
Chapter 1

Safety First

Safety begins with your attitude. If you make it a habit to plan your work carefully and to consider the safety aspects of a project before you begin the work, you will be much safer than “Careless Carl,” who just jumps in, proceeding in a haphazard manner. Learn to have a positive attitude about safety. Think about the dangers involved with a job before you begin the work. Don’t be the one to say, “I didn’t think it could happen to me.”

Having a good attitude about safety isn’t enough, however. You must be knowledgeable about common safety guidelines and follow them faithfully. Safety guidelines can’t possibly cover all the situations you might face, but if you approach a task with a measure of “common sense,” you should be able to work safely.

This chapter offers some safety guidelines and protective measures for you and your Amateur Radio station. You should not consider it to be an all-inclusive discussion of safety practices, though. Safety considerations will affect your choice of materials and assembly procedures when building an antenna. Other chapters of this book will offer further suggestions on safe construction practices. For example, [Chapter 22](#) includes some very important advice on constructing a proper base for your tower installation.

PUTTING UP SIMPLE WIRE ANTENNAS

No matter what type of antenna you choose to erect, you should remember a few key points about safety. If you are using a slingshot or bow and arrow to get a line over a tree, make sure you keep everyone away from the “downrange” area. Hitting one of your helpers with a rock or fishing sinker is considered not nice, and could end up causing a serious injury.

Make sure the ends of the antenna are high enough to be out of reach of passersby. Even when you are transmitting with low power there may be enough voltage at the ends of your antenna to give someone nasty “RF burns.” If you have a vertical antenna with its base at ground level, build a wooden safety fence around it at least 4 feet away from it. Do not use metal fence, as this will interfere with the proper operation of the antenna. Be especially certain that your antenna is not close to any power wires. That is the *only* way you can be sure it won’t come in contact with them.

Antenna work often requires that one person climb up on a tower, into a tree or onto the roof of a house. Never work alone! Work slowly, thinking out each move before you make it. The person on the ladder, tower, tree or rooftop should wear a safety belt, and keep it securely anchored. It is helpful (and safe!) to tie strings or lightweight ropes to all tools. If your tools are tied on, you’ll save time getting them back if you drop them, and you’ll greatly reduce the risk of injuring a helper on the ground. (There are more safety tips for climbing and working on towers later in this chapter. Those tips apply to any work that you must do above the ground to install even the simplest antenna.)

Tower Safety

Working on towers and antennas is dangerous, and possibly fatal, if you do not know what you are doing. Your tower and antenna can cause serious property damage and personal injury if any part of the installation should fall. Always use the highest quality materials in your system. Follow the manufacturer's specifications, paying close attention to base pier and guying details. Do not overload the tower. If you have any doubts about your ability to work on your tower and antennas safely, contact another amateur with experience in this area or seek professional assistance.

Chapter 22 provides more detailed guidelines for constructing a tower base and putting up a tower. It also explains how to properly attach guy wires and install guy anchors in the ground. These are extremely important parts of a tower installation, and you should not take shortcuts or use second-rate materials. Otherwise the strength and safety of your entire antenna may be compromised.

Any mechanical job is easier if you have the right tools. Tower work is no exception. In addition to a good assortment of wrenches, screwdrivers and pliers, you will need some specialized tools to work safely and efficiently on a tower. You may already own some of these tools. Others may be purchased or borrowed. Don't start a job until you have assembled all of the necessary tools. Shortcuts or improvised tools can be fatal if you gamble and lose at 70 feet in the air. The following sections describe in detail the tools you will need to work safely on a tower.

CLOTHING

The clothing you wear when working on towers and antennas should be selected for maximum comfort and safety. Wear clothing that will keep you warm, yet allow complete freedom of movement. Long denim pants and a long-sleeve shirt will protect you from scrapes and cuts. (A pull-on shirt, like a sweat shirt with no openings or buttons to snag on tower parts, is best.) Wear work shoes with heavy soles, or better yet, with steel shanks (steel inserts in the soles), to give your feet the support they need to stand on a narrow tower rung.

Gloves are necessary for both the tower climber and all ground-crew members. Good quality leather gloves will protect hands from injury and keep them warm. They also offer protection and a better grip when you are handling rope. In cooler weather, a pair of gloves with light insulation will help keep your hands warm. The insulation should not be so bulky as to inhibit movement, however.

Ground-crew members should have hard hats for protection in case something falls from the tower. It is not uncommon for the tower climber to drop tools and hardware. A wrench dropped from 100 feet will bury itself several inches in soft ground; imagine what it might do to an unprotected skull.

SAFETY BELT AND CLIMBING ACCESSORIES

Any amateur with a tower *must* own a high-quality safety belt, such as the one shown in Fig 1. Do not attempt to climb a tower, even a



Fig 1—Bill Lowry, W1VV, uses a good quality safety belt, a requirement for working on a tower. The belt should contain large steel loops for the snap straps. Leather loops at the rear of the belt are handy for holding tools. (photo by K1WA)

short distance, without a belt. The climbing belt is more than just a safety device for the experienced climber. It is a tool to free up both hands for work. The belt allows the climber to lean back away from the tower to reach bolts or connections. It also provides a solid surface to lean against to exert greater force when hoisting antennas into place.

A climber must trust his life to his safety belt. For this reason, nothing less than a professional quality, commercially made, tested and approved safety belt is acceptable. Check the suppliers' list in [Chapter 21](#) and ads in *QST* for suppliers of climbing belts and accessories. Examine your belt for defects *before each use*. If the belt or lanyard (tower strap) are cracked, frayed or worn in any way, destroy the damaged piece and replace it with a new one. You should never have to wonder if your belt will hold.

Along with your climbing belt, you should seriously consider purchasing some climbing accessories. A canvas bucket is a great help for carrying tools and hardware up the tower. Two buckets, a large one for carrying tools and a smaller one for hardware, make it easier to find things when needed. A few extra snap hooks like those on the ends of your belt lanyard are useful for attaching tool bags and equipment to the tower at convenient spots. These hooks are better than using rope and tying knots because in many cases they can be hooked and unhooked with one hand.

Gorilla hooks, shown in **Fig 2**, are especially useful for ascending and descending the tower. They attach to the belt and are hooked to the tower on alternating rungs as the climber progresses. With these hooks, the climber is secured to the tower at all times. Gorilla hooks were specially designed for amateur climbers by Ron Williams, W9JVF, 1408 W Edgewood, Indianapolis, IN 46217-3618.

Rope and Pulley

Every amateur who owns a tower should also own a good quality rope at least twice as long as the tower height. The rope is essential for safely erecting towers and installing antennas and cables. For most installations, a good quality $\frac{1}{2}$ -inch diameter manila hemp rope will do the job, although a thicker rope is stronger and may be easier to handle. Some types of polypropylene rope are acceptable also; check the manufacturer's strength ratings. Nylon rope is not recommended because it tends to stretch and cannot be knotted securely without difficulty.

Check your rope *before each use* for tearing or chafing. Do not attempt to use damaged rope; if it breaks with a tower section or antenna in mid-air, property damage and personal injury are likely results. If your rope should get wet, let it air dry thoroughly before putting it away.

Another very worthwhile purchase is a pulley like the one shown in **Fig 3**. Use the right size pulley for your rope. Be sure that the pulley you purchase will not jam or bind as the rope passes through it.

THE GIN POLE

A gin pole, like the one shown in **Fig 4**, is a handy device for working with tower sections and masts. This gin pole is designed to clamp onto one leg of Rohn No. 25 or 45 tower. The tubing, which

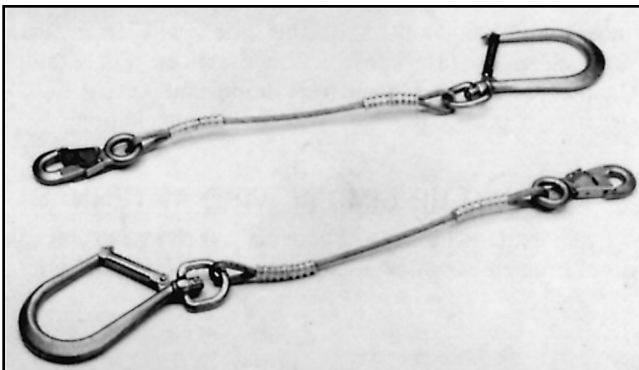


Fig 2—Gorilla hooks are designed to keep the climber attached to the tower at all times when ascending and descending.

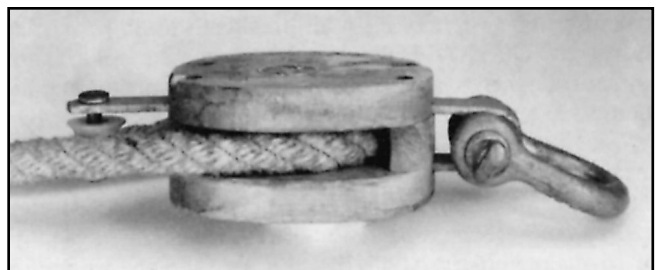


Fig 3—A good quality rope and pulley are essential for anyone working on towers and antennas. This pulley is encased in wood so the rope cannot jump out of the pulley wheel and jam.

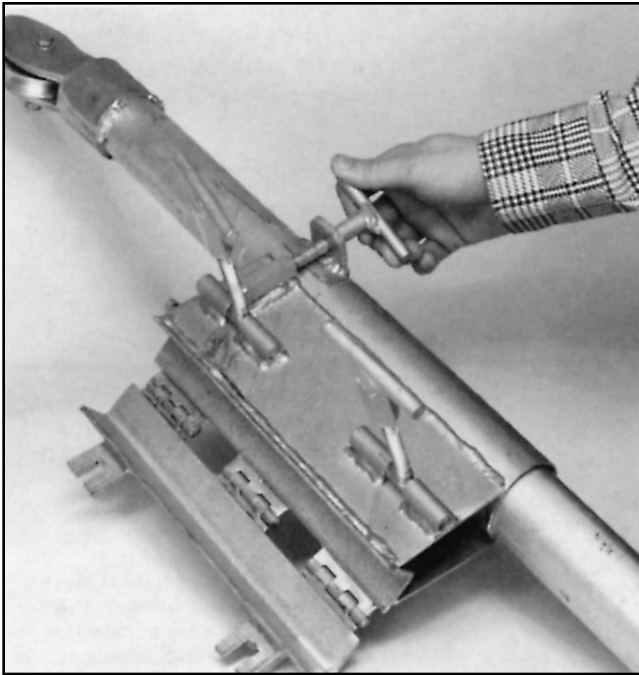


Fig 4—A gin pole is a mechanical device that can be clamped to a tower leg to aid in the assembly of sections as well as the installation of the mast. The aluminum tubing extends through the clamp and may be slipped into position before the tubing clamp is tightened. A rope should be routed through the tubing and over the pulley mounted at the top.



Fig 5—The assembly of tower sections is made simple when a gin pole is used to lift each one into position. Note that the safety belts of both climbers are fastened below the pole, thereby preventing the strap from slipping over the top section. (photo by K1WA)

is about 12 feet long, has a pulley on one end. A rope is routed through the tubing and over the pulley. When the gin pole is attached to the tower and the tubing extended into place, the rope may be used to haul tower sections or the mast into place. **Fig 5** shows the basic process.

A gin pole can be expensive for an individual to buy, especially for a one-time tower installation. Some radio clubs own a gin pole for use by their members. Stores that sell tower sections to amateurs and commercial customers frequently will rent a gin pole to erect the tower. If you attempt to make your own gin pole, use materials heavy enough for the job. Provide a means for securely clamping the pole to the tower. There are many cases on record where homemade gin poles have failed, sending tower sections crashing down amidst the ground crew.

When you use a gin pole, make every effort to keep the load as vertical as possible. Although gin poles are strong, you are asking for trouble if you apply too much lateral force.

INSTALLING ANTENNAS ON THE TOWER

All antenna installations are different in some respects. Therefore, thorough planning is the most important first step in installing any antenna. At the beginning, before anyone climbs the tower, the whole process should be thought through. The procedure should be discussed to be sure each crew member understands what is to be done. Plan how to work out all bugs. Consider what tools and parts must be assembled and what items must be taken up the tower. Extra trips up and down the tower can be avoided by using forethought.

Getting ready to raise a beam requires planning. Done properly, the actual work of getting the antenna into position can be accomplished quite easily with only one person at the top of the tower. The trick is to let the ground crew do all the work and leave the person free to guide the antenna into position.

