.*

The most efficient length for an antenna is related to the wavelength of the signal. The towers used at broadcast stations, or the whip antennas on police cars, are most often one-quarter or five-eighths of a wavelength tall. A horizontal *dipole* antenna is often used by ham radio operators. It's a simple wire, one-half wavelength long.

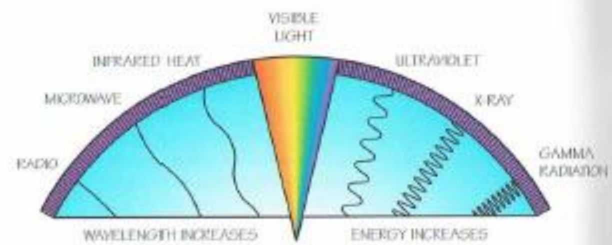
Antennas with several elements, called "yagis" *(yag-eez)* or "beams," allow the signal to be sent or received in one direction better than others. These antennas are used for TV reception, where the TV transmitter is far away, or on a rotator by ham operators so they can direct their signal to the part of the world they want to communicate with.

Look at all of the radios in your home and car to see what radio frequencies you can hear.

Operation on the amateur radio 160-meter frequency band needs an antenna 80 meters (240 feet) long. That takes a pretty big yard!

The Electromagnetic Spectrum

The *electromagnetic spectrum* is the range of frequencies from DC through audio, radio, and light waves (infrared to visible light to ultraviolet), X-rays, and gamma rays. For the Radio merit badge, you will be interested in the radio part of the spectrum—around 0.1 MHz to 10,000 MHz.



The electromagnetic spectrum

You will also see the prefix *giga* (G) used with frequencies. Giga means one billion, so 1.0 GHz is 1,000 MHz. Commonly used metric words (prefixes) for fractions are *milli* (m), one thousandth, and *micro* (µ), one millionth.

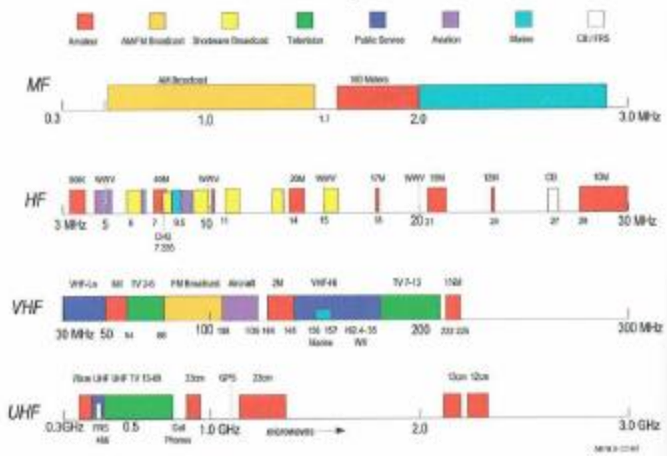
Radio waves travel through space at the speed of light (186,000 miles per second). The distance a radio signal travels in one cycle (positive to negative and back again) is called its *wavelength*. The higher the frequency, the shorter the wavelength. Ham operators and shortwave listeners (SWLs) usually use the wavelength of signals to group radio frequencies into bands. Signals on the 20-meter ham radio band, for instance, have wavelengths of about 20 meters (66 feet).

The radio spectrum is divided into ranges.

Low frequency (LF)	30 to 300 kHz
Medium frequency (MF)	300 to 3000 kHz
High frequency (HF), also known as shortwave	3 to 30 MHz
Very high frequency (VHF)	30 to 300 MHz
Ultra high frequency (UHF)	300 to 3,000 MHz
Super high frequency (SHF)	3 to 30 GHz
Extremely high frequency (EHF)	30 to 300 GHz

Microwaves have frequencies higher than about 1,000 MHz (1 GHz), which includes much of the UHF range and all of the SHF and EHF.

