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- *Electric Current Abroad* — U.S. Dept of Commerce
- Field Day Tower Safety by Don Daso, K4ZA and Ward Silver, NØAX
- How to Interact with a Concerned Neighbor
- Interpreting news about RF Exposure Discoveries
- RF Safety at Field Day by Greg Lapin, N9GL
- RF Safety Standard Development
- RF Surge Suppressor Ratings for Transmissions into Reactive Loads by Gene Hinkle, K5PA
- Shop Safety by Don Daso, K4ZA
- Types of Scientific Studies

Chapter 22
Safe Practices

Previously named "Safety," this chapter focuses on safe practices to avoid common hazards associated with ac electrical power, antennas and towers, and RF exposure. The first section, updated by Jim Lux, W6RMK, and Ward Silver, NØAX, details electrical safety, grounding, bonding, and related issues in the station. The following section on antenna and tower safety was updated by Jim Idelson, K1IR. Finally, the ARRL RF Safety Committee updated the explanations of good amateur practices, standards, and FCC regulations as they apply to RF exposure, including recent updates to station evaluation requirements.

Safety First — Always

We need to learn as much as possible about what could go wrong so we can avoid factors that might result in accidents. Amateur Radio activities are not inherently hazardous, but like many things in modern life, it pays to be informed. Stated another way, while we long to be creative and innovative, there is still the need to act responsibly. Safety begins with our attitude. Make it a habit to plan work carefully. Don't be the one to say, "I didn't think it could happen to me."

Having a good attitude about safety is not enough, however. We must be knowledgeable about common safety guidelines and follow them faithfully. Safety guidelines cannot possibly cover all situations, but if we approach each task with a measure of common sense, we should be able to work safely.

Involve your family in Amateur Radio. Having other people close by is always beneficial in the event that you need immediate assistance. Take the valuable step of showing family members how to turn off the electrical power to your equipment safely. Additionally, cardiopulmonary resuscitation (CPR) training can save lives in the event of electrical shock. Classes are offered in most communities. Take the time to plan with your family members exactly what action should be taken in the event of an emergency, such as electrical shock, equipment fire or power outage. Practice your plan!

22.1 Electrical Safety

The standard power available from commercial mains in the United States for residential service is 120/240-V ac. The "primary" voltages that feed transformers in our neighborhoods may range from 1,300 to more than 10,000 V. Generally, the responsibility for maintaining the power distribution system belongs to a utility company, electric cooperative or city. The "ownership" of conductors usually transfers from the electric utility supplier to the homeowner where the power connects to the meter or weather head. If you are unsure of where the division of responsibility falls in your community, a call to your electrical utility will provide the answer. **Figure 22.1** shows the typical division of responsibility between the utility company and the homeowner. This section is concerned more with wiring practices in the station, as opposed to within the equipment in the station.

There are two facets to success with electrical power: safety and performance. Since we are not professionals, we need to pursue safety first and consult professionals for alternative solutions if performance is unacceptable. The ARRL's Volunteer Consulting Engineers program involves professional engineers who may be able to provide advice or direction on difficult problems.

22.1.1 Station Concerns

There never seem to be enough power outlets in your station. A good solution for small scale power distribution is a switched power strip with multiple outlets. The strip should be listed by a nationally recognized testing laboratory (NRTL) such as Underwriters Lab, UL, and should incorporate a circuit breaker. See the sidebars "What Does UL Listing Mean?" and "How Safe are Outlet Strips?" for warnings about poor quality products. It is poor practice to "daisy-chain" several power strips and may actually be a code violation. If you need more outlets than are available on a strip, have additional wall outlets installed.

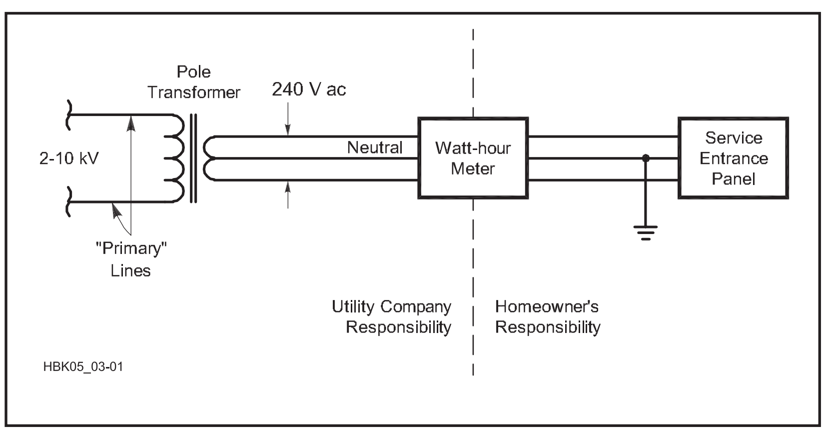

Figure 22.1 — Typical division of responsibility for maintenance of electrical power conductors and equipment. The meter is supplied by the utility company.

Whether you add new outlets or use power strips, be sure not to overload the circuit. National and local codes set permissible branch capacities according to a rather complex process. Here's a safe rule of thumb: consider adding a new circuit if the total load is more than 80% of the circuit breaker or fuse rating. (This assumes that the fuse or breaker is correct. If you have any doubts, have an electrician check it.)

22.1.2. Do-It-Yourself Wiring

Amateurs sometimes "rewire" parts of their homes to accommodate their hobby. Most local codes *do* allow for modification of wiring (by building owners), so long as the electrical codes are met. Before making changes to your wiring, it would be wise to determine what rules apply and what agency has the authority to enforce them. This is called the *authority having jurisdiction* (AHJ) and it varies from location to location. Also see the following section on the National Electrical Code.

Generally, the building owner must obtain an electrical permit before beginning changes or additions to permanent wiring. Some jobs may require drawings of planned work. Often the permit fee pays for an inspector to review the work. Considering the risk of injury or fire if critical mistakes are left uncorrected, a permit and inspection are well worth the effort. *Don't take chances* — seek assistance from the building officials or an experienced electrician if you have *any* questions or doubts about proper wiring techniques.

Ordinary 120-V circuits are the most common source of fatal electrical accidents. Line voltage wiring must use an approved cable, be properly installed in conduit and junction boxes, within a chassis with a cover or lid, or other means described in the electrical code. Remember that high-current, low-voltage power sources, such as car batteries and high-current power supplies, can be just as dangerous as high-voltage sources, from melting metal, sparks and short circuits.

Never work on electrical wiring with the conductors or system energized! Switch off the circuit breaker or remove the fuse or disconnect the power source and take positive steps to ensure that others do not restore the power while you are working, such as using a circuit-breaker lockout. (**Figure 22.2** illustrates one way to ensure that power will be off until you want it turned on.) Check the circuit with an voltmeter to be sure that it is "dead" *each time you begin work*.