Before the antenna can be hoisted into position, the tower and the area around it must be prepared. The ground crew should clear the area around the base while someone climbs the tower to remove any wire antennas or other objects that might get in the way. The first person to climb the tower should also rig the rope and pulley that will be used to raise the antenna. The time to prepare the tower is before the antenna leaves the ground, not after it becomes hopelessly entangled with your 3.5 MHz dipole.

SOME TOWER CLIMBING TIPS

The following tower climbing safety tips were compiled by Tom Willeford, N8ETU. The most important safety factor in any kind of hazardous endeavor is the right attitude. Safety is important and worthy of careful consideration and implementation. The right attitude toward safety is a requirement for tower climbers. Lip service won't do, however; safety must be practiced.

The safe ham's safety attitude is simple: *Don't take any unnecessary chances*. There are no exceptions to this plain and simple rule. It is the first rule of safety and, of course, of climbing. The second rule is equally simple: *Don't be afraid to terminate an activity* (climbing, in this case) at any time if things don't seem to be going well.

Take time to plan your climb; this time is never wasted, and it's the first building block of safety. Talk the climb over with friends who will be helping you. Select the date and alternative dates to do the work. Choose someone to be responsible for all activities on the ground and for all communication with the climbers. Study the structure to be climbed and choose the best route to your objective. Plan emergency ascent and descent paths and methods.

Make a list of emergency phone numbers to keep by your phone, even though they may never be used. Develop a plan for rescuing climbers from the structure, should that become necessary.

Give careful thought to how much time you will need to complete the project. Allow enough time to go up, do the work, and then climb down during daylight hours. Include time for resting during the climb and for completing the work in a quality fashion. Remember that the temperature changes fast as the sun goes down. Climbing up or down a tower with cold hands and feet is very difficult—and dangerous.

Give careful consideration to the weather, and climb only in good weather. Investigate wind conditions, the temperature and the weather forecast. The weather can change quickly, so if you're climbing a really tall tower it may be a good idea to have a weather alert radio handy during the climb. *Never* climb a wet tower.

The person who is going to do the climbing should be the one to disconnect and tag all sources of power to the structure. All switches or circuit breakers should be labeled clearly with DO NOT TOUCH instructions. Use locks on any switches designed to accept them. (See **Fig 6**.) Only the climber should reconnect power sources.

An important part of the climbing plan is to review notes on the present installation and any previ-

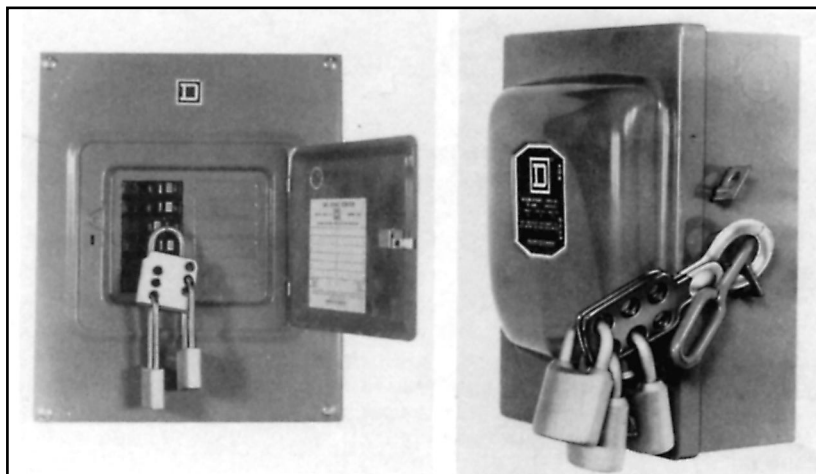


Fig 6—If the switch box feeding power to equipment on your tower is equipped with a lock-out hole, use it. With a lock through the hole on the box, the power cannot be accidentally turned back on. (Photos courtesy of American ED-CO, at left, and Osborn Mfg Corp, at right.)

ous work. It's a good idea to keep a notebook, listing every bolt and nut size on your tower/antenna installation. Then, when you have to go up to make repairs, you'll be able to take the minimum number of tools with you to do the job. If you take too many tools up the tower, there is a much greater chance of dropping something, risking injury to the ground crew and possibly damaging the tool.

It is also a good idea to review the instruction sheets and take them with you. In other words, plan carefully what you are going to do, and what you'll need to do it efficiently and safely.

It's better to use a rope and pulley to hoist tools. Climbing is hard work and there's no sense making it more difficult by carrying a big load of tools. Always rig the pulley and rope so the ground crew raises and lowers tools and equipment.

Climbing Equipment

Equipment is another important safety consideration. By equipment, we don't just mean tools. We mean safety equipment. Safety equipment should be selected and cared for as if your life depends on it—because it does!

The list of safety equipment essential to a safe climb and safe work on the tower should include:

- 1) A first class safety belt,
- 2) Safety glasses,
- 3) Hard hat,
- 4) Long-sleeved, pullover shirt with no buttons or openings to snag (long sleeves are especially important for climbing wooden poles),
- 5) Long pants without cuffs,
- 6) Firm, comfortable, steel-shank shoes with no-slip soles and well-defined heels, and
- 7) Gloves that won't restrict finger movement (insulated gloves if you *must* work in cold weather).

Your safety belt should be approved for use on the structure you are climbing. Different structures may require different types of safety hooks or straps. The belt should be light weight, but strength should not be sacrificed to save weight. It should fit you comfortably. All moving parts, such as snap hooks, should work freely. You should inspect safety belts and harnesses carefully and thoroughly before each climb, paying particular attention to stitching, rivets and weight-bearing mechanical parts.



Fig 7—Mark Wilson, AA2Z, shows the proper way to attach a safety hook, with the opening facing away from the tower. That way the hook can't be accidentally released by pressing it against a tower leg.

Support belt hooks should always be hooked to the D rings in an outward configuration. That is, the opening part of the hook should face away from the tower when engaged in the D rings (see **Fig 7**). Hooks engaged this way are easier to unhook deliberately but won't get squeezed open by a part of the tower or engage and snag a part of the tower while you are climbing. The engagement of these hooks should always be checked visually. A snapping hook makes the same sound whether it's engaged or not. Never check by sound—look to be sure the hook is engaged properly before trusting it.

Remember that the D rings on the safety belt are for support hooks *only*. No tools or lines should be attached to these hooks. Such tools or lines may prevent the proper engagement of support belt hooks, or they may foul the hooks. At best, they could prevent the release of the hooks in an emergency. No one should have to disconnect a support hook to get a tool and then have to reconnect the

support hook before beginning to work again. That's foolish.

Equipment you purchase new is best. Homemade belts or home-spliced lines are dangerous. Used belts may have worn or defective stitching, or other faulty components. Be careful of "bargains" that could cost you your life.

Straps, lanyards and lines should be as short as possible. Remember, in general knots reduce the load strength of a line by approximately 50%.

Before actually climbing, check the structure visually. Review the route. Check for obstacles, both natural (like wasp's nests) and man-made. Check the structure supports and add more if necessary. Guy wires can be obstacles to the climb, but it's better to have too many supports than not enough. Check your safety belt, support belts and hooks at the base of the tower. Really test them before you need them. Never leave the ground without a safety belt—even 5 or 10 feet. After all of this, the climb will be a "cakewalk" if you are careful.

Climb slowly and surely. Don't overreach or overstep. Patience and watchfulness is rewarded with good hand and foot holds. Take a lesson from rock climbers. Hook on to the tower and rest periodically during the climb. Don't try to rest by wedging an arm or leg in some joint; to rest, hook on. Rests provide an opportunity to review the remainder of the route and to make sure your safety equipment feels good and is working properly. Rest periods also help you conserve a margin of energy in case of difficulty.

Finally, keep in mind that the most dangerous part of working on a tower occurs when you are actually climbing. Your safety equipment is not hooked up at this time, so be extra careful during the ascent or descent.

You must climb the tower to install or work on an antenna. Nevertheless, any work that can be done on the ground should be done there. If you can do any assembly or make any adjustments on the ground, that's where you should do the work! The less time you have to spend on the tower, the better off you'll be.

When you arrive at the work area, hook on to the tower and review what you have to do. Determine the best position to do the work from, disconnect your safety strap and move to that position. Then reconnect your safety strap at a safe spot, away from joints and other obstacles. If you must move around an obstacle, try to do it while hooked on to the tower. Find a comfortable position and go to work. Don't overreach—move to the work.

Use the right tool for the task. If you don't have it, have the ground crew haul it up. Be patient. Lower tools, don't drop them, when you are finished with them. Dropped tools can bounce and cause injury or damage, or can be broken or lost. It's a good idea to tie a piece of string or light rope to the tools, and to tie the other end to the tower or some other point so if you do drop a tool, it won't fall all the way to the ground. Don't tie tools to the D ring or your safety belt, however!

Beware of situations where an antenna may be off balance. It's hard to obtain the extra leverage needed to handle even a small beam when you are holding it far from the balance point. Leverage can apply to the climber as well as the device being levered. Many slips and skinned knuckles result from such situations. A severely injured hand or finger can be a real problem to a climber.

Before descending, be sure to check all connections and the tightness of all the bolts and nuts that you have worked with. Have the ground crew use the rope and pulley to lower your tools. Lighten your load as much as possible. Remember, you're more tired coming down than going up. While still hooked on, wiggle your toes and move a little to get your senses working again. Check your downward route and begin to descend slowly and even more surely than you went up. Rest is even more important during the descent.

The ground captain is the director of all activities on the ground, and should be the only one to communicate with a person on a tower. Hand-held transceivers can be very helpful for this communication, but no one else should transmit to the workers on the tower. Even minor confusion or misunderstanding about a move to be made could be very dangerous.

"Antenna parties" can be lots of fun, but the joking and fooling around should wait until the job is done and everyone is down safely. Save the celebrating until after the work is completed, even for the ground crew.

These are just a few ideas on tower climbing safety; no list can include everything you might run into. You can't be too careful when climbing. Keep safety in mind while doing antenna work, and help ensure that after you have fallen *for* ham radio, you don't fall *from* ham radio.

THE TOWER SHIELD

A tower can be legally classified as an “attractive nuisance” that could cause injuries. You should take some precautions to ensure that “unauthorized climbers” can't get hurt on your tower. This tower shield was originally described by Baker Springfield, W4HYY, and Richard Ely, WA4VHM, in September 1976 *QST*, and should eliminate the worry.

Generally, the “attractive nuisance” doctrine applies to your responsibility to trespassers on your property. (The law is much stricter with regard to your responsibility to an invited guest.) You should expect your tower to attract children, whether they are already technically trespassing or whether the tower itself lures them onto your property. A tower is dangerous to children, especially because of their inability to appreciate danger. (What child could resist trying to climb a tower once they see one?) Because of this danger, you have a legal duty to exercise reasonable care to eliminate the danger or otherwise protect children against the perils of the attraction.

The tower shield is composed simply of panels that enclose the tower and make climbing practically impossible. These panels are 5 feet in height and are wide enough to fit snugly between the tower legs and flat against the rungs. A height of 5 feet is sufficient in almost every case. The panels are constructed from 18-gauge galvanized sheet metal obtained and cut to proper dimensions from a local sheet-metal shop. A lighter gauge could probably be used, but the extra physical weight of the heavier gauge is an advantage if no additional means of securing the panels to the tower rungs are used. The three types of metals used for the components of the shield are supposedly rustproof and nonreactive. The panels are galvanized sheet steel, the brackets aluminum, and the screws and nuts are brass. For a triangular tower, the shield consists of three panels, one for each of the three sides, supported by two brackets. Construct these brackets from 6-inch pieces of thin aluminum angle stock. Bolt two of the pieces together to form a Z bracket (see **Figs 8, 9 and 10**). The Z brackets are bolted together with binding head brass machine screws.

Lay the panels flat for measuring, marking and drilling. First measure from the top of the upper mounting rung on the tower to the top of the bottom rung. (Mounting rungs are selected to position the panel on the tower.) Then mark this distance on the panels. Use the same size brass screws and nuts throughout the shield. Bolt the top vertical portion of each Z bracket to the panel. Drill the mounting-screw holes about 1 inch from the end of the Z brackets so there is an offset clearance between the Z-bracket binding-screw holes and the panel-bracket mounting-screw holes. Drill holes in each panel to match the Z-bracket holes.