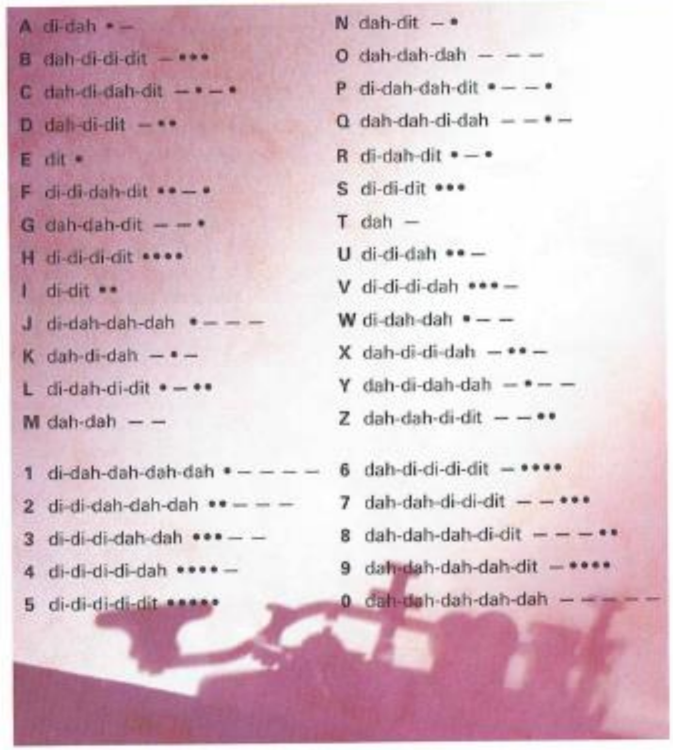
The Radio Spectrum



Look at the spectrum chart shown here. It shows where the various users of the radio spectrum ("services") fit. You should be able to locate at least eight of these services for your merit badge counselor. Locate the services that best match the option you choose in requirement 9 for the Radio merit badge. That is, if you choose the amateur radio option, you will find it most helpful to locate the various amateur radio bands.

Most radio services are located in a given area of the spectrum because something about the signals used by the service needs to be in that spot. For example, shortwave broadcasting is on several HF bands so that long-distance broadcasts to most of the world can be made 24 hours a day. Police are on VHF and UHF because these bands generally are good only for the short-range work of police radio needs. Cell phones are in the UHF and SHF spectrum, because the cell phone system works by keeping the range of any base station ("cell") short, so that the frequencies can be reused by another nearby cell—which is why you see so many cell phone towers along every highway. Other radio services are where they are for purely historical reasons.

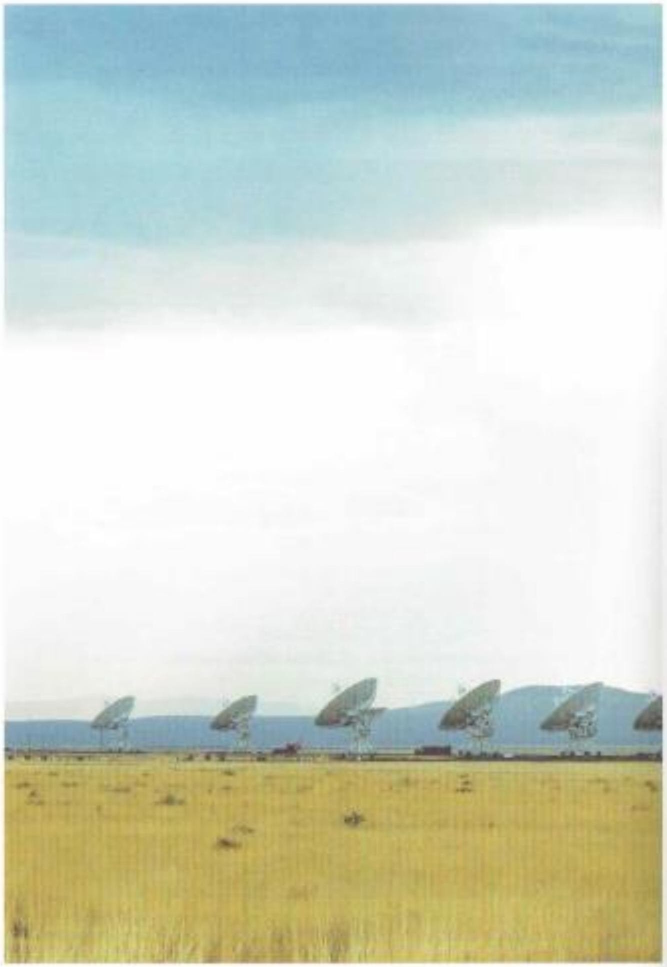
To see a detailed spectrum chart with all of the frequency allocations for the United States, visit http://www.ntia.doc.gov/osmhome/allochrt.html, website of the National Telecommunications and Information Administration, Office of Spectrum Management. Be sure to get your parent's permission first.