Before restoring power, check the wiring with an ohmmeter: From an installed ac outlet, there should be good continuity between the neutral conductor (white wire, "silver" screw) and the grounding conductor (green or bare wire, green screw). An ohmmeter should indicate a closed circuit between the conductors. (In the power line, high voltage world, line workers apply a shorting jumper before starting work so if the power does get reapplied, the safety jumper takes the hit.) For dc systems, test the wiring at the source. Resistance for a dc system can be quite low — a few ohms in some cases. By switching loads on and off as you measure, you should see a change in the system resistance.

With all other loads removed from the circuit (by turning off or unplugging them), an ohmmeter should indicate an *open* circuit between the hot wire and either of the other two conductors. There should be no continuity between the hot conductor (black wire, "brass" screw) and the grounding conductor or the neutral conductor.

Grounding and Bonding for the Radio Amateur

There is so much information about ac safety, lightning protection, and dealing with RF in the station that it can be difficult to understand it all. While this chapter is a helpful summary, it is still just a summary. To help hams setting up a station for the first time or trying to improve an existing station, the ARRL has published *Grounding and Bonding for the Radio Amateur*. Along with its website (**www.arrl.org/grounding-and-bonding-for-the-radio-amateur**) the book collects information about these important practices into one reference.

How Safe Are Outlet Strips?

The switch in outlet strips is generally *not* rated for repetitive *load break* duty. Early failure and fire hazards may result from using these devices to switch heavy loads on and off. Misapplications are common (another bit of bad technique that has evolved from the use of personal computers), and manufacturers are all too willing to accommodate the market with marginal products. A lockable disconnect switch or circuit breaker is a better and safer station master switch.

Older power strips not complying with current standards can also be a safety hazard. MOVs in these older strips that are subjected to repeated transients can fail and cause a fire hazard, especially in outlet strips with plastic enclosures. Power strips made after 2009 that comply with UL standards are safe to use.

What Does UL Listing Mean?

UL is one of several *nationally recognized testing laboratories* (NRTLs), and probably the most well known. Listing *does not* mean what most consumers expect it to mean! More often than not the listing *does not* relate to the performance of the listed product. The listing simply indicates that a sample of the device meets certain manufacturers' construction criteria. Similar devices from the same or different manufacturers may differ significantly in overall construction and performance even though all are investigated and listed against the same UL product category. There is also a difference between a listed device and a listed component.

Many local laws and regulations, as well as the National Electrical Code, require that equipment and components used in electrical installations be listed by a NRTL. Some jurisdictions (Los Angeles County) require that any electrical equipment sold to consumers be listed.

The consumer must also be aware of the fine distinctions in advertising between a device or component that is advertised as "listed" or "designed to meet" or "meets." The latter two may not actually have been tested, or if tested, may have been tested by the manufacturer, and not an independent body.

It's also important to know that in some cases UL (and other standards organizations) only publish a standardized test procedure, but don't necessarily list or test the devices. Many standards also define varying levels of compliance, so knowing that your device meets some part of the standard may not be enough to know whether it meets *your* particular needs.

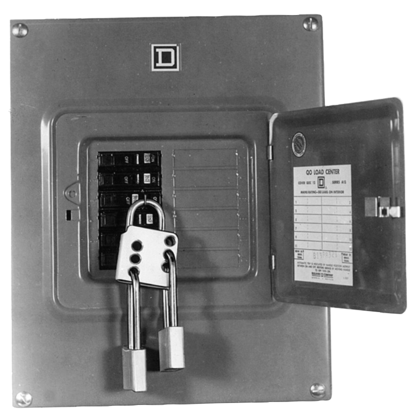

Figure 22.2 — If the switch box feeding power to your shack is equipped with a lock-out hole, use it. With a lock through the hole on the box, the power cannot be accidentally turned back on. [Photo courtesy of American ED-CO]

Commercially available plug-in testers are a convenient way to test regular three-wire receptacles, but can't distinguish between the neutral and ground being reversed. Some plug-in testers draw enough current between hot and safety ground to trip a GFCI breaker.

It is wise to have an up-to-date reference guide to wiring practices. These guides may be available from home improvement stores and electrical supply houses. As of 2022, one widely available book is the *Black & Decker Complete Guide to Wiring, 7th edition*. The book is inexpensive and includes many step-by-step instructions for basic and intermediate wiring projects. It has been updated to the 2020 NEC version.

22.1.3 National Electrical Code (NEC)

Fortunately, much has been learned about how to harness electrical energy safely. This collective experience has been codified into the *National Electrical Code*, or *NEC*, simply known as "the code." The code details safety requirements for many kinds of electrical installations. Compliance with the NEC provides an installation that is *essentially* free from hazard, but not necessarily efficient, convenient or adequate for good service (paraphrased from NEC Article 90-1a and b). While the NEC is national in nature and sees wide application, it is not universal.

Local building authorities set the codes for their area of jurisdiction. They often incorporate the NEC in some form, while considering local issues. For example, Washington State specifically exempts telephone, telegraph, radio and television wires and equipment from conformance to electrical codes, rules and regulations. However, some local jurisdictions (city, county and so on) do impose a higher level of installation criteria, including some of the requirements exempted by the state.

Code interpretation is a complex subject, and untrained individuals should steer clear of the NEC itself. The NEC is not written to be understood by do-it-yourselfers, and one typically has to look in several places to find *all* the requirements. (For instance, Articles 810, 250, *and* 100 all contain things applicable to typical Amateur Radio installations.) The *NEC Handbook* is a version of the code with additional drawings and discussion. It explains the requirements of the code and how to satisfy those requirements. Written for electricians, even the *NEC Handbook* may be difficult for the non-electrician to understand completely. You may wish to contact local sources of information about code compliance and acceptable practices such as local building officials or inspectors, electrical engineers, and practicing electricians. The NEC and the *NEC Handbook* are available from local libraries.

How Does the NEC Affect Me?

Exactly how does the National Electrical Code become a requirement? How is it enforced?

States, cities and, political subdivisions (jurisdictions) have the responsibility to act for the safety and welfare of the public. To address the safety and welfare of everyone, specific codes may be adopted by these jurisdictions. Because the technology for the development of general construction, mechanical, and electrical codes is beyond the scope of most jurisdictions, existing codes are adopted. These codes may be adopted by reference as they stand, or they may be amended and incorporated into local laws and ordinances. Many jurisdictions include some form of permit and accompanying inspection process within the local laws and ordinances. These codes may include, but are not limited to, the International Building Code (IBC), International Residential Code (IRC), and the National Electrical Code (NEC). For electrical issues, the National Electrical Code has been adopted by every state and most local jurisdictions within the United States. Officials within these jurisdictions will serve as "the authority having jurisdiction" (AHJ) and interpret the provisions of these Codes as they apply to specific cases.