The panels are held on the tower by their own weight. They are not easy to grasp because they fit snugly between the tower legs. If you feel a need for added safety against deliberate removal of the panels, this can be accomplished by means of tie wires. Drill a small hole in the panel just above, just below, and in the center of each Z bracket. Run a piece of heavy galvanized wire through the top hole, around the Z bracket, and then back through the hole just below the Z bracket. Twist together the two ends of the wire. One tie wire should be sufficient for each panel, but use two if desired.

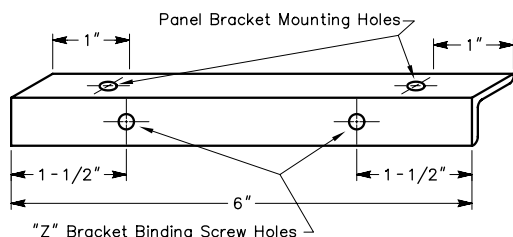


Fig 8—Z-bracket component pieces.

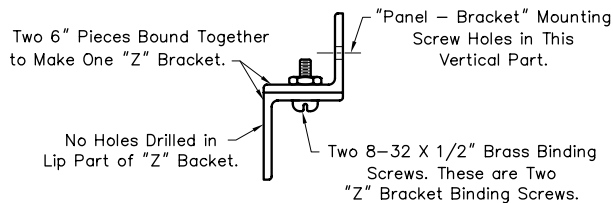


Fig 9—Assembly of the Z bracket.

PANEL WITH MOUNTED "Z" BRACKET

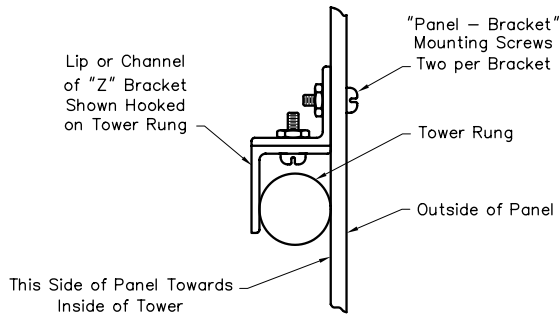
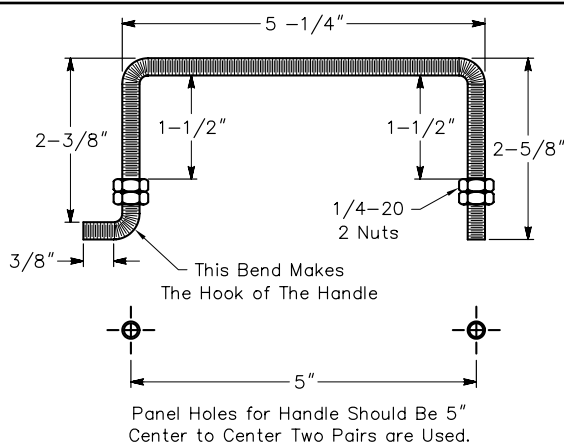


Fig 10—Installation of the shield on a tower rung.

The completed panels are rather bulky and difficult to handle. A feature that is useful if the panels have to be removed often for tower climbing or accessibility is a pair of removable handles. The removable handles can be constructed from one threaded rod and eight nuts (see **Fig 11**). Drill two pair of handle holes in the panels a few inches below the top Z bracket and several inches above the bottom Z bracket. For panel placement or removal, you can hook the handles in these panel holes. The hook, on the top of the handle, fits into the top hole of each pair of the handle holes. The handle is optional, but for the effort required it certainly makes removal and replacement much safer and easier.

Fig 12 shows the shield installed on a tower. This relatively simple device could prevent an accident.



Notes:

1. Standard Rodstock 1/4"-20 X 36" was Used.
2. Two Pieces were Cut from Rod Stock. Each Approximately 10 7/8".
3. Make The Three Bends of The Rod in Vise.
4. Two Nuts 1/4-20 of The Same Threads as Rods. Jam or Lock Together. This Makes a Handle Stop.

Fig 11—Removable handle construction.

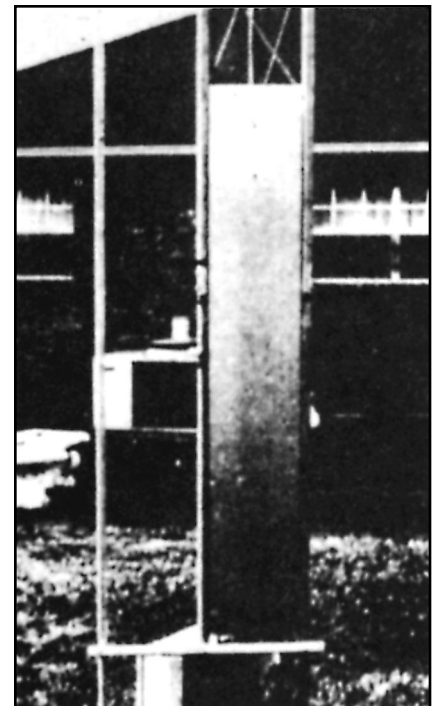


Fig 12—Installed tower shield. Note the holes for using the handles.

Electrical Safety

Although the RF, ac and dc voltages in most amateur stations pose a potentially grave threat to life and limb, common sense and knowledge of safety practices will help you avoid accidents. Building and operating an Amateur Radio station can be, and is for almost all amateurs, a perfectly safe pastime. However, carelessness can lead to severe injury, and even death. The ideas presented here are only guidelines; it would be impossible to cover all safety precautions. Remember, there is no substitute for common sense.

A fire extinguisher is a requirement for the well-equipped amateur station. The fire extinguisher should be of the carbon-dioxide type to be effective in electrical fires. Store it in an easy-to-reach spot and check it at recommended intervals.

Family members should know how to turn the power off in your station. They should also know how to apply artificial respiration. Many community groups offer courses on cardiopulmonary resuscitation (CPR).

AC AND DC SAFETY

The primary wiring for your station should be controlled by one master switch, and other members of your family should know how to kill the power in an emergency. All equipment should be connected to a good ground. All wires carrying power around the station should be of the proper size for the current to be drawn and should be insulated for the voltage level involved. Bare wire, open-chassis construction and exposed connections are an invitation to accidents. Remember that high-current, low-voltage power sources are just as dangerous as high-voltage, low-current sources. Possibly the most-dangerous voltage source in your station is the 120-V primary supply; it is a hazard often overlooked because it is a part of everyday life. Respect even the lowliest power supply in your station.

Whenever possible, kill the power and unplug equipment before working on it. Discharge capacitors with an insulated screwdriver; don't assume the bleeder resistors are 100% reliable. In a power amplifier, always short the tube plate cap to ground just to be sure the supply is discharged. If you must work on live equipment, keep one hand in your pocket. Avoid bodily contact with any grounded object to prevent your body from becoming the return path from a voltage source to ground. Use insulated tools for adjusting or moving any circuitry. Never work alone. Have someone else present; it could save your life in an emergency.

National Electrical Code

The National Electrical Code is a comprehensive document that details safety requirements for all types of electrical installations. In addition to setting safety standards for house wiring and grounding, the Code also contains a section on Radio and Television Equipment—Article 810. Sections C and D specifically cover Amateur Transmitting and Receiving Stations. Highlights of the section concerning Amateur Radio stations follow. If you are interested in learning more about electrical safety, you may purchase a copy of *The National Electrical Code* or *The National Electrical Code Handbook*, edited by Peter Schram, from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

Antenna installations are covered in some detail in the Code. It specifies minimum conductor sizes for different length wire antennas. For hard-drawn copper wire, the Code specifies #14 wire for open (unsupported) spans less than 150 feet, and #10 for longer spans. Copper-clad steel, bronze or other high-strength conductors may be #14 for spans less than 150 feet and #12 wire for longer runs. Lead-in conductors (for open-wire transmission line) should be at least as large as those specified for antennas.

The Code also says that antenna and lead-in conductors attached to buildings must be firmly mounted at least 3 inches clear of the surface of the building on nonabsorbent insulators. The only exception to this minimum distance is when the lead-in conductors are enclosed in a “permanently and effectively grounded” metallic shield. The exception covers coaxial cable.

According to the Code, lead-in conductors (except those covered by the exception) must enter a

building through a rigid, noncombustible, nonabsorbent insulating tube or bushing, through an opening provided for the purpose that provides a clearance of at least 2 inches or through a drilled window pane. All lead-in conductors to transmitting equipment must be arranged so that accidental contact is difficult.

Transmitting stations are required to have a means of draining static charges from the antenna system. An antenna discharge unit (lightning arrester) must be installed on each lead-in conductor (except where the lead-in is protected by a continuous metallic shield that is permanently and effectively grounded, or the antenna is permanently and effectively grounded). An acceptable alternative to lightning arrester installation is a switch that connects the lead-in to ground when the transmitter is not in use.

Grounding connectors are described in detail in the Code. Grounding connectors may be made from copper, aluminum, copper-clad steel, bronze or similar erosion-resistant material. Insulation is not required. The “protective grounding conductor” (main conductor running to the ground rod) must be as large as the antenna lead-in, but not smaller than #10. The “operating grounding connector” (to bond equipment chassis together) must be at least #14. Grounding conductors must be adequately supported and arranged so they are not easily damaged. They must run in as straight a line as practical between the mast or discharge unit and the ground rod.

The Code also includes some information on safety inside the station. All conductors inside the building must be at least 4 inches away from conductors of any lighting or signaling circuit except when they are separated from other conductors by conduit or a nonconducting material. Transmitters must be enclosed in metal cabinets, and the cabinets must be grounded. All metal handles and controls accessible by the operator must be grounded. Access doors must be fitted with interlocks that will disconnect all potentials above 350 V when the door is opened.

Ground

An effective ground system is necessary for every amateur station. The mission of the ground system is twofold. First, it reduces the possibility of electrical shock if something in a piece of equipment should fail and the chassis or cabinet becomes “hot.” If connected properly, three-wire electrical systems ground the chassis, but older amateur equipment may use the ungrounded two-wire system. A ground system to prevent shock hazards is generally referred to as “dc ground.”

The second job the ground system must perform is to provide a low-impedance path to ground for any stray RF current inside the station. Stray RF can cause equipment to malfunction and contributes to RFI problems. This low-impedance path is usually called “RF ground.” In most stations, dc ground and RF ground are provided by the same system.

The first step in building a ground system is to bond together the chassis of all equipment in your station. Ordinary hookup wire will do for a dc ground, but for a good RF ground you need a low-impedance conductor. Copper strap, sold as “flashing copper,” is excellent for this application, but it may be hard to find. Braid from coaxial cable is a popular choice; it is readily available, makes a low-impedance conductor, and is flexible.

Grounding straps can be run from equipment chassis to equipment chassis, but a more convenient approach is illustrated in **Fig 13**. In this installation, a 1/2-inch diameter copper water pipe runs the entire length of the operating bench. A thick braid (from discarded RG-8 cable) runs from each piece of equipment to a clamp on the pipe. Copper water pipe is available at most hardware stores and home centers. Alternatively, a strip of flashing copper may be run along the rear of the operating bench.

After the equipment is bonded to a common ground bus, the ground bus must be wired to a good earth ground. This run should be made with a heavy conductor (braid is a popular choice, again) and should be as short and direct as possible. The earth ground usually takes one of two forms.

In most cases, the best approach is to drive one or more ground rods into the earth at the point where the conductor from the station ground bus leaves the house. The best ground rods to use are those available from an electrical supply house. These rods are 8 to 10 feet long and are made from steel with a heavy copper plating. Do not depend on shorter, thinly plated rods sold by some home

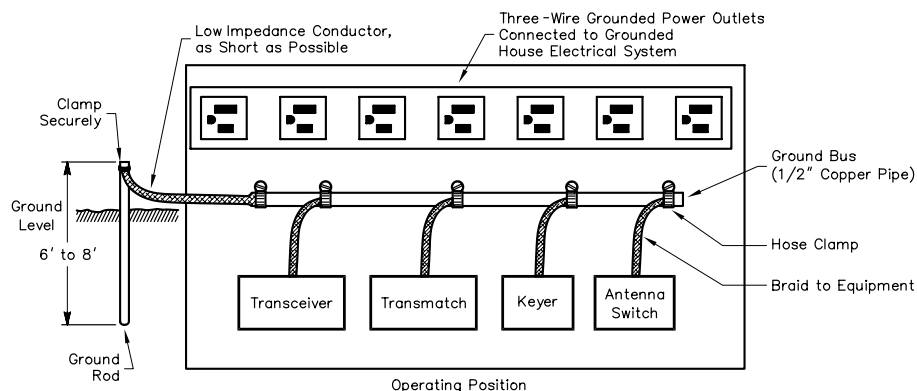


Fig 13—An effective station ground bonds the chassis of all equipment together with low-impedance conductors and ties into a good earth ground.

electronics suppliers. These rods begin to rust almost immediately after they are driven into the soil, and become worthless within a short time. Good ground rods, while more expensive initially, offer long-term protection.