A di-dah • —
B dah-di-di-dit — • • •
C dah-di-dah-dit — • — •
D dah-di-dit — • •
E dit •
F di-di-dah-dit • • — •
G dah-dah-dit — — •
H di-di-di-dit • • • •
I di-dit • •
J di-dah-dah-dah • — — —
K dah-di-dah — • —
L di-dah-di-dit • — • •
M dah-dah — —
N dah-dit — •
O dah-dah-dah — — —
P di-dah-dah-dit • — — •
Q dah-dah-di-dah — — • —
R di-dah-dit • — •
S di-di-dit • • •
T dah —
U di-di-dah • • —
V di-di-di-dah • • • —
W di-dah-dah • — —
X dah-di-di-dah — • • —
Y dah-di-dah-dah — • — —
Z dah-dah-di-dit — — • •

1 di-dah-dah-dah-dah • — — — —
2 di-di-dah-dah-dah • • — — —
3 di-di-di-dah-dah • • • — —
4 di-di-di-di-dah • • • • —
5 di-di-di-di-dit • • • • •
6 dah-di-di-di-dit — • • • •
7 dah-dah-di-di-dit — — • • •
8 dah-dah-dah-di-dit — — — • •
9 dah-dah-dah-dah-dit — — — — •
0 dah-dah-dah-dah-dah — — — — —

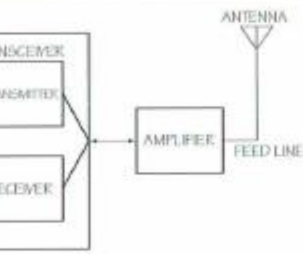
Many ham radio operators use Morse code, a sort of secret language. These short and long sounds *(di, dit, dah)* are formed when the switch (key) opens or closes the electrical circuit.



Schematics: The Code of Electronics

A *block diagram* shows a system by diagramming it as connected boxes (blocks). The blocks are usually major parts of the system. In this block diagram, for example, the boxes represent a transmitter, a receiver, a transceiver, an amplifier, and an antenna.

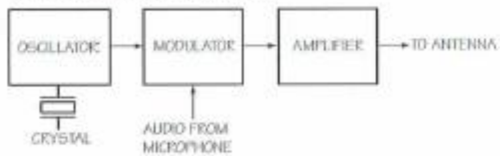
The *transceiver* is a device that combines a *transmitter* (to send radio signals) and a *receiver* (to receive radio signals). An *amplifier* makes the transmitted signals stronger. The *antenna* receives radio signals from the amplifier and sends them into the air, or picks up signals from the air for the receiver to decode. The *feed line* is a cable that connects the transceiver to the antenna.



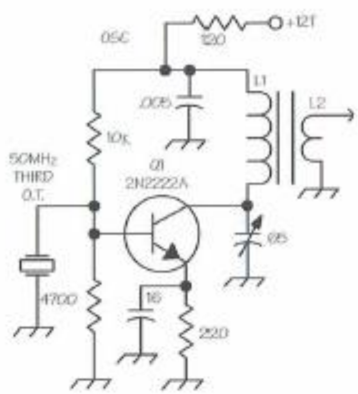
This block diagram shows the parts of a typical amateur radio station.

A *schematic diagram* or "schematic" of an electrical circuit is a drawing that shows how that circuit is built. While the blocks in the block diagram show major systems, a schematic shows how individual electronic parts are put together to form a system. In many cases, you may have both a block diagram and a schematic of the same system.

For example, you could make a block diagram of a transmitter with three blocks showing an *oscillator* (which produces an alternating current of a certain frequency) feeding a carrier to a modulator, which modulates the carrier and feeds it to an amplifier, with lines between the boxes representing the carrier and the modulated signal. Or, you could draw a schematic of the transmitter showing the collection of electronic parts (*transistors*, *resistors*, *coils*, and *capacitors*—more about these later) that make up the oscillator, modulator, and amplifier, and the wires connecting them all.



This *block diagram* shows a simple crystal-controlled transmitter.



This is the *schematic* of the circuit represented by the box labeled "oscillator" in the block diagram of the crystal-controlled transmitter. The schematic shows individual electronic parts.

Like a map, a schematic uses symbols in place of actual drawings of electronic parts. A symbol is a picture that represents a thing, such as an image of an airplane on a map to mean an airport. To read a schematic, you need to know what the symbols represent.

Ohm's Law

Before we look at some schematic symbols for electronic parts, you should be familiar with the basic law that governs electronics—Ohm's law, named after Georg Simon Ohm, a German scientist who first published his law in 1827. Ohm's law relates the three basic units of electronics: voltage, current, and resistance.