Building codes differ from planning or zoning regulations: Building codes are directed only at safety, fire and health issues. Zoning regulations often are aimed at preservation of property values and aesthetics.

The NEC is part of a series of reference codes published by the National Fire Protection Association, a nonprofit organization. Published codes are regularly kept up-to-date and are developed by a series of technical committees whose makeup represents a wide consensus of opinion. The NEC is updated every three years. It's important to know which version of the code your local jurisdiction uses, since it's not unusual to have the city require compliance to an older version of the code. Fortunately, the NEC is usually backward compatible: that is, if you're compliant to the 2008 code, you're probably also compliant to the 1999 code.

Do I have to update my electrical wiring as code requirements are updated or changed?

Generally, no. Codes are typically applied for new construction and for renovating existing structures. Room additions, for example, might not directly trigger upgrades in the existing service panel unless the panel was determined to be inadequate. However, the wiring of the new addition would be expected to meet current codes. Prudent homeowners, however, may want to add safety features for their own value. Many homeowners, for example, have added GFCI protection to bathroom and outdoor convenience outlets.

The internet has a lot of information about electrical safety, the electrical code, and wiring practices, but you need to be careful to make sure the information you are using is current and not out of date. The ARRL Volunteer Consulting Engineer (VCE) program can help you find a professional who understands the amateur radio world, as well as the regulatory environment. There are also a variety of websites with useful information (such as **www.mikeholt.com**), but you need to be aware that advice may be specific to a particular installation or jurisdiction and not applicable for yours. With that understanding, let's look at a few NEC requirements for radio installations.

HOMEBREW AND "THE CODE"

In many cases, there are now legal requirements that electrical equipment have been listed by an NRTL, such as Underwriter Laboratories. This raises an issue for hams and homebrew gear, since it's unlikely you would take your latest project down to a test lab and pay them to evaluate it for safety.

For equipment that is not permanently installed, there's not much of an issue with homebrew, as far as the code goes, because the code doesn't deal with what's inside the equipment. For a lot of low voltage equipment, the code rules are fairly easy to meet, as well, as long as the equipment is supplied

International Power Standards

The power grid of the United States and Canada uses a frequency of 60 Hz and the voltage at ac power outlets is 120 V. This is also the case in other North American countries. If you travel, though, you'll encounter 220 V and 50 Hz with quite an array of plugs and sockets and color codes. If you are planning on taking amateur radio equipment with you on a vacation or DXpedition, you'll need to be prepared with the proper adapters and/or transformers to operate your equipment.

A table of international voltage and frequencies is provided with this chapter's online content, along with a figure showing the most common plug and socket configurations.

by a listed power source of the appropriate type.

The problem arises with permanent installations, where the scope of the code and local regulations is ever increasing. Such things as solar panel installations, standby generators, personal computers and home LANs all have received increased attention in local codes.

22.1.4 Station Power

Amateur radio stations generally require a 120-V ac power source, which is then converted to the proper ac or dc levels required for the station equipment. In residential systems voltages from 110 V through 125 V are treated equivalently, as are those from 220 V through 250 V. Amateurs setting up a station in a light industrial or office environment may encounter 208 V line voltage. Most power supplies operate over these ranges, but it's a good idea to measure the voltage range at your station. (The measured voltage usually varies by hour, day, season and location.) Power supply application and use are covered in the **Power Sources** chapter.

Modern solid state rigs often operate from dc power, provided by a suitable dc power supply, perhaps including battery backups. Sometimes, the dc power supply is part of the rig (as in a 50-V power supply for a solid-state linear). Other times, your station might have a 12-V (13.8 V) bus that supplies many devices. Just because it's low voltage doesn't mean that there aren't aspects of the system that raise safety concerns. A 15-A, 12-V power supply can start a fire as easily as a 15-A, 120-V branch circuit.

22.1.5 Connecting and Disconnecting Power

Something that is sometimes overlooked is that you need to have a way to safely disconnect all power to everything in the station. This includes not only the ac power, but also battery banks, solar panels, and uninterruptible power supplies (UPS). Most hams won't have the luxury of a dedicated room with a dedicated power feed and the "big red switch" on the wall, so you'll have several switches and cords that would need to be disconnected.

The realities of today's stations, with computers, multiple wall transformers ("wall-warts"), network interfaces and the radio equipment itself makes this tricky to do. One convenient means is a switched outlet strip, as used for computer equipment, if you have a limited number of devices. If you need more switched outlets, you can control multiple low-voltage controlled switched outlets from a common source. Or you can build or buy a portable power distribution box similar to those used on construction sites or stage sets; they are basically a portable subpanel with individual circuit breakers (or GFCIs, discussed later) for each receptacle, and fed by a suitable cord or extension cord. No matter what scheme you use, however, it's important that it be labeled so that someone else will know what to do to turn off the power.

AC LINE POWER

If your station is located in a room with electrical outlets, you're in luck. If your station is located in the basement, an attic or other area without a convenient 120-V source, you may need to have a new line run to your operating position.

Stations with full-power (1.5 kW) amplifiers should have a 240-V ac power source in addition to the 120-V supply. Some amplifiers can be powered from 120 V, but will require current levels that may exceed the limits of standard house wiring or cause objectionable voltage drops on the circuit To avoid overloading the circuit and to reduce household light dimming or blinking when the amplifier is in use, and for the best possible voltage regulation in the equipment, it is advisable to install a separate 240 or 120-V line with an appropriate current rating if you use an amplifier.

The usual circuits feeding household outlets are rated at 15 or 20 A., This may or may not be enough current to power your station. To determine how much current your station requires, check the VA (volt-amp) ratings for each piece of gear. (See the **Electrical Fundamentals** chapter for a discussion of VA.) Usually, the manufacturer will specify the required current at 120 V; if the power consumption is rated in watts, divide that rating by 120 V to get amperes. Modern switching power supplies draw more current as the line voltage drops, so if your line voltage is markedly lower than 120 V, you need to take that into account.

Note that the code requires you to use the "nameplate" current, even if you've measured the actual current and it's less. If the total current required is near 80% of the circuit's rating (12 A on a 15-A circuit or 16 A on a 20-A circuit), you need to install another circuit. Keep in mind that other rooms may be powered from the same branch of the electrical system, so the power consumption of any equipment connected to other outlets on the branch must be taken into account. If you would like to measure just how much power your equipment consumes, the inexpensive Kill-A-Watt meters by P3 International (**www.p3international.com**) measure volts, amps, VA and power factor.

If you decide to install a separate 120-V line or a 240-V line, consult the local requirements as discussed earlier. In some areas, a licensed electrician must perform this work. Others may require a special building permit. Even if you are allowed to do the work yourself, it might need inspection by a licensed electrician. Go through the system and get the necessary permits and inspections! Faulty wiring can destroy your possessions and take away your loved ones. Many fire insurance policies are void if there is unapproved wiring in the structure.