If your soil is soft and contains few rocks, an acceptable alternative to “genuine” ground rods is 1/2-inch diameter copper water pipe. A 6- to 8-foot length of this material offers a good ground, but it may bend while being driven into the earth. Some people have recommended that you make a connection to a water line and run water down through the copper pipe so that it forces its own hole in the ground. There may be a problem with this method, however. When the ground dries, it may shrink away from the pipe and not make proper contact with the ground rod. This would provide a rather poor ground.

Once the ground rod is installed, clamp the conductor from the station ground bus to it with a clamp that can be tightened securely and will not rust. Copper-plated clamps made especially for this purpose are available from electrical supply houses, but a stainless-steel hose clamp will work too. Alternatively, drill several holes through the pipe and bolt the conductor in place. If a torch is available, solder the connection.

Another popular station ground is the cold water pipe system in the building. To take advantage of this ready made ground system, run a low-impedance conductor from the station ground bus to a convenient cold water pipe, preferably somewhere near the point where the main water supply enters the house. Avoid hot water pipes; they do not run directly into the earth. The advent of PVC (plastic) plumbing makes it mandatory to inspect the cold water system from your intended ground connection to the main inlet. PVC is an excellent insulator, so any PVC pipe or fittings rule out your cold water system for use as a station ground.

For some installations, especially those located above the first floor, a conventional ground system such as that just described will make a fine dc ground but will not provide the necessary low-impedance path to ground for RF. The length of the conductor between the ground bus and the ultimate ground point becomes a problem. For example, the ground wire may be about $\frac{1}{4}\lambda$ (or an odd multiple of $\frac{1}{4}\lambda$) long on some amateur band. A $\frac{1}{4}\lambda$ wire acts as an impedance inverter from one end to the other. Since the grounded end is at a very low impedance, the equipment end will be at a high impedance. The likely result is RF hot spots around the station while the transmitter is operating. A ground system like this may be worse than having no ground at all.

An alternative RF ground system is shown in **Fig 14**. Connect a system of $\frac{1}{4}\lambda$ radials to the station ground bus. Install at least one radial for each band used. You should still be sure to make a connection to earth ground for the ac power wiring. Try this system if you have problems with RF in the shack. It may just solve a number of problems for you.

Ground Noise

Noise in ground systems can affect sensitive radio equipment. It is usually related to one of three problems:

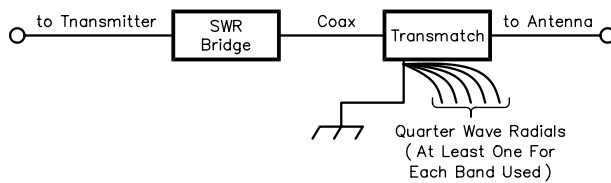


Fig 14—Here is an alternative to earth ground if the station is located far from the ground point and RF in this station is a problem. Install at least one $\frac{1}{4}\lambda$ radial for each band used.

- 1) Insufficient ground conductor size,
- 2) Loose ground connections, or
- 3) Ground loops.

These matters are treated in precise scientific research equipment and some industrial instruments by paying attention to certain rules. The ground connector should be at least as large as the largest conductor in the primary power circuit. Ground connectors should provide a solid connection to both ground and to the equipment being grounded. Liberal use of lock washers and star washers is highly recommended. A loose ground connection is a tremendous source of noise, particularly in a sensitive receiving system.

Ground loops should be avoided at all costs. A short discussion of what a ground loop is and how to avoid them may lead you down the garden path. A ground loop is formed when more than one ground current is flowing in a single conductor. This commonly occurs when grounds are “daisy-chained” (series linked). The correct way to ground equipment is to bring all ground conductors out radially from a common point to either a good driven earth ground or to a cold water system.

Ground noise can affect transmitted as well as received signals. With the low audio levels required to drive amateur transmitters, and with the ever-increasing sensitivity of our receivers, correct grounding is critical.

Lightning and EMP Protection

The National Fire Protection Association (NFPA) publishes a booklet called *Lightning Protection Code* (NFPA no. 78-1983) that should be of interest to radio amateurs. For information about obtaining a copy of this booklet, write to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Two paragraphs of particular interest to amateurs are presented here:

“3-26 Antennas. Radio and Television masts of metal, located on a protected building, shall be bonded to the lightning protection system with a main size conductor and fittings.

“3-27 Lightning arresters, protectors or antenna discharge units shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins.”

The best protection from lightning is to disconnect all antennas from equipment and disconnect the equipment from the power lines. Ground antenna feed lines to safely bleed off static buildup. Eliminate the possible paths for lightning strokes. Rotator cables and other control cables from the antenna location should also be disconnected during severe electrical storms.

In some areas, the probability of lightning surges entering homes via the 120/240-V line may be high. Lightning produces both electrical and magnetic fields that vary with distance. These fields can be coupled into power lines and destroy electronic components in equipment that is miles from where the lightning occurred. Radio equipment can be protected from these surges to some extent by using transient-protective devices.

ELECTROMAGNETIC PULSE AND THE RADIO AMATEUR

The following material is based on a 4-part *QST* article by Dennis Bodson, W4PWF, that appeared in the August through November 1986 issues of *QST* (see the Bibliography at the end of this chapter). The series was condensed from the National Communications System report NCS TIB 85-10.

An equipment test program demonstrated that most Amateur Radio installations can be protected from lightning and EMP transients with a basic protection scheme. Most of the equipment is not susceptible to damage when all external cabling is removed. You can duplicate this stand-alone configuration simply by unplugging the ac power cord from the outlet, disconnecting the antenna feed line at the rear of the radio, and isolating the radio gear from any other long metal conductors. Often it is not practical to completely disconnect the equipment whenever it is not being used. Also, there is the danger that a lightning strike several miles away could induce a large voltage transient on the power lines or antenna while the radio is in use. You can add two transient-protection devices to the interconnected system, however, that will also closely duplicate the safety of the stand-alone configuration.

The ac power line and antenna feed line are the two important points that should be outfitted with transient protection. This is the minimum basic protection scheme recommended for all Amateur Radio installations. (For fixed installations, consideration should also be given to the rotator connections—see **Fig 15**.) Hand-held radios equipped with a “rubber duck” require no protection at the antenna jack. If a larger antenna is used with the hand-held, however, a protection device should be installed.

General Considerations

Because of the unpredictable energy content of a nearby lightning strike or other large transient, it is possible for a metal-oxide varistor (MOV) to be subjected to an energy surge in excess of its rated capabilities. This may result in the destruction of the MOV and explosive rupture of the package. These fragments can cause damage to nearby components or operators and possibly ignite flammable material. Therefore, the MOV should be physically shielded.

A proper grounding system is a key factor in achieving protection from lightning and EMP transients. A low-impedance ground system should be installed to eliminate transient paths through radio equipment and to provide a good physical ground for the transient-suppression devices. A single-point

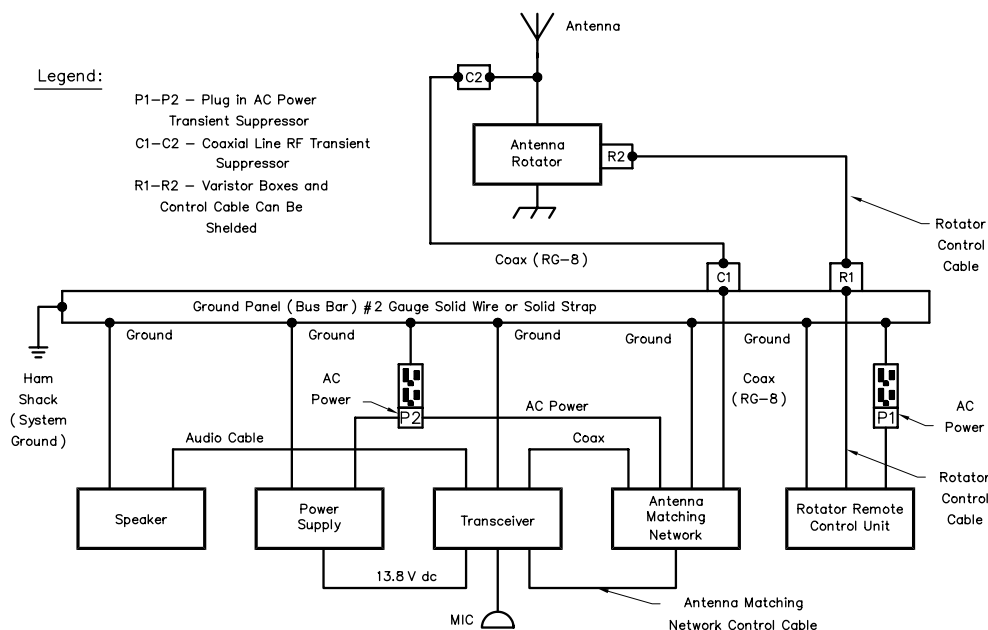


Fig 15—Transient suppression techniques applied to an Amateur Radio station.

ground system is recommended (see **Fig 16**). Inside the station, single-point grounding can be had by installing a ground panel or bus bar. All external conductors going to the radio equipment should enter and exit the station through this panel. Install all transient-suppression devices directly on the panel. Use the shortest length(s) possible of #6 solid wire to connect the radio equipment case(s) to the ground bus.

Ac Power-Line Protection

Tests have indicated that household electrical wiring inherently limits the maximum transient current that it will pass to approximately 120 A. Therefore, if possible, the amateur station should be installed away from the house ac entrance panel and breaker box to take advantage of these limiting effects.

Ac power-line protection can be provided with easy-to-install, plug-in transient protectors. Ten such devices were tested (see **Table 1**). Six of these can be plugged directly into an ac outlet. Four are modular devices that require more extensive installation and, in some cases, more than one module.

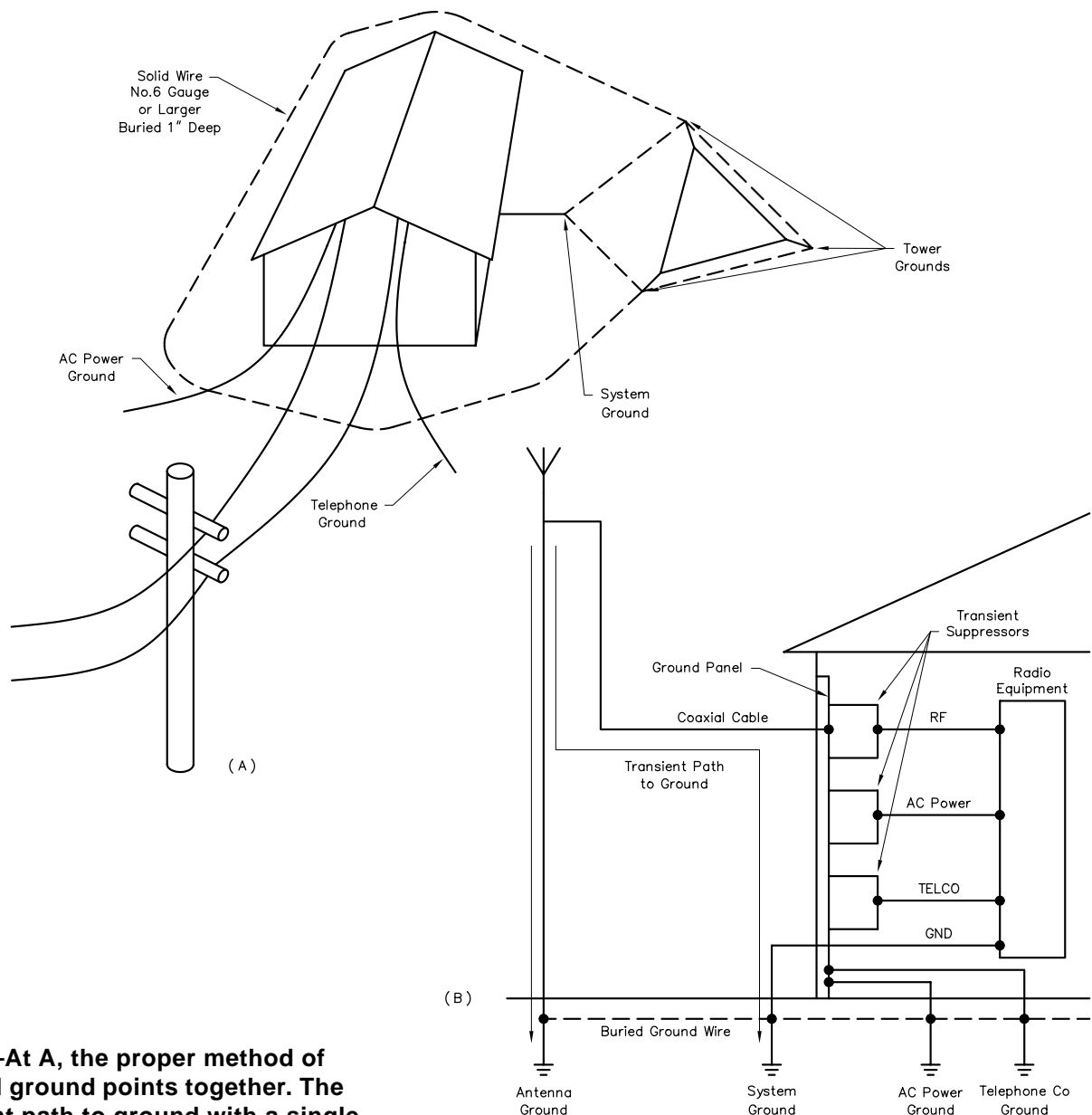


Fig 16—At A, the proper method of tying all ground points together. The transient path to ground with a single-point ground system and use of transient suppressors is shown at B.