Voltage, also called *electromotive force* or EMF, is the force that causes electrons (negatively charged particles) to flow. It is measured in volts, and you can think of it like the water pressure that pushes water through a hose. The AA batteries in your flashlight supply 1.5 volts of direct current (DC). The large storage battery in a car supplies 12 volts to power the car's electrical system. The wall outlets in your room provide alternating current (AC) at 120 volts and a frequency of 60 hertz.

Current, measured in *amperes (amps)*, is the quantity of electron flow. One amp is the flow of 6.25 billion billion (6.25 followed by 18 zeros) electrons per second. You can think of current as the amount of water flowing through a hose.

Resistance opposes ("resists") the flow of current. You can think of resistance as being like a sponge stuck in that water hose. It allows water to pass through, but not as easily as in an open hose. Resistance is measured in *ohms*. Substances such as metals that have very low resistance are called *conductors*. Substances like plastic or glass that have a very high resistance are called *insulators*.

Ohm's law is usually written as an equation. Using the units of voltage, current, and resistance, here is the formula:

Volts = amps X ohms

Another way of saying Ohm's law in words is "voltage equals current times resistance."

We can use this formula to find voltage if current and resistance are known. For example, how much voltage is needed to force 2 amps of current to flow through 10 ohms of resistance? Twenty volts are required:

2 amps X 10 ohms = 20 volts

To find current if voltage and resistance are known, turn the formula around: Volts divided by ohms equal amps. How much current will flow in a circuit having 5 ohms of resistance when 15 volts are applied?

15 volts ÷ 5 ohms = 3 amps
A current of 3 amperes will flow.

Finally, the formula can be rewritten to find resistance if voltage and current are known:

Voltage ÷ current = resistance

If 12 volts cause 4 amps of current to flow through a circuit, what is the resistance of the circuit?

12 volts ÷ 4 amps = 3 ohms of resistance

Mechanical power is usually measured in horsepower; one horsepower is about 750 watts.

Using these formulas you can solve simple problems involving current, voltage, and resistance. There is one more basic quantity in electronics: *power*, the ability to do work. Power is measured in *watts*.

Power can be calculated using this formula:

Watts = amps X volts

With simple arithmetic you can determine the amount of power used by a circuit if the current and voltage are known. For example, how much power is used by a 120-volt toaster that draws 5 amps?

5 amps X 120 volts = 600 watts

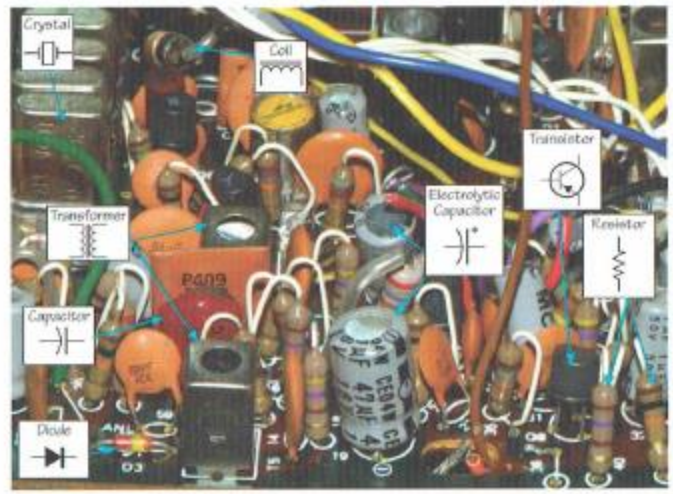
Try another practical example. Suppose the outlet in your room is on a circuit that has a 15-amp fuse. Could you plug in a 1500-watt popcorn popper without blowing the fuse? The power-line voltage is 120 volts, you will remember. Do the calculation:

1500 watts ÷ 120 volts = 12.5 amps

Yes, you can plug in that popcorn popper—but only if you don't have 2.5 amps of other things already plugged in on the same circuit. How much is that? Do the math:

2.5 amps X 120 volts = 300 watts

That would be three 100-watt lights, or a 150-watt computer and a 75-watt monitor and a 75-watt desk lamp, or . . . you get the idea.

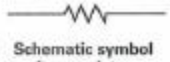


Electronic components with the schematic symbols that represent various parts

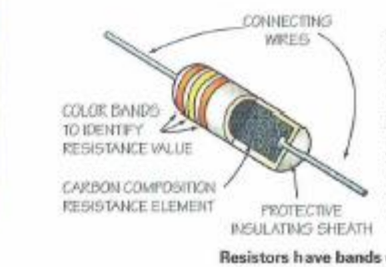
Now that you are familiar with Ohm's law and know about current, voltage, and resistance, let's look more closely at electronic components and schematic symbols.