If you decide to do the job yourself, work closely with local building officials. Most home-improvement centers sell books to guide do-it-yourself wiring projects. If you

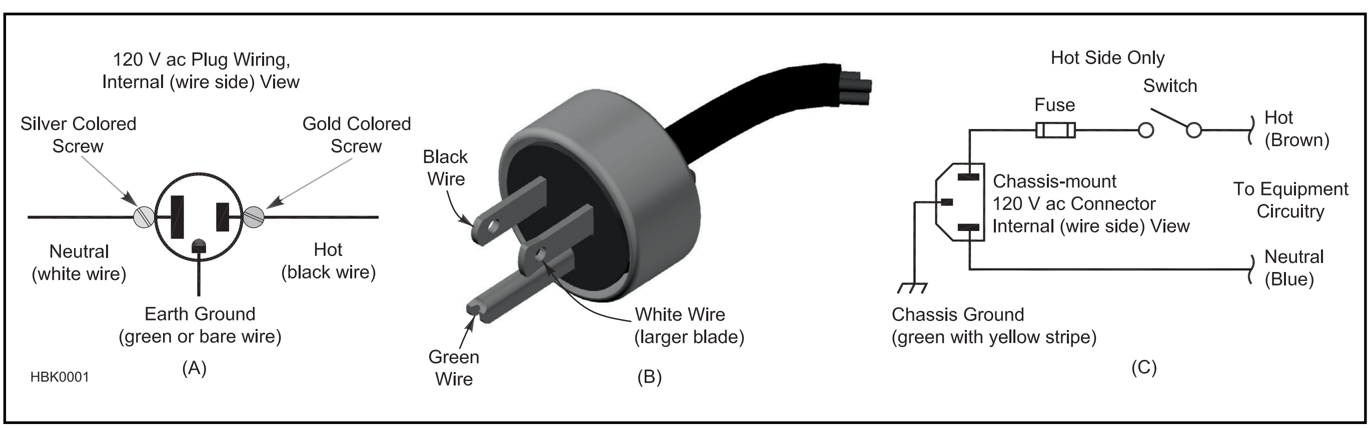

Figure 22.3 — 120 V ac plug wiring as viewed from the wire side (A) and viewed from the blade side (B). Wiring for an IEC type chassis connector is shown at C.

have any doubts about doing the work yourself, get a licensed electrician to do the installation.

THREE-WIRE 120-V POWER CORDS

Most metal-cased electrical tools and appliances are equipped with three-conductor power cords. Two of the conductors carry power to the device, while the third conductor is connected to the case, enclosure, or frame. **Figure 22.3** shows two commonly used connectors. (See the **Construction Techniques** chapter for a more comprehensive drawing of ac plugs and receptacles.)

When both plug and receptacle are properly wired, the three-contact polarized plug bonds the equipment to the system ground. If an internal short from line to case occurs, the "ground" pin carries the fault current and hopefully has a low enough impedance to trip the branch circuit breaker or blow the fuse in the device. A second reason for grounding the case is to reduce the possibility of shock for a user simultaneously connected to ground and the device. In modern practice, however, shock prevention is often done with GFCI circuit breakers as described below. These devices trip at a much lower level and are more reliable. Most commercially manufactured test equipment and ac-operated amateur equipment is supplied with three-wire cords.

It's a good idea to check for continuity from case to ground pin, particularly on used equipment, where the ground connection might have been broken or modified by the previous owner. If there is no continuity, have the equipment repaired before use.

Use such equipment only with properly installed three-wire outlets. If your house does not have such outlets, either consult a local electrician to learn about safe alternatives or have a professional review information you might obtain from online or other sources.

Equipment with plastic cases is considered "double insulated" and fed with a two-wire cord. Such equipment is safe because both conductors are insulated from the user by two layers. Nonetheless, there is still a hazard if, say, a double insulated drill were used to drill an improperly grounded case of a transmitter that was still plugged in. Remember, all insulation is prey to age, damage and wear that may erode its initial protection.

TRANSFER SWITCHES AND GENERATORS

More hams are adding standby generators and using alternate power sources such as solar panels or wind turbines, not as standalone systems like at Field Day, but interconnected with their home electrical system. These present some potential safety problems, such as preventing the local power source from "backfeeding" the utility's system during a power failure, and the fact that a solar panel puts out power whenever there is light falling on it.

For generators, the recommended approach is to use a *transfer switch*, which is a multipole switch that connects a selection of the house's circuits to the generator, rather than the utility power. If you have a solar panel installation, connecting a generator is more complex and depends on the installation. Consult an electrician for this type of system. The NEC and local regulations should be consulted for transfer switch selection and connection.

The required wiring practices for permanently installed (stationary) generators are different from those for portable generators. Some issues that need to be considered are whether the neutral should be switched (many transfer switches do not switch the neutral, only the hot wire), and how the generator chassis is bonded to the building's grounding/bonding system. Most proper transfer switches are of the ON-OFF-ON configuration, with a mechanical interlock that prevents directly switching from one source to the other in a single operation.

Back-feeding your home's power panel should *never* be done unless the main breakers are in the OFF position or preferably removed. If you have an older home in which the circuit-breaker panel does not have main breakers that can disconnect the external power line, *do not* use this technique to connect your generator to the home's wiring. Your generator is likely to be damaged when power is restored, and back-feeding also endangers power utility workers. Connect appliances to the generator directly with extension cords.

The most dangerous thing to do with a generator is to use a so-called "suicide cord" with a male plug at each end: one end plugged into the generator's output receptacle and the other plugged into a convenient receptacle in the home. This is frequently illegal and at any rate should be avoided because of the inherent danger of having exposed, live contacts and the ease of overloading the circuit being fed.

22.1.6 Ground-Fault and Arc-Fault Circuit Interrupters

GFCIs are devices that can be used with common 120 V household circuits to reduce the chance of electrocution when the path of current flow leaves the branch circuit (say, through a person's body to another branch or ground). An AFCI is similar in that it monitors current to watch for a fault condition. Instead of current imbalances, the AFCI detects patterns of current that indicate an arc — one of the leading causes of home fires. The AFCI is not supposed to trip because of "normal" arcs that occur when a switch is opened or a plug is removed.

The NEC requires GFCI outlets in all wet or potentially wet locations, such as bathrooms, kitchens, and any outdoor outlet with ground-level access, garages and unfinished basements. AFCI protection is required for all circuits that supply bedrooms. Any area with bare concrete floors or concrete masonry walls should be GFCI equipped. GFCIs are available as portable units, duplex outlets and as individual circuit breakers. Some early units may have been sensitive to RF radiation but this problem appears to have been solved. Ham radio stations in potentially wet areas (basements, out buildings) should be GFCI equipped. **Figure 22.4** is a simplified diagram of a GFCI.