The plug-in strip units are the best overall choice for the typical amateur installation. They provide the protection needed, they're simple to install and can be easily moved to other operating locations with the equipment. The modular devices are second choices because they all require some installation, and none of the units tested provided full EMP protection for all three wires of the ac power system.

NCS considers the TII model 428 Plug-In Powerline Protector to be the best overall protector. It provides transient paths to ground from the hot and neutral lines (common mode) as well as a transient path between the hot and neutral lines (normal mode). The model 428 uses three MOVs and a 3-electrode gas-discharge-tube arrester to provide fast operation and large power dissipation capabilities. This unit was tested repeatedly without failure.

Several other plug-in transient protectors provide 3-wire protection but all operate at higher clamping voltages. Other low-cost plug-in devices either lack the 3-wire protection capability or have substantially higher clamping voltages. Some of these are the:

- 1) Joslyn 1270-02. It provides full 3-wire (common and normal mode) transient-path protection but at a slightly higher cost and at a higher clamping voltage.
- 2) Lemon and Peach protection devices, manufactured by Electronic Protection Devices, Inc. The Lemon provides full (common and normal mode) 3-wire protection, but at a higher clamping voltage; the Peach has a dangerously high (1000 V) clamping voltage.
- 3) Archer (Radio Shack) 61-2785 [replaced by a new model that wasn't tested—Ed.]. This unit provides excellent clamping performance at low cost, but it offers normal-mode protection only (a transient path between the hot and neutral leads). It will provide some protection for lightning transients, but not enough for EMP.
- 4) S. L. Waber LG-10. The lowest-cost device does not provide full 3-wire protection (normal mode only) and has a clamping voltage of 600. This unit can provide limited transient protection for lightning, but not the 3-wire protection recommended for EMP transistors.

The transient suppressors require a 3-wire outlet; the outlet should be tested to ensure all wires are properly connected. In older houses, an ac ground may have to be installed by a qualified technician. The ac ground must be available for the plug-in transient suppressor to function properly. The ac ground of the receptacle should be attached to the station ground bus, and the plug-in receptacle should be installed on the ground panel behind the radio equipment.

Table 1
Ac Power-Line Protection Devices

<i>Manufacturer</i>	<i>Device</i>	<i>Approximate Cost (US Dollars)</i>	<i>Measured High-Z Clamping Voltage (Volts)</i>
(Modules)			
Fischer	FCC-120F-P	55	420
Joslyn	1250-32	31	940
General Semi-conductor	587B051	56	600
General Semi-conductor	PHP 120	50	400
(Plug-Ins)			
Joslyn	1270-02	49	600
TII	428	45	410
Electronic Protection Devices	Lemon	45	580
Electronic Protection Devices	Peach	60	1000
S. L. Waber	LG-10	13	600
Archer	61-2785*	22	300

*No longer available.

Emergency Power Generators

Emergency power generators provide two major transient-protection advantages. First, the station is disconnected from the commercial ac power system. This isolates the radio equipment from a major source of damaging transients. Second, tests have shown that the emergency power generator may not be susceptible to EMP transients.

When the radio equipment is plugged directly into the generator outlets, transient protection may not be needed. If an extension cord or household wiring is used, transient protection should be employed.

An emergency power generator should be wired into the household circuit only by a qualified electrician. When connected properly, a switch

is used to disconnect the commercial ac power source from the house lines before the generator is connected to them. This keeps the generator output from feeding back into the commercial power system. If this is not done, death or injury to unsuspecting linemen can result.

Feed Line Protection

Coaxial cable is recommended for use as the transmission line because it provides a certain amount of transient surge protection for the equipment to which it is attached. The outer conductor shields the center conductor from the transient field. Also, the cable limits the maximum conducted transient voltage on the center by arcing the differential voltage from the center conductor to the grounded cable shield.

By providing a path to ground ahead of the radio equipment, the gear can be protected from the large currents impressed upon the antenna system by lightning and EMP. A single protection device installed at the radio antenna jack will protect the radio, but not the transmission line. To protect the transmission line, another transient protector must be installed between the antenna and the transmission line. (See Fig 15.)

RF transient protection devices from three manufacturers were tested (see Table 2) using RG-8 cable equipped with UHF connectors. All of the devices shown can be installed in a coaxial transmission line. Recall that during the tests the RG-8 cable acted like a suppressor; damaging EMP energy arced from the center conductor to the cable shield when the voltage level approached 5.5 kV.

Low price and a low clamping-voltage rating must be considered in the selection of an RF transient-protection device. The lower-cost devices have the higher clamping voltages, however, and the higher-cost devices have the lower clamping voltages. Because of this, medium-priced devices manufactured by Fischer Custom Communications were selected for testing. The Fischer Spikeguard Suppressors (\$55 price class) for coaxial lines can be made to order to operate at a specific clamping voltage. The Fischer devices satisfactorily suppressed the damaging transient pulses, passed the transmitter RF output power without interfering with the signal, and operated effectively over a wide frequency range.

Polyphaser Corporation devices are also effective in providing the necessary transient protection. The devices available limited the transmitter RF output power to 100 W or less, however. These units cost approximately \$83 each.

Table 2
RF Coaxial-Line Protectors

Manufacturer Device		Approximate Cost (US Dollars)	Measured High-Z Clamping Voltage (Volts)
Fischer	FCC-250-300-UHF	55	393
Fischer	FCC-250-350-UHF	55	260
Fischer	FCC-250-150-UHF	55	220
Fischer	FCC-250-120-UHF	55	240
Fischer	FCC-450-120-UHF	55	120
Polyphaser	IS-NEMP	83	140
Polyphaser	IS-NEMP-1	83	150
Polyphaser	IS-NEMP-2	83	160
Alpha Delta	LT	20	700*
Alpha Delta	R-T	30	720*

Note: The transmitter output power, frequency of operation, and transmission line SWR must be considered when selecting any of these devices.
*The newer Alpha Delta LT and R-T “EMP” models have clamping voltages rated to be one-third of those shown here.

The Alpha Delta Transi-Traps tested were low-cost items, but not suitable for EMP suppression because of their high (over 700-V) clamping levels. [New Alpha Delta “EMP” units have clamping voltages rated to be about one-third that of the older units tested here.—Ed.]

RF coaxial protectors should be mounted on the station ground bus bar. If the Fischer device is used, it should be attached to a grounded UHF receptacle that will serve as a hold-down bracket. This creates a conductive path between the outer shield of the protector and the bus bar. The polyphaser device can be mounted directly to the bus bar with the bracket provided.

Attach the transceiver or antenna matching network to the grounded protector with a short (6 foot or less) piece of coaxial cable. Although the cable provides a ground path to the bus bar from the radio equipment, it is not a satisfactory transient-protection ground path for the transceiver. Another ground should be installed between the

transceiver case and the ground bus using solid #6 wire. The coaxial cable shield should be grounded to the antenna tower leg at the tower base. Each tower leg should have an earth ground connection and be connected to the single-point ground system as shown in [Fig 16](#).

Antenna Rotators

Antenna rotators can be protected by plugging the control box onto a protected ac power source and adding protection to the control lines to the antenna rotator. When the control lines are in a shielded cable, the shield must be grounded at both ends. MOVs of the proper size should be installed at both ends of the control cable. At the station end, terminate the control cable in a small metal box that is connected to the station ground bus. Attach MOVs from each conductor to ground inside the box. At the antenna end of the control cable, place the MOVs inside the rotator case or in a small metal box that is properly grounded.

For example, the Alliance HD73 antenna rotator uses a 6-conductor unshielded control cable with a maximum control voltage of 24.7 V dc. Select an MOV with a clamping voltage level 10% higher (27 V or more) so the MOV won't clamp the control signal to ground. If the control voltage is ac, be sure to convert the RMS voltage to peak voltage when considering the clamping voltage level.

Mobile Power Supply Protection

The mobile amateur station environment exposes radio equipment to other transient hazards in addition to those of lightning and EMP. Currents as high as 300 A are switched when starting the engine, and this can produce voltage spikes of over 200 V on the vehicle's electrical system. Lightning and EMP are not likely to impact the vehicle's electrical system as much as they would that of a fixed installation because the automobile chassis is not normally grounded. This would not be the case if the vehicle is parked against a grounded metal conductor. The mobile radio system has two advantages over a fixed installation: Lightning is almost never a problem, and the vehicle battery is a natural surge suppressor.

Mobile radio equipment should be installed in a way that takes advantage of the protection provided by the battery. See [Fig 17](#). To do this, connect the positive power lead of the radio directly to the positive battery post, not to intermediate points in the electrical system such as the fuse box or the auxiliary contacts on the ignition switch. To prevent equipment damage or fire, should either lead short to ground, an in-line fuse should be installed in both leads where they attach to the battery post.

An MOV should be installed between the two leads of the equipment power cord. A GE MOV

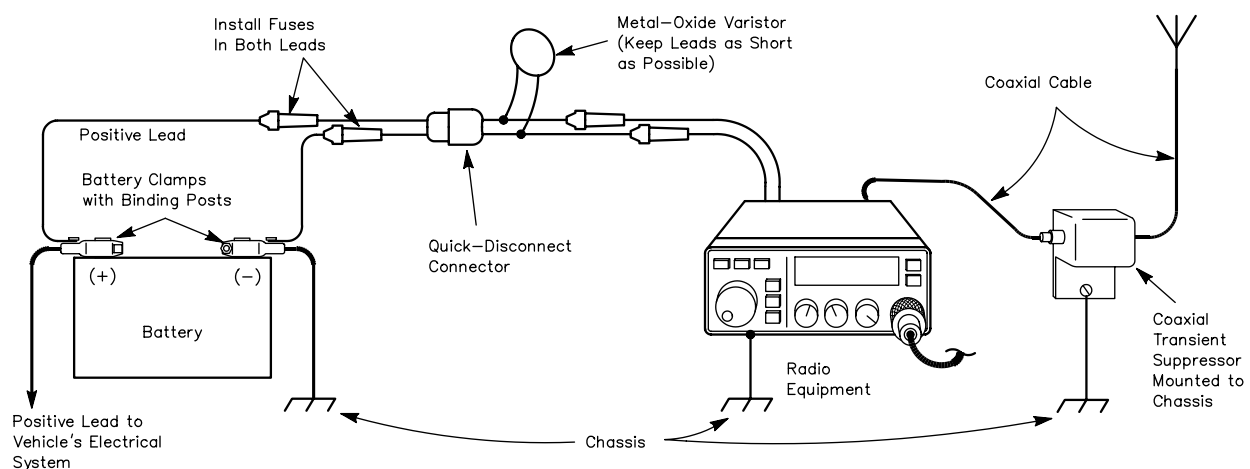


Fig 17—Recommended method of connecting mobile radio equipment to the vehicle battery and antenna.

(V36ZA80) is recommended for this application. This MOV provides the lowest measured clamping voltage (170 V) and is low in cost.