Resistors

Resistors are electrical parts that resist the amount of current that flows through a circuit. If you were to cut open most small resistors, you would find they are just a piece of carbon, like pencil lead. Other resistors have thin wire, which is why the symbol for a resistor looks like a zigzag of wire.



Schematic symbol for a resistor



Resistors come in values from a few ohms to several million ohms. The value usually is marked on the resistor in printed numbers or using a color code. Here is the code, along with a little saying to help you memorize it: "*B*ig *b*oys *r*ace *o*ur *y*oung *g*irls, *b*ut *V*iolet *g*enerally *w*ins." It stands for black (0), brown (1), red (2), orange (3), yellow (4), green (5), blue (6), violet (7), gray (8), and white (9).

Resistors have bands of color, which let you figure their mathematical value. If you cut open a resistor, you would find it is made of carbon.

One end of the resistor will have a color band. Counting from that end, the first two bands represent a two-digit number, and the third band gives the number of zeros after the two-digit number. If you had a resistor with yellow, violet (purple), and orange bands, for example, then its value would be 4 (first digit), 7 (second digit), and three zeros, or 47,000 ohms. If there is a fourth band, it tells you how accurate the value is.

A *variable resistor* is a resistor whose value can be changed. A variable resistor can act as a volume control on a radio, controlling the amount of power supplied to the speaker.

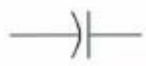
Schematic symbol for a variable resistor (Note the arrow.)

One microfarad is one-millionth of a farad.

Capacitors

A capacitor is two conductors separated by an insulator. Usually, a capacitor is formed of two metal or foil plates separated by plastic, waxed paper, or air. The amount of capacitance is measured in *farads*. The farad (F) is such a large quantity, however, that it is more common to see microfarad (µF) or even smaller values on capacitors.

Capacitors are used to block the flow of direct current (DC) but allow alternating current (AC) to pass through an electrical circuit. In combination with resistors or coils (described below), they can form a *resonant circuit* in a filter to pass or block signals by frequency, or to determine the frequency of an oscillator.



Schematic symbol for a capacitor

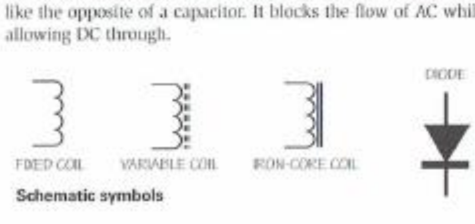
Some large-value *electrolytic* capacitors are used in power supplies to store and release a charge, to smooth out ripples in the DC voltage from the supply. You can get a painful shock from the electrolytic capacitors in a power supply long after it was last used, so it is a good idea to know what they look like. Electrolytic capacitors are usually fairly large metal cylinders, compared to the small discs of other capacitors.

A *variable capacitor* is a capacitor whose value can be changed. Variable capacitors are used in radio tuners or tunable filters, to change the frequency of a resonant circuit.

Schematic symbol for a variable capacitor (Note the arrow.)

More Electronic Components

A *choke*, or *coil*, is a coil of wire, sometimes wound around a core of ferrite (compressed iron dust) or metal. A choke works like the opposite of a capacitor. It blocks the flow of AC while allowing DC through.



Schematic symbols

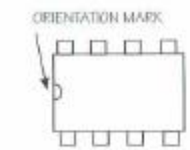
Some diodes serve other purposes. Light-emitting diodes (LEDs), for instance, are the little lightbulbs on the front of electronic equipment like stereos.

A *diode* is like a check valve. It allows electrons to flow through in only one direction. If you used a solar panel to charge a battery, you might use a diode to be sure the battery did not run itself down through the solar panel at night when the sun was no longer out.

Transistors are like faucets. A small turn on a faucet can start a large flow of water; a little current on the base of a transistor will control a much larger flow of electrons. Common types of transistors are PNP, NPN, and field effect transistors (FET). Older electronic equipment may use vacuum tubes, which work much like transistors.

The *Electronics* merit badge pamphlet covers transistors and tubes in more detail.

Schematic symbols for NPN and PNP transistors (Notice the arrow points in a different direction on each.)