Older equipment with capacitors in the 0.01 μF to 0.1 μF range connected between line inputs and chassis as an EMI filter (or that has been modified with bypass capacitors) will often cause a GFCI to trip, because of the leakage current through the capacitor. The must-trip current is 5 mA, but many GFCIs trip at lower levels. At 60 Hz, a 0.01 μF capacitor has an impedance of about 265 kΩ,

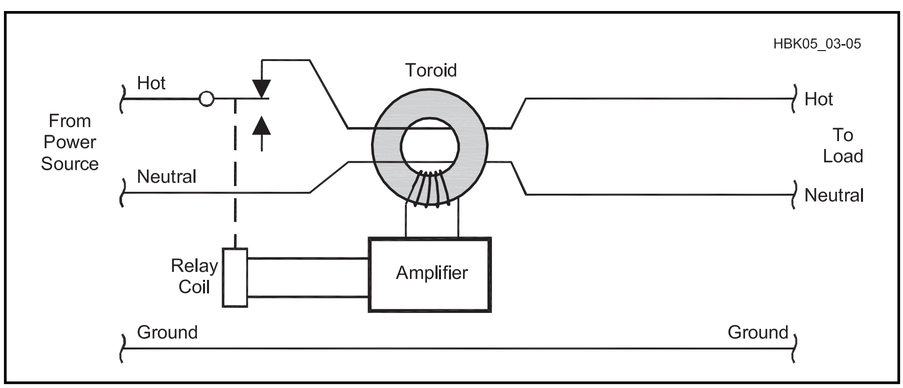

Figure 22.4 — Simplified diagram of a 120-V ac ground fault circuit interrupter (GFCI). When a stray current flows from the load (or outlet) side to ground, the current through the toroid becomes unbalanced allowing detection, amplification and relay actuation to immediately cut off power to the load (and to the stray path!). GFCI units require a manual reset after tripping. GFCIs are required in wet locations (near kitchen sinks, in garages, in outdoor circuits and for construction work). They are available as portable units or combined with over-current circuit breakers for installation in entrance panels.

so there could be a leakage current of about 0.5 mA from the 120 V line. If you had several pieces of equipment with such capacitors, the leakage current will trip the GFCI.

Some early GFCI breakers were susceptible to RFI but as the technology has improved, fewer and fewer such reports have been received. While it is possible to add filtering or RF suppression to the breaker wiring, a simpler and less expensive solution is to simply replace the GFCI breaker with a new unit less susceptible to RF. Reports have not yet been received on AFCI products. For more information on RFI and GFCI/AFCI devices, check the ARRL web page **www.arrl.org/gfci-devices**.

22.1.7 Low-Voltage Wiring

Many ham stations use low-voltage control wiring for rotators or antenna relays. The electrical code isn't consistent in what it calls low voltage, but a guideline is "less than 50 V." Article 725 of the code contains most of the rules for low voltage/low power remote control and signaling, which is what hams are typically doing. These circuits are divided into three classes, with Class 1 being further subdivided, as shown in **Table 22.1**. There used to be code rules defining the classes in terms of power and voltage, but these days, the code is written so that the class of the circuit is defined by the power source, which has to be listed and labeled with the class. That is, if you have something powered by a wall transformer that is listed and labeled as Class 2, the circuit is Class 2.

A typical example of a Class 1 Power Limited circuit that you might find in your home is 12 V low-voltage garden lighting or halogen lightning systems. A lot of amateur homebrew gear probably is also in this class, although because it's not made with "listed" components, it technically doesn't qualify. The other Class 1 would apply to a circuit using an isolation transformer of some sort.

Class 2 is very common: doorbells, network wiring, thermostats, and so on are almost all Class 2. To be Class 2, the circuit must be powered from a listed power supply that's marked as being Class 2 with a capacity less than 100 VA. For many applications that hams encounter, this will be the familiar "wall wart" power supply. If you have a bunch of equipment that runs from dc power, and you build a dc power distribution panel with regulators to supply them from a storage battery or a big dc power supply, you're most likely not Class 2 anymore, but logically Class 1. Since your homebrew panel isn't likely to be listed, you're really not even Class 1, but something that isn't covered by the code.

A common example of a Class 3 circuit that is greater than 30 V is the 70 V audio distribution systems used in paging systems and the like. Class 3 wiring must be done with appropriately rated cable.

WIRING PRACTICES

Low voltage cables must be separated from power circuits. Class 2 and 3 cannot be run with Class 1 low voltage cables. They can't share a cable tray or the same conduit. A more subtle point is that the 2005 code added a restriction [Article 725.56(F)] that audio cables (speakers, microphone, etc.) cannot be run in the same conduit with other Class 2 and Class 3 circuits (like network wiring).

Grounding or Bonding?

You may notice the term "bonding" is replacing "grounding" in many instances. A primary safety concern is for whatever carries fault currents to be mechanically rugged and reasonably conductive. It's also important that the fault-carrying conductor be connected to a ground rod, but that's a different consideration. Bonding is the term to use when contact between pieces of equipment or between conductors is the primary concern. Grounding is the term to use when referring to an earth connection for electrical safety or lightning protection.

Table 22.1
Traditional Divisions Among the Classes of Circuits

Class	*Power*	*Notes*
Class 1		
Power Limited	<30V, <1000VA	Transformer protected per Article 450. If not transformer, other overcurrent and fault protection requirements apply
Remote Control and Signaling	<600V	No limit on VA Transformers protected as defined in Article 450
Class 2	Power supply <100VA Voltage <30V	
Class 3	Power supply <100VA Voltage <100V	

Low voltage and remote control wiring should not be neglected from your transient suppression system. This includes putting appropriate protective devices where wiring enters and leaves a building, and consideration of the current paths to minimize loops which can pick up the field from transients (or RF from your antenna).

22.1.8 Grounding and Bonding

As hams we are concerned with at least four kinds of connections called "ground," even if they really aren't in the sense of connection to the Earth. These are easily confused because we call each of them "ground."

1) Electrical safety ground (equipment ground or earth connection)

2) Lightning and transient dissipation ground

3) RF voltage and current management ("RF ground")

4) Common reference potential (chassis ground or circuit common)

This section of the chapter is primarily concerned with connections for electrical or safety grounding and lightning and transient dissipation. The remaining types are covered elsewhere in chapters on circuit- and antenna-building and in station construction.

Several commercial and military standards can be used as guidebooks for grounding and bonding:

National Electrical Code (NEC) — This is the primary standard for residential and commercial electrical work in the United States. NEC Article 250 deals with grounding and bonding. NEC Article 810 deals with antenna installation. (See the previous section on the NEC.)

MIL-HDBK-419A — Grounding, Bonding, and Shielding for Electronic Equipments and Facilities (Vol 1 and 2) — This military standard applies to communication facilities and equipment installations at any frequency. It provides many useful drawings and guidelines covering ground connections and how equipment should be bonded together. It is a public-domain document and is available from a number of sources. An internet search for "MIL-HDBK-419A" will find several available copies.