Mobile Antenna Installation

Although tests indicate that mobile radios can survive an EMP transient without protection for the antenna system, protection from lightning transients is still required. A coaxial-line transient suppressor should be installed on the vehicle chassis between the antenna and the radio's antenna connector.

A Fischer suppressor can be attached to a UHF receptacle that is mounted on, and grounded to, the vehicle chassis. The Polyphaser protector can be mounted on, and grounded to, the vehicle chassis with its flange. Use a short length of coaxial cable between the radio and the transient suppressor.

Clamping Voltage Calculation

When selecting any EMP-protection device to be used at the antenna port of a radio, several items must be considered. These include transmitter RF power output, the SWR, and the operating frequency. The protection device must allow the outgoing RF signal to pass without clamping. A clamping voltage calculation must be made for each amateur installation.

The RF-power input to a transmission line develops a corresponding voltage that becomes important when a voltage-surge arrester is in the line. SWR is important because of its influence on the voltage level. The maximum voltage developed for a given power input is determined by:

$$V = \sqrt{2 \times P \times Z \times \text{SWR}} \quad (\text{Eq 1})$$

where

P = peak power in W

Z = impedance of the coaxial cable (ohms)

V = peak voltage across the cable

Eq 1 should be used to determine the peak voltage present across the transmission line. Because the RF transient-protection devices use gas-discharge tubes, the voltage level at which they clamp is not fixed; a safety margin must be added to the calculated peak voltage. This is done by multiplying the calculated value by a factor of three. This added safety margin is required to ensure that the transmitter's RF output power will pass through the transient suppressor without causing the device to clamp the RF signal to ground. The final clamping voltage obtained is then high enough to allow normal operation of the transmitter while providing the lowest practical clamping voltage for the suppression device. This ensures the maximum possible protection for the radio system.

Here's how to determine the clamping voltage required. Let's assume the SWR is 1.5:1. The power output of the transceiver is 100 W PEP. RG-8 coaxial cable has an impedance of 52 Ω . Therefore:

$$P = 100 \text{ W}$$

$$Z = 52 \Omega$$

$$\text{SWR} = 1.5$$

Substituting these values into Eq 1:

$$V = \sqrt{2 \times 100 \times 52 \times 1.5} = 124.89$$

Note that the voltage, V, is the peak value at the peak of the RF envelope. The final clamping voltage (FCV) is three times this value, or 374.7 V. Therefore, a coaxial-line transient suppressor that clamps at or above 375 V should be used.

The cost of a two-point basic protection scheme is estimated to be \$100 for each fixed amateur station. This includes the cost of one TII model 428 plug-in power-line protector (\$45) and one Fischer coaxial-line protector (\$55).

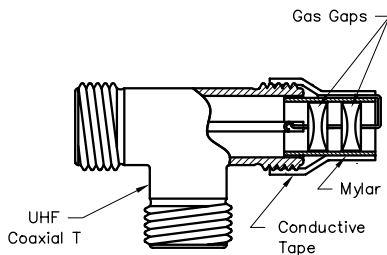


Fig 18—Pictorial diagram of an inexpensive, homemade transmission-line transient protector. See text for description of assembly.

Inexpensive Transient-Protection Device

Here is a low-cost protection device you can assemble. It performed flawlessly in the tests.

The radio antenna connection can be protected by means of a simple device. As shown in Fig 18, two spark gaps (Siemens BI-A350) are installed in series at one end of a coaxial-cable T connector. Use the shortest practical lead length (about $\frac{1}{4}$ inch) between the two spark gaps. One lead is bent forward and forced between the split sections of the inner coaxial connector until the spark gaps approach the body of the connector. A short length of insulating material (such as Mylar) is placed between the spark gaps and the connector shell. The other spark-gap lead is folded over the insulator, then conductive (metallic) tape is wrapped around the assembly. This construction method proved durable enough to allow many insertions and removals of the device during testing. Estimated cost of this assembly is \$9. Similar devices can be built using components from Joslyn, General Electric, General Semiconductor or Siemens.

Summary

Amateurs should be aware of which components in their radio system are most likely to be damaged by EMP. They should also know how to repair the damaged equipment. Amateurs should know how to reestablish communications after an EMP event, taking into account its adverse effects on the earth's atmosphere and radio equipment. One of the first things that would be noticed, providing the radio equipment is operative, is a sudden silence in radio transmissions across all frequencies below approximately 100 MHz. This silence would be caused in part by damage to unprotected radio gear from the EMP transient. Transmissions from one direction, the direction of the nuclear blast, would be completely out. RF signal loss by absorption and attenuation by the nuclear fireball are the reasons for this.

After an EMP event, the amateur should be prepared to operate CW. CW gives the most signal power under adverse conditions. It also provides a degree of message security from the general public.

Amateurs should develop the capability and flexibility to operate in more than one frequency band. The lower ground-wave frequencies should be useful for long-distance communications immediately after an EMP event. Line-of-sight VHF would be of value for local communications.

What can be done to increase the survivability of an Amateur Radio station? Here are some suggestions:

- 1) If you have spare equipment, keep it disconnected; use only the primary station gear. The spare equipment would then be available after an EMP event.
- 2) Keep equipment turned off and antenna and power lines disconnected when the equipment is not in use.
- 3) Connect only those external conductors necessary for the current mode of operation.
- 4) Tie all fixed equipment to a single-point earth ground to prevent closed loops through the ground.
- 5) Obtain schematic diagrams of your equipment and tools for repair of the equipment.
- 6) Have spare parts on hand for sensitive components of the radio equipment and antenna system.
- 7) Learn how to repair or replace the sensitive components of the radio equipment.
- 8) Use nonmetallic guy lines and antenna structural parts where possible.
- 9) Obtain an emergency power source and operate from it during periods of increased world political tension. The power source should be completely isolated from the commercial power lines.
- 10) Equipment power cords should be disconnected when the gear is idle. Or the circuit breaker

for the line feeding the equipment should be kept in the OFF position when the station is off the air.

11) Disconnect the antenna lead-in when the station is off the air. Or use a grounding antenna switch and keep it in the GROUND position when the equipment is not in use.

12) Have a spare antenna and transmission line on hand to replace a damaged antenna system.

13) Install EMP surge arresters and filters on all primary conductors attached to the equipment and antenna.

14) Retain tube-type equipment and spare components; keep them in good working order.

15) Do not rely on a microprocessor to control the station after an EMP event. Be able to operate without microprocessor control.

The recommendations contained in this section were developed with low cost in mind; they are not intended to cover all possible combinations of equipment and installation methods found in the amateur community. Amateurs should examine their own requirements and use this report as a guideline in providing protection for the equipment.

RF Radiation and Electromagnetic Field Safety

Amateur Radio is basically a safe activity. In recent years, however, there has been considerable discussion and concern about the possible hazards of electromagnetic radiation (EMR), including both RF energy and power-frequency (50-60 Hz) electromagnetic fields. FCC regulations set limits on the maximum permissible exposure (MPE) allowed from the operation of radio transmitters. These regulations do not take the place of RF-safety practices, however. This section deals with the topic of RF safety. See the sidebar, “FCC RF-Exposure Regulations,” for information about the rules.

Extensive research on RF safety is underway in many countries. This section was prepared by members of the ARRL RF Safety Committee and coordinated by Dr Robert E. Gold, WBØKIZ. It summarizes what is now known and offers safety precautions based on the research to date.

All life on Earth has adapted to survive in an environment of weak, natural, low-frequency electromagnetic fields (in addition to the Earth’s static geomagnetic field). Natural low-frequency EM fields come from two main sources: the sun, and thunderstorm activity. But in the last 100 years, man-made fields at much higher intensities and with a very different spectral distribution have altered this natural EM background in ways that are not yet fully understood. Much more research is needed to assess the biological effects of EMR.

Both RF and 60-Hz fields are classified as *nonionizing radiation* because the frequency is too low for there to be enough photon energy to ionize atoms. (*Ionizing radiation*, such as X-rays, gamma rays and even some ultraviolet radiation has enough energy to knock electrons loose from their atoms. When this happens, positive and negative ions are formed.) Still, at sufficiently high power densities, EMR poses certain health hazards. It has been known since the early days of radio that RF energy can cause injuries by heating body tissue. (Anyone who has ever touched an improperly grounded radio chassis or energized antenna and received an *RF burn* will agree that this type of injury can be quite painful.) In extreme cases, RF-induced heating in the eye can result in cataract formation and can even cause blindness. Excessive RF heating of the reproductive organs can cause sterility. Other serious health problems can also result from RF heating. These heat-related health hazards are called *thermal effects*. In addition, there is evidence that magnetic fields may produce biologic effects at energy levels too low to cause body heating. The proposition that these *athermal effects* may produce harmful health consequences has produced a great deal of research.

In addition to the ongoing research, much else has been done to address this issue. For example, FCC regulations set limits on exposure from radio transmitters. The American National Standards Institute and the National Council for Radiation Protection and Measurement, among others, have recommended voluntary guidelines to limit human exposure to RF energy. And the ARRL has established the RF Safety Committee, a committee of concerned medical doctors and scientists, serving voluntarily to

monitor scientific research in the fields and to recommend safe practices for radio amateurs.

THERMAL EFFECTS OF RF ENERGY

Body tissues that are subjected to very high levels of RF energy may suffer serious heat damage. These effects depend upon the frequency of the energy, the power density of the RF field that strikes the body, and even on factors such as the polarization of the wave.

At frequencies near the body's natural resonant frequency, RF energy is absorbed more efficiently, and maximum heating occurs. In adults, this frequency usually is about 35 MHz if the person is grounded, and about 70 MHz if the person's body is insulated from the ground. Also, body parts may be resonant; the adult head, for example is resonant around 400 MHz, while a baby's smaller head resonates near 700 MHz. Body size thus determines the frequency at which most RF energy is absorbed. As the frequency is increased above resonance, less RF heating generally occurs. However, additional longitudinal resonances occur at about 1 GHz near the body surface. *Specific absorption rate (SAR)* is a term that describes the rate at which RF energy is absorbed into the human body. Maximum permissible exposure (MPE) limits are based on whole-body SAR values. This helps explain why these safe exposure limits vary with frequency.

Nevertheless, thermal effects of RF energy should not be a major concern for most radio amateurs because of the relatively low RF power we normally use and the intermittent nature of most amateur transmissions. Amateurs spend more time listening than transmitting, and many amateur transmissions such as CW and SSB use low-duty-cycle modes. (With FM or RTTY, though, the RF is present continuously at its maximum level during each transmission.) In any event, it is rare for radio amateurs to be subjected to RF fields strong enough to produce thermal effects unless they are fairly close to an energized antenna or unshielded power amplifier. Specific suggestions for avoiding excessive exposure are offered later.

ATHERMAL EFFECTS OF EMR

Nonthermal effects of EMR may be of greater concern to most amateurs because they involve lower level energy fields. Research about possible health effects resulting from exposure to the lower level energy fields, the athermal effects, has been of two basic types: epidemiological research and laboratory research.

Scientists conduct laboratory research into biological mechanisms by which EMR may affect animals including humans. Epidemiologists look at the health patterns of large groups of people using statistical methods. These epidemiological studies have been inconclusive. By their basic design, these studies do not demonstrate cause and effect, nor do they postulate mechanisms of disease. Instead, epidemiologists look for associations between an environmental factor and an observed pattern of illness. For example, in the earliest research on malaria, epidemiologists observed the association between populations with high prevalence of the disease and the proximity of mosquito infested swamp-lands. It was left to the biological and medical scientists to isolate the organism causing malaria in the blood of those with the disease and identify the same organisms in the mosquito population.

In the case of athermal effects, some studies have identified a weak association between exposure to EMF at home or at work and various malignant conditions including leukemia and brain cancer. A larger number of equally well designed and performed studies, however, have found no association. A risk ratio of between 1.5 and 2.0 has been observed in positive studies (the number of observed cases of malignancy being 1.5 to 2.0 times the "expected" number in the population). Epidemiologists generally regard a risk ratio of 4.0 or greater to be indicative of a strong association between the cause and effect under study. For example, men who smoke one pack of cigarettes per day increase their risk for lung cancer tenfold compared to nonsmokers, and two packs per day increase the risk to more than 25 times the nonsmokers' risk.

Epidemiological research by itself is rarely conclusive, however. Epidemiology only identifies health patterns in groups—it does not ordinarily determine their cause. And there are often confounding factors: Most of us are exposed to many different environmental hazards that may affect our health

in various ways. Moreover, not all studies of persons likely to be exposed to high levels of EMR have yielded the same results.