Integrated circuit

An *integrated circuit*, or IC, isn't really an electronic component—it is lots of components all rolled into one small package. An IC can have thousands of transistors, resistors, and capacitors, all in a package a fraction of an inch on a side. ICs come in different shapes and sizes and can be as simple as a few transistors or as complicated as an entire computer. The central processing unit (CPU) on the computer you use is probably a single integrated circuit. Some ICs are sensitive to static electricity—you can ruin them just by touching the pins.

Schematic symbol for a speaker

Speakers or headphones turn electrical energy into sound energy. Electrical current flowing through a coil moves a magnet attached to a cone made of paper or plastic, making the cone vibrate in time to the current. The cone moves air, and sound results.

Transformers are made of two or more coils of wire, wound around a common center. They pass AC signals from one coil to another without allowing DC current to pass. In a radio, transformers are mostly used to isolate one part of the circuit from another. Such transformers can be made to pass signals of certain frequencies, and block others. If the number of turns is the same in each coil, the AC signal will pass through at the same voltage. By varying the number of turns of one coil, the transformer can increase or decrease the voltage passed from one coil to the other.

Schematic symbol for an iron core transformer

Schematic symbol for an air core transformer

The black "brick" used to power a portable computer or charge a cell phone is mostly a transformer, used to step down the 120 volts on the power line to the 5 to 20 volts needed by the computer or phone.

Crystals are carefully cut pieces of quartz. By passing an electric current through the crystal, it can be made to vibrate at very exact frequencies. A *crystal oscillator* uses the vibrations of a crystal to produce extremely accurate radio frequency signals.

Open, Closed, and Short Circuits

A circuit is a path for electricity. It is important to remember that a circuit must be a complete path from a power supply, through some number of electronic parts, and back to the power supply. Sometimes the return path to the power supply from many different components might run through the case of the equipment or even a water pipe, or a rod stuck into the earth—which is why such a return path is called a *ground*.

Schematic symbol for a ground connection

A simple circuit might be a flashlight—just a battery, a switch, and a lightbulb, and the wires connecting them. When the switch is in the "off" position, there is no complete path for the electrons and you have an *open circuit:* No current flows through an open circuit. With the switch in the "on" position, you have a *closed circuit:* Current flows correctly through its path from the battery through the switch and lightbulb, and back to the battery.

A *short circuit* happens when the current flowing through the components doesn't follow the proper course. Instead, some flaw in the circuit causes the current to flow someplace else—say, to the equipment case or another wire. A short circuit can cause wires to overheat and even catch fire.

"When my rabbit, Scone MacBunny, bit through the power wire for my laptop computer, he caused a short circuit between the power wires, which created some very entertaining sparks. At least, they seemed to be fun for the rabbit."

—Mike Brown, WB2JWD

Safety Precautions

Operating a radio station is probably less dangerous than riding in a car. To stay safe, you need to think about safety. The following is a safety code based on guidelines from the American Radio Relay League, the national association of amateur radio operators. Read it and practice it.

The most dangerous shock you can receive is one that goes from one hand to the other, directly through the heart. A current of as little as 10 milliamps (0.01 amps) can be fatal if it passes through your heart. Be very careful around any electrical power.

Radio Safety Code

1. Unplug equipment before working on it and before touching anything behind or inside the radio.
2. Never let anyone turn the power on and off for you when you are working on a radio.
3. Do not work on a radio when you are tired or sleepy. Never work alone.

4. Never adjust internal electrical components bare-handed. Use the proper plastic or insulated tools, and be sure the insulation is in good condition.
5. To prevent your body from becoming the return path from a voltage source to the ground, don't touch grounded metal (like radiators or water pipes) or wet floors when you are working on radio equipment. Never handle equipment with wet hands—water is a good conductor.
6. Never wear headphones while working on radios.
7. Keep one hand in your pocket when working on radios. That way, if you do touch a "hot" point, the electricity cannot travel across your chest and cause a heart attack.
8. Tell your family how to turn the power off and how to give artificial respiration. Be sure you are up-to-date in first aid.
9. Take the time to be careful; death is permanent.

Electricity won't give you a break because you are a beginner. Develop good safety habits now so that you can enjoy your hobby for a long time.

Be especially careful when putting up antennas. Do so only with your parent's permission and direct supervision. Be sure the antenna cannot touch a power line if it falls or while you are carrying it into position. People have been killed while they were lifting an antenna into place when the antenna touched a live electrical wire. *Never* run a wire antenna over or under power lines.