R56 Standards and Guidelines for Communications Sites — Motorola is a large vendor of communications systems, mostly for VHF/UHF/microwave applications. This standard applies primarily to equipment and facilities used at those frequencies. It is not a public domain document but may be downloaded without charge from numerous sources.

IEEE Std 1100-2005 (also known as the "Emerald Book," see the Reference listing, section 22.1.13) provides detailed information from a theoretical and practical standpoint for grounding and powering electrical equipment, including lightning protection and RF EMI/EMC concerns. It's expensive to buy, but is available through libraries.

BONDING

The definition of bonding is "to connect equipment together electrically in order to minimize the potential (voltage) difference between them." A good bonding connection must have very low impedance and approximately equal voltage everywhere along it at the frequency of interest. As amateurs know, electrical length and impedance of any type of conductor — wire, strap, braid, or sheet — varies with frequency. In addition, the amount of current flowing through the conductor can create significant voltage differences along the conductor. Because of these concerns, it is important to consider the purposes of bonding when making a bonding connection.

In general, for amateurs constructing a station, even a temporary one, it is a good practice to make bonding conductors as short as practical and as heavy as is needed to satisfy all bonding requirements. By doing so, the bonding connection will serve its purpose for all three of the primary bonding needs in your station: ac safety, lightning protection, and RF management.

ELECTRICAL SAFETY GROUND

Power-line ground is required by building codes to ensure the safety of life and property surrounding electrical systems. The NEC requires that all grounds be bonded together; this is a very important safety feature as well as an NEC requirement.

The usual term one sees for the "third prong" or "green-wire ground" is the *electrical safety ground* or *equipment ground*. The purpose of the third, non-load current carrying wire is to provide a path to ensure that the overcurrent protection will trip in the event of a line-to-case short circuit in a piece of equipment. This could either be the fuse or circuit breaker back at the main panel, or the fuse inside the equipment itself.

There is a secondary purpose — shock reduction: The electrical safety ground provides a common reference potential for all parts of the ac system. The conductive case of equipment is required to be connected to the bonded grounding system, which is also connected to earth ground at the service entrance, so someone who is connected to "earth" (for example, standing in bare feet on a conductive floor) that touches the case won't get shocked.

An effective safety ground system is necessary for every amateur station. If you have equipment at the base of the tower, generally, you need to provide a separate bonding conductor to connect the chassis and cases at the tower to the bonding system in the station. **Figure 22.5A** shows an overall grounding system, emphasizing the requirement to bond all ground connections together, regardless of their purpose.

Equipment-to-equipment bonding can be done directly with wire (#6 to #14 AWG), strap (20 gauge), with strips of flashing (24 gauge), or through a bonding bus or single-point ground panel (SPGP). The equipment

When to Use Strap, Wire, or Braid

The standard for grounding in the communication industry is solid strap or heavy wire. Both can be used indoors or outdoors. Flat-weave, tinned grounding braid can be used if the equipment is subject to vibration or needs to be moved around.

Do not use any type of braid if it will be exposed to moisture or corrosive chemicals. Corrosion on the surface of the small wires used to make up the braid reduces its effectiveness by raising the surface resistance, where the RF currents flow. Poor contact between the individual wires can also result in noise and mixing products. Unless it is mechanically necessary, such as for a gate or door, use solid strap or wire.

It is not recommended to reuse braid removed from coaxial cable. Once removed from its protective jacket, the braid wires immediately begin to loosen and oxidize or corrode. This reduces the braid's effectiveness at RF quite a bit, making it a poor choice for long-term grounding conductors.

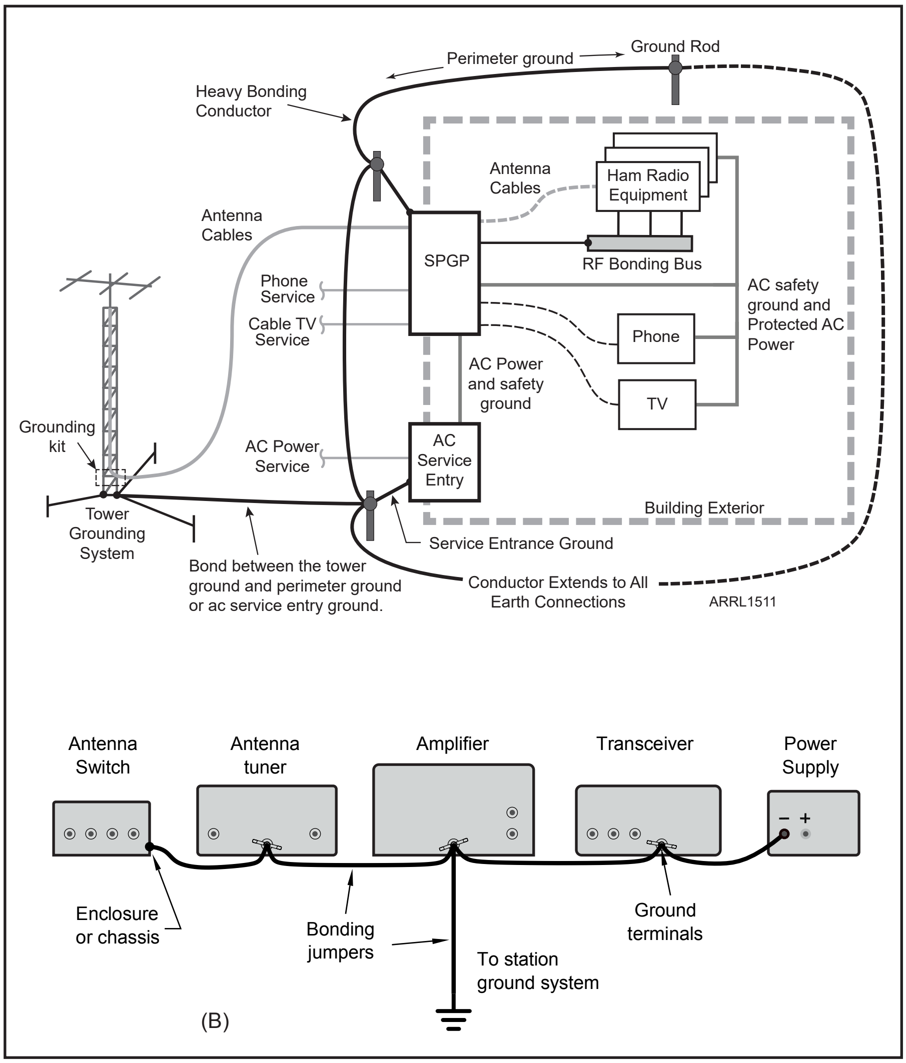

Figure 22.5 — A grounding system that includes ac safety, lightning protection, and RF management. All ground electrodes must be bonded together and to the residence's ac service entry ground rod. If a protected ac branch circuit is included, the protector should be mounted on the SPGP (single-point ground panel). Direct equipment-to-equipment bonding (B) can be done with heavy wire or strap or to an RF bonding bus. See the chapter on Assembling a Station for more information on making these connections.

ground or "third-wire" connection in a residence's branch circuit must be made with the same size wire as the hot and neutral conductors. Connections directly to a ground electrode, such as a ground rod, are made with heavy wire (#6 AWG minimum) or 20-gauge strap. Clamps and terminals should be rated or listed for grounding use, particularly for earth connections that are exposed to the weather or buried.