There has also been considerable laboratory research about the biological effects of EMR in recent years. For example, it has been shown that even fairly low levels of EMR can alter the human body's circadian rhythms, affect the manner in which cancer-fighting T lymphocytes function in the immune system, and alter the nature of the electrical and chemical signals communicated through the cell membrane and between cells, among other things.

Much of this research has focused on low-frequency magnetic fields, or on RF fields that are keyed, pulsed or modulated at a low audio frequency (often below 100 Hz). Several studies suggested that humans and animals can adapt to the presence of a steady RF carrier more readily than to an intermittent, keyed or modulated energy source. There is some evidence that while EMR may not directly cause cancer, it may sometimes combine with chemical agents to promote its growth or inhibit the work of the body's immune system.

None of the research to date conclusively proves that low-level EMR causes adverse health effects. Given the fact that there is a great deal of ongoing research to examine the health consequences of exposure to EMF, the American Physical Society (a national group of highly respected scientists) issued a statement in May 1995 based on its review of available data pertaining to the possible connections of cancer to 60-Hz EMF exposure. This report is exhaustive and should be reviewed by anyone with a serious interest in the field. Among its general conclusions were the following:

1. "The scientific literature and the reports of reviews by other panels show no consistent, significant link between cancer and powerline fields."
2. "No plausible biophysical mechanisms for the systematic initiation or promotion of cancer by these extremely weak 60-Hz fields has been identified."
3. "While it is impossible to prove that no deleterious health effects occur from exposure to any environmental factor, it is necessary to demonstrate a consistent, significant, and causal relationship before one can conclude that such effects do occur."

The APS study is limited to exposure to 60-Hz EMF. Amateurs will also be interested in exposure to EMF in the RF range. A 1995 publication entitled *Radio Frequency and ELF Electromagnetic Energies, A Handbook for Health Professionals* includes a chapter called "Biologic Effects of RF Fields." In it the authors state: "In conclusion, the data do not support the finding that exposure to RF fields is a causal agent for any type of cancer" (page 176). Later in the same chapter they write: "Although the data base has grown substantially over the past decades, much of the information concerning nonthermal effects is generally inconclusive, incomplete, and sometimes contradictory. Studies of human populations have not demonstrated any reliably effected end point." (page 186).

Readers may want to follow this topic as further studies are reported. Amateurs should be aware that exposure to RF and ELF (60 Hz) electromagnetic fields at all power levels and frequencies may not be completely safe. Prudent avoidance of any avoidable EMR is always a good idea. However, an Amateur Radio operator should not be fearful of using his or her equipment. If any risk does exist, it will almost surely fall well down on the list of causes that may be harmful to your health (on the other end of the list from your automobile).

Safe Exposure Levels

How much EM energy is safe? Scientists and regulators have devoted a great deal of effort to deciding upon safe RF-exposure limits. This is a very complex problem, involving difficult public health and economic considerations. The recommended safe levels have been revised downward several times in recent years—and not all scientific bodies agree on this question even today. An Institute of Electrical and Electronics Engineers (IEEE) standard for recommended EM exposure limits went into effect in 1991 (see [Bibliography](#)). It replaced a 1982 American National-Standards Institute (ANSI) standard that permitted somewhat higher exposure levels. The new IEEE standard was adopted by ANSI in 1992.

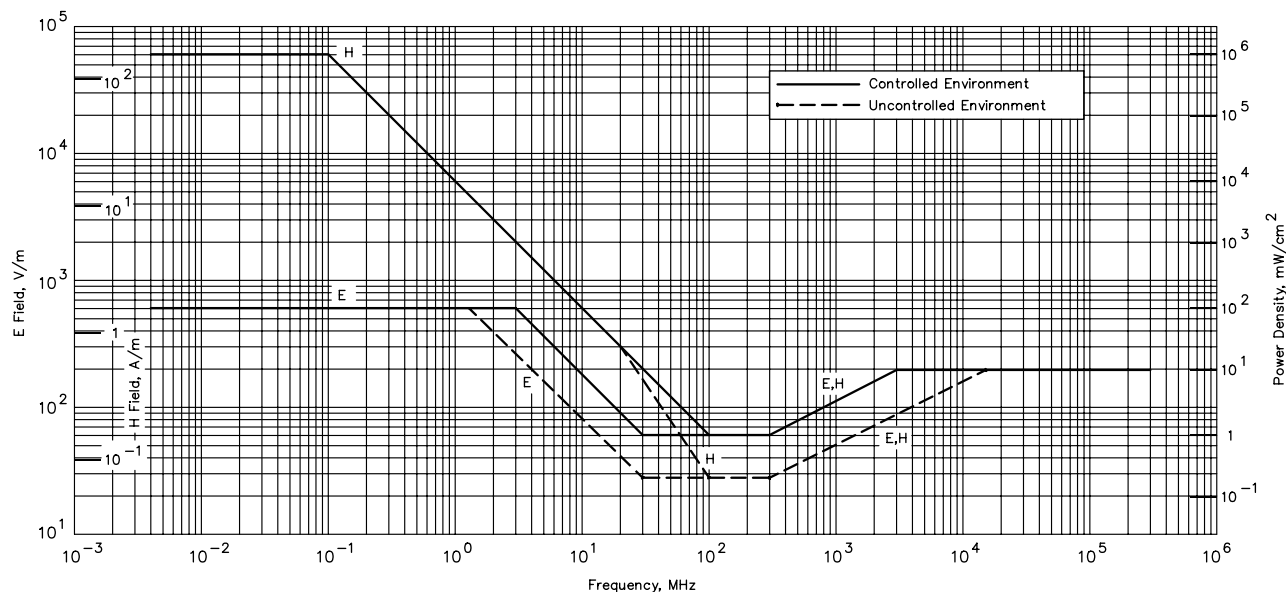


Fig 20—1991 RF protection standard for body exposure of humans. It is known officially as the “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.”

The IEEE standard recommends frequency-dependent and time-dependent maximum permissible exposure levels. Unlike earlier versions of the standard, the 1991 standard recommends different RF exposure limits in *controlled environments* (that is, where energy levels can be accurately determined and everyone on the premises is aware of the presence of EM fields) and in *uncontrolled environments* (where energy levels are not known or where some persons present may not be aware of the EM fields).

The graph in **Fig 20** depicts the 1991 IEEE standard. It is necessarily a complex graph because the standards differ not only for controlled and uncontrolled environments but also for electric fields (E fields) and magnetic fields (H fields). Basically, the lowest E-field exposure limits occur at frequencies between 30 and 300 MHz. The lowest H-field exposure levels occur at 100-300 MHz. The ANSI standard sets the maximum E-field limits between 30 and 300 MHz at a power density of 1 mW/cm² (61.4 V/m) in controlled environments—but at one-fifth that level (0.2 mW/cm² or 27.5 V/m) in uncontrolled environments. The H-field limit drops to 1 mW/cm² (0.163 A/m) at 100-300 MHz in controlled environments and 0.2 mW/cm² (0.0728 A/m) in uncontrolled environments. Higher power densities are permitted at frequencies below 30 MHz (below 100 MHz for H fields) and above 300 MHz, based on the concept that the body will not be resonant at those frequencies and will therefore absorb less energy.

In general, the 1991 IEEE standard requires averaging the power level over time periods rang-

Table 3

Typical 60-Hz Magnetic Fields Near Amateur Radio Equipment and AC-Powered Household Appliances

Values are in milligauss.

Item	Field	Distance
Electric blanket	30-90	Surface
Microwave oven	10-100	Surface
	1-10	12"
IBM personal computer	5-10	Atop monitor
	0-1	15" from screen
Electric drill	500-2000	At handle
Hair dryer	200-2000	At handle
HF transceiver	10-100	Atop cabinet
	1-5	15" from front
1-kW RF amplifier	80-1000	Atop cabinet
	1-25	15" from front

(Source: measurements made by members of the ARRL RF Safety Committee)

ing from 6 to 30 minutes for power-density calculations, depending on the frequency and other variables. The ANSI exposure limits for uncontrolled environments are lower than those for controlled environments, but to compensate for that the standard allows exposure levels in those environments to be averaged over much longer time periods (generally 30 minutes). This long averaging time means that an intermittently operating RF source (such as an Amateur Radio transmitter) will show a much lower power density than a continuous-duty station for a given power level and antenna configuration.

Time averaging is based on the concept that the human body can withstand a greater rate of body heating (and thus, a higher level of RF energy) for a short time than for a longer period. Time averaging may not be appropriate, however, when considering nonthermal effects of RF energy.

The IEEE standard excludes any transmitter with an output below 7 W because such low-power transmitters would not be able to produce significant whole-body heating. (Recent studies show that hand-held transceivers often produce power densities in excess of the IEEE standard within the head.)

There is disagreement within the scientific community about these RF exposure guidelines. The IEEE standard is still intended primarily to deal with thermal effects, not exposure to energy at lower levels. A small but significant number of researchers now believe athermal effects should also be taken into consideration. Several European countries and localities in the United States have adopted stricter standards than the recently updated IEEE standard.

Another national body in the United States, the National Council for Radiation Protection and Measurement (NCRP), has also adopted recommended exposure guidelines. NCRP urges a limit of 0.2 mW/cm² for nonoccupational exposure in the 30-300 MHz range. The NCRP guideline differs from IEEE in two notable ways: It takes into account the effects of modulation on an RF carrier, and it does not exempt transmitters with outputs below 7 W.

Cardiac Pacemakers and RF Safety

It is a widely held belief that cardiac pacemakers may be adversely affected in their function by exposure to electromagnetic fields. Amateurs with pacemakers may ask whether their operating might endanger themselves or visitors to their shacks who have a pacemaker. Because of this and similar concerns regarding other sources of electromagnetic fields, pacemaker manufacturers apply design methods that for the most part shield the pacemaker circuitry from even relatively high EM field strengths.

It is recommended that any amateur who has a pacemaker or is being considered for one discuss this matter with his or her physician. The physician will probably put the amateur into contact with the technical representative of the pacemaker manufacturer. These representatives are generally excellent resources and may have data from laboratory or “in the field” studies with pacemaker units of the type the amateur needs to know about.

One study examined the function of a modern (dual chamber) pacemaker in and around an Ama-

Table 4

Typical RF Field Strengths Near Amateur Radio Antennas

A sampling of values as measured by the Federal Communications Commission and Environmental Protection Agency, 1990

<i>Antenna Type</i>	<i>Freq (MHz)</i>	<i>Power (W)</i>	<i>E Field (V/m)</i>	<i>Location</i>
Dipole in attic	14.15	100	7-100	In home
Discone in attic	146.5	250	10-27	In home
Half sloper	21.5	1000	50	1 m from base
Dipole at 7-13 ft	7.14	120	8-150	1-2 m from earth
Vertical	3.8	800	180	0.5 m from base
5-element Yagi at 60 ft	21.2	1000	10-20 14	In shack 12 m from base
3-element Yagi at 25 ft	28.5	425	8-12	12 m from base
Inverted V at 22-46 ft	7.23	1400	5-27	Below antenna
Vertical on roof	14.11	140	6-9 35-100	In house At antenna tuner
Whip on auto roof	146.5	100	22-75 15-30 90	2 m from antenna In vehicle Rear seat
5-element Yagi at 20 ft	50.1	500	37-50	10 m from antenna

THE RULES

Maximum Permissible Exposure (MPE)

The regulations control *exposure* to RF fields, not the *strength* of RF fields. There is no limit to how strong a field can be as long as no one is being exposed to it, although FCC regulations require that amateurs use the minimum necessary power at all times (§97.311 [a]). All radio stations must comply with the requirements for MPEs, even QRP stations running only a few watts or less. The MPEs vary with frequency, as shown in Table 1.

MPE limits are specified in maximum electric and magnetic fields for frequencies below 30 MHz, in power density for frequencies above 300 MHz and all

three ways for frequencies from 30 to 300 MHz. For compliance purposes, all of these limits must be considered separately—if any one is exceeded, the station is not in compliance. For example, your 2-meter (146 MHz) station radiated electric field strength and power density may be less than the maximum allowed. If the radiated magnetic field strength exceeds that limit, however, your station does not meet the requirements.

Environments

In the latest rules, the FCC has defined two exposure environments—controlled and uncontrolled. A controlled environment is one in which the people

Table 1 (From §1.1310)

Limits for Maximum Permissible Exposure (MPE)

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm ²)	Averaging Time (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	(900/f ²)*	6
30-300	61.4	0.163	1.0	6
300-1500	—	—	f/300	6
1500-100,000	—	—	5	6

f = frequency in MHz

* = Plane-wave equivalent power density (see Note 1).