Read and follow the manufacturer's advice for safety on a ladder. Think about each step before you take it. Test each step before putting your full weight on the rung. Follow the three-point rule: Keep three parts of your body (two feet and a hand, or two hands and a foot) in contact with the ladder at all times. Also, be cautious about loose roof shingles, which can pull out and cause a fall.

Grounding

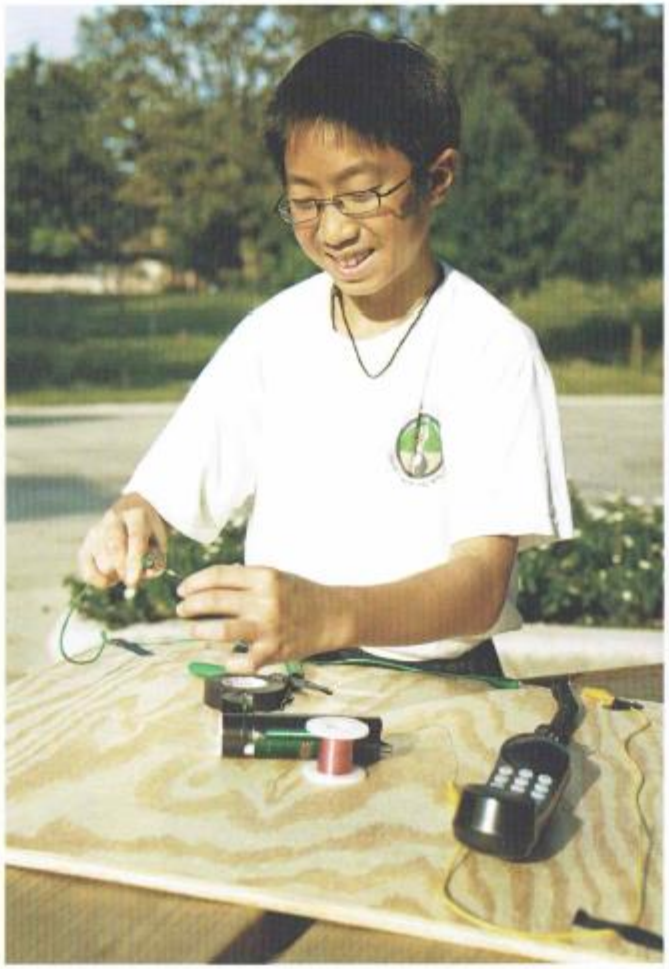
All equipment must be connected to a good ground—preferably to a long metal rod driven into the earth (which is why it is called a "ground"). There is probably a ground rod near where the power comes into your house; the electrical boxes will be connected to that rod through the ground or neutral wire in the house wiring. Connecting the case of radio equipment to a ground reduces the possibility of electrical shock should a piece of equipment fail and the radio chassis or cabinet becomes connected to the power line or some high-voltage source in the radio—that is, it becomes electrically "hot."

If connected properly, three-wire power cables plugged into three-wire grounded power outlets, or two-wire plugs with one larger pin plugged into polarized outlets, will connect the chassis to ground through your house wiring. But most amateur radio operators prefer to drive a separate ground rod close by, just for their station. A ground system to prevent shock is generally referred to as "DC ground."

Another feature of the grounding system is to provide a path to ground for any stray radio-frequency (RF) current inside the station. Stray RF can cause equipment to malfunction. Also, a good RF ground is important to make the whole station work at its best; the ground provides the "return path" for the radio waves you are sending out.

Antennas may be hit by lightning and you must provide a path to ground for the energy from lightning strikes. Ground antenna feed lines to safely bleed off static buildup during electrical storms. Many operators put *lightning protectors* in their feed lines where the lines enter the house. These devices provide a safe path for static to discharge to ground, even if the feed line is still connected to the radio.

Nothing can protect your radio against a direct lightning hit, or even a nearby strike. During stormy weather, unplug radio equipment from power outlets and disconnect the antenna feed line at the back of the radio.