At ac power frequencies of 50 or 60 Hz, the wavelength is miles long so the electrical length of the connection is insignificant. Reactance created by the bonding conductor (about 300 nH per foot for a straight wire) is likewise negligible. The most important characteristics of the bonding connection is resistance and mechanical strength. Unfortunately, an effective bonding conductor at 60 Hz may present very high impedance at RF because of the inductance, or worse yet, wind up being an excellent antenna that picks up the signals radiated by your antenna.

RF MANAGEMENT AND CHASSIS GROUND

"RF ground" is an obsolete term from days gone by when most operation was at low frequencies and a wire from the chassis or antenna tuner in the station to a ground rod had low RF impedance. The RF voltage difference between the chassis and "Earth ground" was small. And even if there were small potential differences, the surrounding equipment of those days was relatively insensitive to them.

Today, we have a lot of circuits that are sensitive to interfering signals at millivolt levels, such as audio signals to and from sound cards. As a result, we can no longer ignore the RF voltage differences and shouldn't be using the equipment enclosures or shielding conductors as part of the RF circuit.

Instead, we design our stations to manage the RF picked up on cables, connecting wires, and enclosures so that it does not cause problems. The first step is to create a common reference potential, called the *ground plane* or *reference plane*. Equipment connected to the ground plane is maintained at a common potential. This minimizes RF current that would flow between pieces of equipment. (See the **RFI and EMC** chapters for more information.) The ground plane can be an actual sheet of metal or a low-inductance conductor to which all of the equipment can be connected, often called an *RF bonding bus*. The ground plane is then bonded to the station ground system.

It is sometimes suggested that RF grounds should be isolated from the ac safety and lightning protection ground system — that is not correct! All grounds, including safety, RF, lightning protection and commercial communications, must be bonded together in order to protect life and property. The electrical code requires that antenna grounds be bonded to the rest of the grounding system, although that connection can have an RF choke. Remember that the focus of the electrical code bonding requirement is safety in the event of a short to a power distribution line or other transient.

For decades, amateurs have been advised to bond all equipment cabinets to an RF ground located near the station. Given today's operating frequencies and equipment sensitivity, this practice is inadequate. Even a few meters of wire can have an impedance of hundreds of ohms (1 µH/meter = 88 Ω/meter at 14 MHz). So a better approach is to connect the chassis together in a well-organized fashion to ensure that the chassis-to-chassis connections minimize RF voltage differences as in Figure 22.5B. An RF bonding bus can be used, as well. (See the **RFI and EMC** and **Assembling a Station** chapters for more information.)

LIGHTNING DISSIPATION GROUND

Lightning dissipation ground is concerned with conducting currents to the surrounding earth. There are distinct similarities between lightning dissipation ground systems and a good ground system for a vertical antenna. Lightning strokes produce electrical energy from a few kHz to more than 10 MHz so the length of the connection is important as well as its resistance. The difference is that an antenna ground plane may handle perhaps a few tens of amps, while the lightning ground needs to handle a peak current of tens of kiloamperes.

A typical lightning stroke is a pulse with a rise time of a few microseconds, a peak current of 20 to 30 kA, and a fall time of 50 µs. The average current is not all that high (a few hundred amps), so the conductor size needed to carry the current without melting is surprisingly small.

However, large conductors (usually specified as #6 AWG minimum by building codes) are used in lightning grounds for other reasons: to reduce inductance, to handle the mechanical forces from the magnetic fields, and for ruggedness to prevent inadvertent breakage. A large diameter wire, or even better, a wide flat strap, has lower inductance. The voltage along a wire is proportional to the change in current and its inductance:

$$|V| = L\frac{\Delta i}{\Delta t}$$

where

$\Delta i/\Delta t$ = rate of change in current, about 20kA/2µs for lightning, or 10^9 A/s, and

L = the inductance of the wire.

Consider a connection box on a tower that contains some circuitry terminating a control cable from the station, appropriately protected internally with overvoltage protection. If the connection from the box to ground is high inductance, the lightning transient will raise the box potential (relative to the wiring coming from the station), possibly beyond the point where the transient suppression in the box can handle it. Lowering the inductance of the connection to ground reduces the potential.

The other reason for large conductors on lightning grounds is to withstand the very high mechanical forces from the high currents. This is also the reason behind the recommendation that lightning conductors be run directly, with minimal bends and large radii for bends that are needed, and certainly no loops. A wire carrying 20,000 A has a powerful magnetic field surrounding it, and if current is flowing in multiple wires that are close to each other, the forces pushing the wires together or apart can actually break the conductors or deform them permanently.

The force between two conductors carrying 20,000 A, spaced a centimeter apart, is 8000 newtons/meter of length (over 500 pounds/foot). Such forces can easily break cable strands or rip up brackets and screws. This problem is aggravated if there are loops in the wire, since the interaction of the current and its magnetic field tends to make the loop get larger, to the point where the wire will actually fail from the tension stresses.

EARTH GROUND

Earth ground usually takes one of several forms, all identified in the NEC and NFPA 780. The preferred earth ground, both as required in the NEC, and verified with years of testing in the field, is a *concrete encased grounding electrode* (CEGR), also known as a *Ufer ground*, after Herb Ufer, who invented it as a way to provide grounding for military installations in dry areas where ground rods are ineffective. The CEGR can take many forms, but the essential aspect is that a suitable conductor at least 20 feet long is encased in concrete which is buried in the ground. The conductor can be a copper wire (#8 AWG at least 20 feet long) or the reinforcing bars (rebar) in the concrete, often the foundation footing for the building. The connection to the rebar is either with a stub of the rebar protruding through the concrete's top surface or the copper wire extending through the concrete. There are other variations of the CEGR described in the NEC and in the electrical literature, but they're all functionally the same: a long conductor embedded in a big piece of concrete.

The electrode works because the concrete has a huge contact area with the surrounding soil, providing very low impedance and, what's also important, a low current density, so that localized heating doesn't occur. Concrete tends to absorb water, so it is also less susceptible to problems with the soil drying out around a traditional ground rod.