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm ²)	Averaging Time (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f ²)*	30
30-300	27.5	0.073	0.2	30
300-1500	—	—	f/1500	30
1500-100,000	—	—	1.0	30

f = frequency in MHz

* = Plane-wave equivalent power density (See Note 1.)

Note 1: This means the equivalent far-field strength that would have the E or H-field component calculated or measured. It does not apply well in the near field of an antenna. The equivalent far-field power density can be found in the near or far field regions from the relationships: $P_d = (E_{total})^2 / 3770 \text{ mW/cm}^2$ or from $P_d = (H_{total})^2 \times 37.7 \text{ mW/cm}^2$.

teur Radio station. The pacemaker generator has circuits that receive and process electrical signals produced by the heart and also generate electrical signals that stimulate (pace) the heart. In one series of experiments the pacemaker was connected to a heart simulator. The system was placed on top of the cabinet of a 1-kW HF linear amplifier during SSB and CW operation. In addition, the system was placed in close proximity to several 1 to 5-W 2-meter hand-held transceivers. The test pacemaker connected to the heart simulator was also placed on the ground 9 meters below and 5 meters in front of

who are being exposed are aware of that exposure and can take steps to minimize that exposure, if appropriate. In an uncontrolled environment, the people being exposed are not normally aware of the exposure. The uncontrolled environment limits are more stringent than the controlled environment limits.

Although the controlled environment is usually intended as an occupational environment, the FCC has determined that it generally applies to amateur operators and members of their immediate households. In most cases, controlled-environment limits can be applied to your home and property to which you can control physical access. The uncontrolled environment is intended for areas that are accessible by the general public, normally your neighbors' properties and the public sidewalk areas around your home. In either case, you can apply the more restrictive limits, if you choose.

Station Evaluations

The FCC requires that certain amateur stations be evaluated for compliance with the MPEs. This will help ensure a safe operating environment for amateurs, their families and neighbors. Although an amateur can have someone else do the evaluation, it is not difficult for hams to evaluate their own stations. FCC Bulletin 65 contains basic information about the regulations and a number of tables that show compliance distances for specific antennas and power levels. Generally, hams will use these tables to evaluate their stations. If they choose, however, they can do more extensive calculations, use a computer to model their antenna and exposure, or make actual measurements.

In most cases, hams will be able to use an FCC table that best describes their station's operation to determine the minimum compliance distance for their specific operation. Although such tables are not yet available from the FCC at the time of printing, we expect that they will show the compliance distances for uncontrolled environments for a particular type of antenna at a particular height. The power levels shown in a table would be average power levels, adjusted for the duty cycle of the operating mode being used, and operating on and off time. The data would be averaged over 6 minutes for controlled environments or 30 minutes for uncontrolled environments.

Categorical Exemptions

Some types of amateur stations do not need to

be evaluated, but these stations must still comply with the MPE limits. The station licensee remains responsible for ensuring that the station meets these requirements.

The FCC has exempted these stations from the evaluation requirement because their output power, operating mode and frequency are such that they are presumed to be in compliance with the rules. Amateur stations using 50 W PEP or less output power on any frequency do not need to be evaluated. Hand-held radios and vehicle-mounted mobile radios that operate using a push-to-talk (PTT) button are also categorically exempt from performing the routine evaluation.

ARRL has petitioned the FCC that stations using 150 W PEP or less on frequencies below 30 MHz *not* have to be evaluated, if all parts of the antenna being used are more than 10 meters (just under 33 feet) from areas in which people could be exposed while the station is in operation. At time of printing, the FCC has not made a decision on this.

Correcting Problems

Most hams are already in compliance with the MPE requirements. Some amateurs, especially those using indoor antennas or high-power, high-duty-cycle modes such as a RTTY bulletin station and specialized stations for moonbounce operations and the like may need to make adjustments to their station or operation to be in compliance.

The FCC permits amateurs considerable flexibility in complying with these regulations. Hams can adjust their operating frequency, mode or power to comply with the MPE limits. They can also adjust their operating habits or control the direction their antenna is pointing. For example, if an amateur were to discover that the MPE limits had been exceeded for uncontrolled exposure after 28 minutes of transmitting, the FCC would consider it perfectly acceptable to take a 2-minute break after 28 minutes.

Ongoing Developments

A number of organizations and individuals, including the ARRL, have filed petitions seeking changes to these regulations. Any of these could result in significant changes to the rules. The ARRL will announce any of these changes that could affect Amateur Radio. Check QST, W1AW bulletins and the RF Exposure News page on the ARRL Web site, <http://www.arrl.org/news/rfsafety>.

a 3-element Yagi HF antenna. No interference with pacemaker function was observed in this experimental system.

Although the possibility of interference cannot be entirely ruled out by these few observations, these tests represent more severe exposure to EM fields than would ordinarily be encountered by an amateur with an average amount of common sense. Of course prudence dictates that amateurs with pacemakers using hand-held VHF transceivers keep the antenna as far from the site of the implanted

pacemaker generator as possible and use the lowest transmitter output required for adequate communication. For high power HF transmission, the antenna should be as far from the operating position as possible and all equipment should be properly grounded.

Low-Frequency Fields

Recently, much concern about EMR has focused on low-frequency energy rather than RF. Amateur Radio equipment can be a significant source of low-frequency magnetic fields, although there are many other sources of this kind of energy in the typical home. Magnetic fields can be measured relatively accurately with inexpensive 60-Hz dosimeters that are made by several manufacturers.

Table 3 shows typical magnetic field intensities of Amateur Radio equipment and various household items. Because these fields dissipate rapidly with distance, “prudent avoidance” would mean staying perhaps 12 to 18 inches away from most Amateur Radio equipment (and 24 inches from power supplies with 1-kW RF amplifiers) whenever the ac power is turned on. The old custom of leaning over a linear amplifier on a cold winter night to keep warm may not be the best idea!

There are currently no non-occupational US standards for exposure to low-frequency fields. Some epidemiological evidence, however, suggests that when the general level of 60-Hz fields exceeds 2 milligauss, there is an increased cancer risk in both domestic environments and industrial environments. Typical home environments (not close to appliances or power lines) are in the range of 0.1-0.5 milligauss.

Determining RF Power Density

Unfortunately, determining the power density of the RF fields generated by an amateur station is not as simple as measuring low-frequency magnetic fields. Although sophisticated instruments can be used to measure RF power densities quite accurately, they are costly and require frequent recalibration. Most amateurs don’t have access to such equipment, and the inexpensive field-strength meters that we do have are not suitable for measuring RF power density. The best we can usually do is to estimate our own RF power density based on measurements made by others or, given sufficient computer programming skills, use computer modeling techniques. The FCC has prepared a bulletin, “OET Bulletin 65: Evaluating Compliance With FCC-Specified Guidelines for Human Exposure to Radio Frequency Radiation,” that contains charts and tables that amateurs can use to estimate compliance with the rules.

Table 4 shows a sampling of measurements made at Amateur Radio stations by the Federal Communications Commission and the Environmental Protection Agency in 1990. As this table indicates, a good antenna well removed from inhabited areas poses no hazard under any of the various exposure guidelines. However, the FCC/EPA survey also indicates that amateurs must be careful about using indoor or attic-mounted antennas, mobile antennas, low directional arrays or any other antenna that is close to inhabited areas, especially when moderate to high power is used.

Ideally, before using any antenna that is in close proximity to an inhabited area, you should measure the RF power density. If that is not feasible, the next best option is make the installation as safe as possible by observing the safety suggestions listed in **Table 5**.

It is also possible, of course, to calculate the probable power density near an antenna using simple equations. Such calculations have many pitfalls. For one, most of the situations in which the

FCC RF-EXPOSURE REGULATIONS

FCC regulations control the amount of RF exposure that can result from your station’s operation (§§97.13, 97.503, 1.1307 (b)(c)(d), 1.1310 and 2.1093). The regulations set limits on the maximum permissible exposure (MPE) allowed from operation of transmitters in all radio services. They also require that certain types of stations be evaluated to determine if they are in compliance with the MPEs specified in the rules. The FCC has also required that five questions on RF environmental safety practices be added to Novice, Technician and General class examinations.

These rules were announced on August 1, 1996. They were originally scheduled to go into effect on January 1, 1997, but the FCC responded to an ARRL petition and delayed the implementation date until January 1, 1998. This was done to give amateurs time to understand the rules, to conduct the required station evaluation and to make any changes necessary to be in compliance. The material presented here is the latest available at the time of printing. This discussion offers only an overview of this topic.

power density would be high enough to be of concern are in the near field. The boundary between the near field and the far field of an antenna is approximately several wavelengths from the antenna. In the near field, ground interactions and other variables produce power densities that cannot be determined by simple arithmetic. In the far field, conditions become easier to predict with simple calculations. It is difficult to accurately evaluate the effects of RF radiation exposure in the near field. The boundary between the near field and the far field depends on the wavelength of the transmitted signal and the physical size and configuration of the antenna.

Computer antenna-modeling programs such as *MININEC* or other codes derived from *NEC* (Numerical Electromagnetics Code) are suitable for estimating RF antenna will generally suffice. Those who are familiar with *MININEC* can estimate their power densities by computer modeling, and those who have access to professional power-density meters can make useful measurements.

While our primary concern is ordinarily the intensity of the signal radiated by an antenna, we should also remember that there are other potential energy sources to be considered. You can also be exposed to RF radiation directly from a power amplifier if it is operated without proper shielding. Transmission lines may also radiate a significant amount of energy under some conditions.

FURTHER RF EXPOSURE SUGGESTIONS

Potential exposure situations should be taken seriously. Based on the FCC/EPA measurements and other data, the “RF awareness” guidelines of Table 5 were developed by the ARRL RF Safety Committee. A longer version of these guidelines, along with a complete list of references, appeared in a *QST* article by Ivan Shulman, MD, WC2S (see the list of RF Safety References at the end of this chapter).

In addition, *QST* carries information regarding the latest developments for RF safety precautions and regulations at the local and federal levels.

RF SAFETY REFERENCES

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Standard C95.1-1991, Institute of Electrical and Electronics Engineers, New York, 1992.

For an unbiased assessment of ELF hazards, read the series in *Science*, Vol 249 beginning 9/7/90 (p 1096), continuing 9/21/90 (p 1378), and ending 10/5/90 (p 23). Also see *Science*, Vol 258, p 1724 (1992). You can find *Science* in any large library.

The Environmental Protection Agency publishes a free consumer-level booklet entitled, “EMF in Your Environment,” document 402-R-92-008, dated December 1992. Look for the nearest office of the EPA in your phone book.

Table 5

RF Awareness Guidelines

These guidelines were developed by the ARRL RF Safety Committee, based on the FCC/EPA measurements of Table 4 and other data.

- Although antennas on towers (well away from people) pose no exposure problem, make certain that the RF radiation is confined to the antennas’ radiating elements themselves. Provide a single, good station ground (earth), and eliminate radiation from transmission lines. Use good coaxial cable, not open-wire lines or end-fed antennas that come directly into the transmitter area.
 - No person should ever be near any transmitting antenna while it is in use. This is especially true for mobile or ground-mounted vertical antennas. Avoid transmitting with more than 25 W in a VHF mobile installation unless it is possible to first measure the RF fields inside the vehicle. At the 1-kW level, both HF and VHF directional antennas should be at least 35 ft above inhabited areas. Avoid using indoor and attic-mounted antennas if at all possible.
 - Don’t operate high-power amplifiers with the covers removed, especially at VHF/UHF.
 - In the UHF/SHF region, never look into the open end of an activated length of waveguide or microwave feed-horn antenna or point it toward anyone. (If you do, you may be exposing your eyes to more than the maximum permissible exposure level of RF radiation.) Never point a high-gain, narrow-bandwidth antenna (a paraboloid, for instance) toward people. Use caution in aiming an EME (moonbounce) array toward the horizon; EME arrays may deliver an effective radiated power of 250,000 W or more.
 - With hand-held transceivers, keep the antenna away from your head and use the lowest power possible to maintain communications. Use a separate microphone and hold the rig as far away from you as possible. This will reduce your exposure to the RF energy.
 - Don’t work on antennas that have RF power applied.
 - Don’t stand or sit close to a power supply or linear amplifier when the ac power is turned on. Stay at least 24 inches away from power transformers, electrical fans and other sources of high-level 60-Hz
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