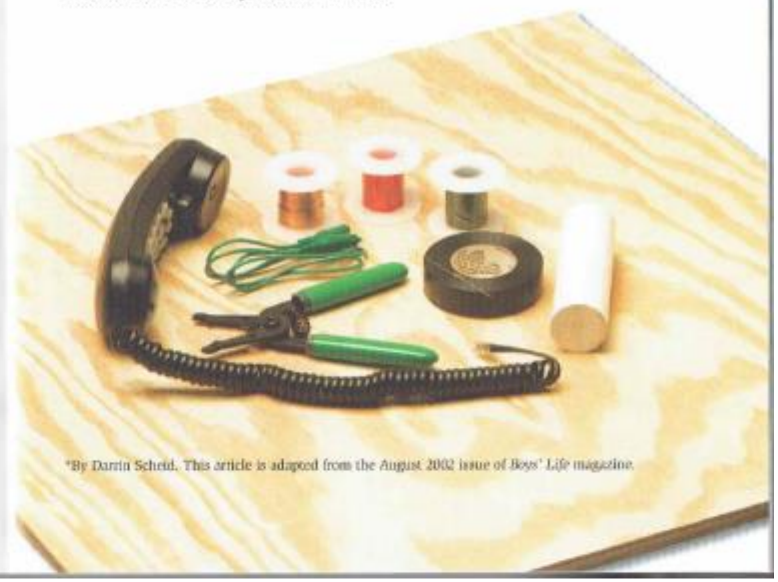


Building Project

Here is your chance to put your knowledge about electrical components, currents, and circuits to practical use. Plus, you will get a souvenir for your effort. Once you complete this project, you can try more challenging projects.

Make a Crystal Radio*

Radios might seem super high-tech. But with about $10 and one afternoon, you can make one at home. Your AM creation—also called a crystal radio—will operate the same basic way radios did in the late 1800s. A crystal radio is a simple receiver. It needs no battery or power source other than the energy of radio waves received by the antenna wire.



*By Darrin Scheid. This article is adapted from the August 2002 issue of *Boys' Life* magazine.

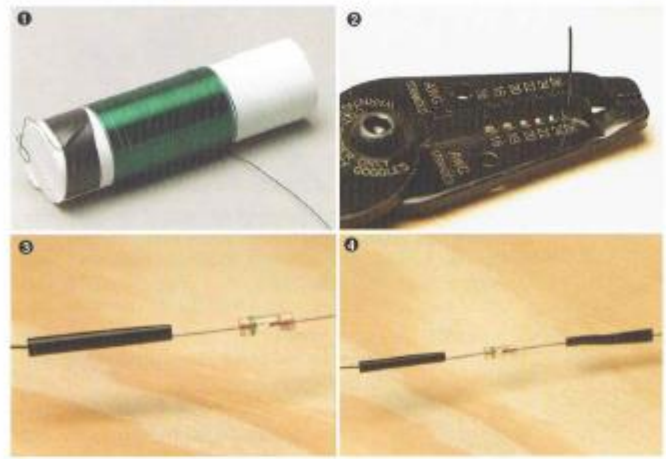
What You'll Need

- **Magnet wire.** Electronics supply stores sell a set, for about $4, that comes with 40 feet of 22-gauge, 75 feet of 26-gauge, and 200 feet of 30-gauge magnet wire.
- **1 set of alligator leads** with clips at each end.
- **1 diode.** Look for IN34A diodes, also called "germanium diodes," at an electronics supply store.
- **1 insulated tube** about 1 inch in diameter and 6 inches long. It can be a toilet paper or paper towel roll, a piece of wood, or even a glue stick, as long as it isn't metal. It doesn't have to be perfectly round, but using something round is easier for winding.
- **Electrical tape.**
- **Wire stripping pliers.**
- **Telephone handset with cord.** If you don't have an old phone that you don't use anymore, you will need to buy a telephone cord, then borrow the handset from a phone to make the radio work. (Get your parent's permission first.)
- **One board** for mounting your radio—2 feet by 2 feet will work. You can make the radio without this, but having a workspace and a place to mount the radio makes it easier to carry around while you're looking for a place to hook the ground wire.

What You'll Do

Step 1—Wind 26-gauge wire (the green magnet wire) around the insulated tube until it covers nearly the entire cylinder. Keep the wire tight. Leave about 6 inches of wire on each end. Once you are finished winding it, tape around both ends of the cylinder to make sure the wire holds. Then mount the coil to the board with electrical tape.

Step 2—Strip the ends of the wire you have left from each end of the coil. Use wire stripping pliers or sandpaper to remove the enamel or coating and expose about 1 inch of wire.



Step 3—Attach the wire from the right side of the coil to one end of your diode. Tape the connection.

Step 4—Cut the end of the phone cord and strip about 2 inches of it. Removing the outer insulation should expose two wires. Strip those wires. This wire is thin; take your time and work carefully. (Tip: Before hooking up the tiny telephone cord wires, get some thicker insulated magnet wire and tape about 2 inches to each wire. This will make the rest of the task easier.) Attach one end of the wire to the exposed end of the diode. Tape that connection.