The techniques required for welding rebar and making the necessary connection to the CEGR are somewhat specialized. If you are not familiar with those skills, hire a professional to do the job correctly. Similarly, unless you have documented evidence that the necessary rebar connection or embedded wire are present in a concrete footing or slab, do not attempt to use it as a CEGR.

Ground rods are a traditional approach to making a suitable ground connection and are appropriate as supplemental grounds, say at the base of a tower, or as part of an overall grounding system. The best ground rods to use are those available from an electrical supply house. The code requires that at least 8 feet of the rod be in contact with the soil, so if the rod sticks out of the ground, it must be longer than 8 feet (10 feet is standard). The rod doesn't have to be vertical, and can be driven at an angle if there is a rock or hard layer, or even buried laying sideways in a suitable trench, although this is a compromise installation. Suitable rods are generally 10 feet long and made from steel with a heavy copper plating. (Stainless steel and galvanized rods are also available and may be required by soil conditions in your area. Check with a local electrician or electrical inspector.) Do not depend on shorter, thinly plated rods sold by some home electronics suppliers, as they can quickly rust and soon become worthless.

If multiple ground rods are installed, many references specify a minimum spacing of the rod's length. If the rods are not spaced by at least half the length of the rod, the effectiveness is compromised. IEEE Std 142 and IEEE Std 1100 (see the Reference listing) and other references have tables to give effective ground resistances for various configurations of multiple rods.

Once the ground rods are installed, they must be connected with either an exothermic weld (such as CadWeld) or with a listed pressure clamp. The exothermic weld is preferred, because it doesn't require annual inspection like a clamp does. Some installers use brazing to attach the wiring to the ground rods. Although this is not permitted for a primary ground, it is acceptable for secondary or redundant grounds. Soft solder (tin-lead, as used in plumbing or electrical work) should never be used for grounding conductors because it gets brittle with temperature cycling and can melt if a current surge (as from a lightning strike) heats the conductor. Soft solder is specifically prohibited in the code.

Building cold water supply systems were used as station grounds in years past, but this is no longer recommended or even permitted in some jurisdictions, because of increased used of plastic plumbing both inside and outside houses and concerns about stray currents causing pipe corrosion.. If you do use the cold water line, perhaps because it is an existing grounding electrode, it must be bonded to the electrical system ground, typically at the service entrance panel.

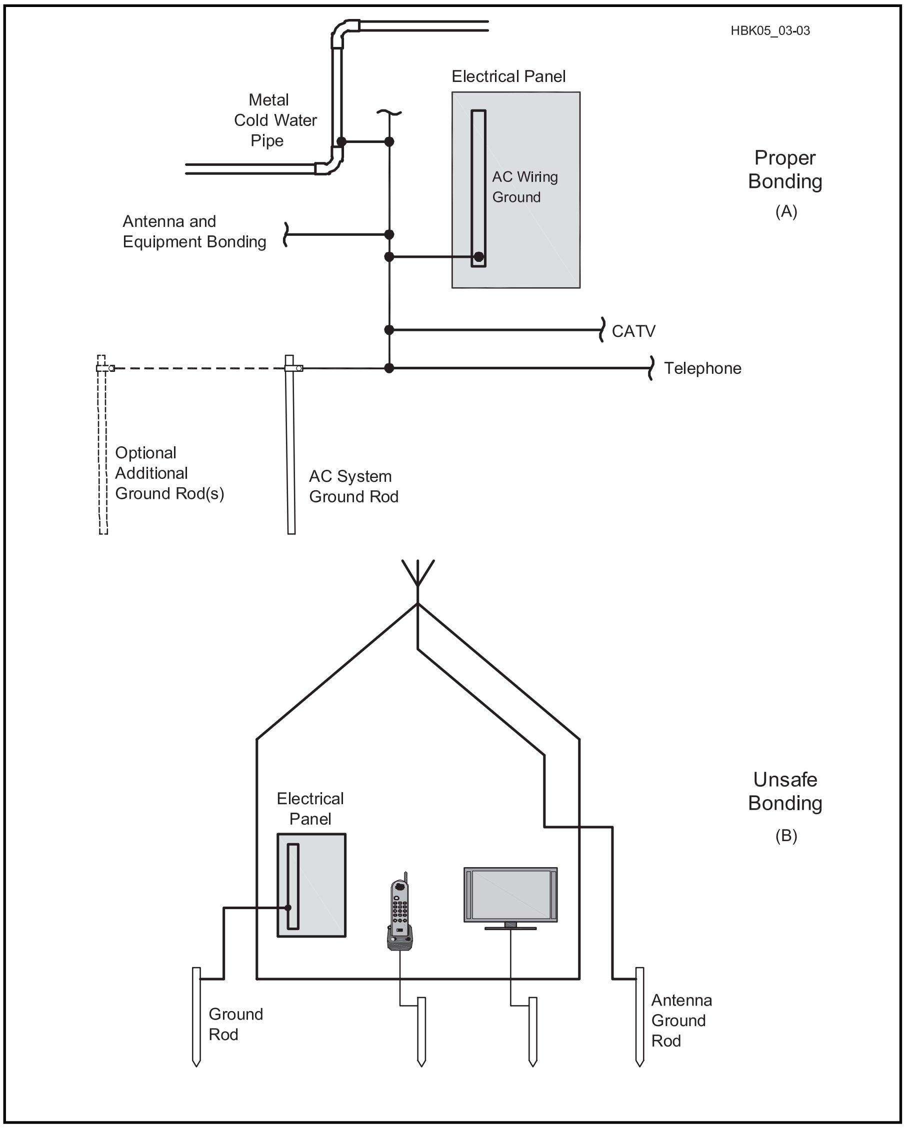

Figure 22.6 — At A, proper bonding of all grounds to electrical service panel. The installation shown at B is unsafe — the separate grounds are not bonded. This could result in a serious accident or electrical fire.

22.1.9 Ground Conductors

Building codes and wiring standards are quite specific as to the types of conductors that can be used for bonding the various parts of the system together. Grounding conductors may be made from copper, aluminum, copper-clad steel, bronze or similar corrosion-resistant materials. Note that the sizes of the conductors required are based largely on mechanical strength considerations (to insure that the wire isn't broken accidentally) rather than electrical resistance. Insulation is not required.

There is a "unified" grounding electrode requirement — it is necessary to bond *all* grounds to the electric service entrance ground. All utilities, antennas and any separate grounding rods used must be bonded together. **Figure 22.6** shows correct (A) and incorrect (B) ways to bond ground rods. **Figure 22.7** demonstrates the importance of correctly bonding ground rods. (Note: The NEC requirements do not address effective RF bonding. See the **RFI and EMC** and **Assembling a Station** chapters of this book for information about RF practices. Keep in mind that RFI is not an acceptable reason to violate the NEC.) For additional information on good grounding practices, the *NEC Handbook* and IEEE "Emerald Book" (IEEE STD 1100-2005) are good references. Both are available

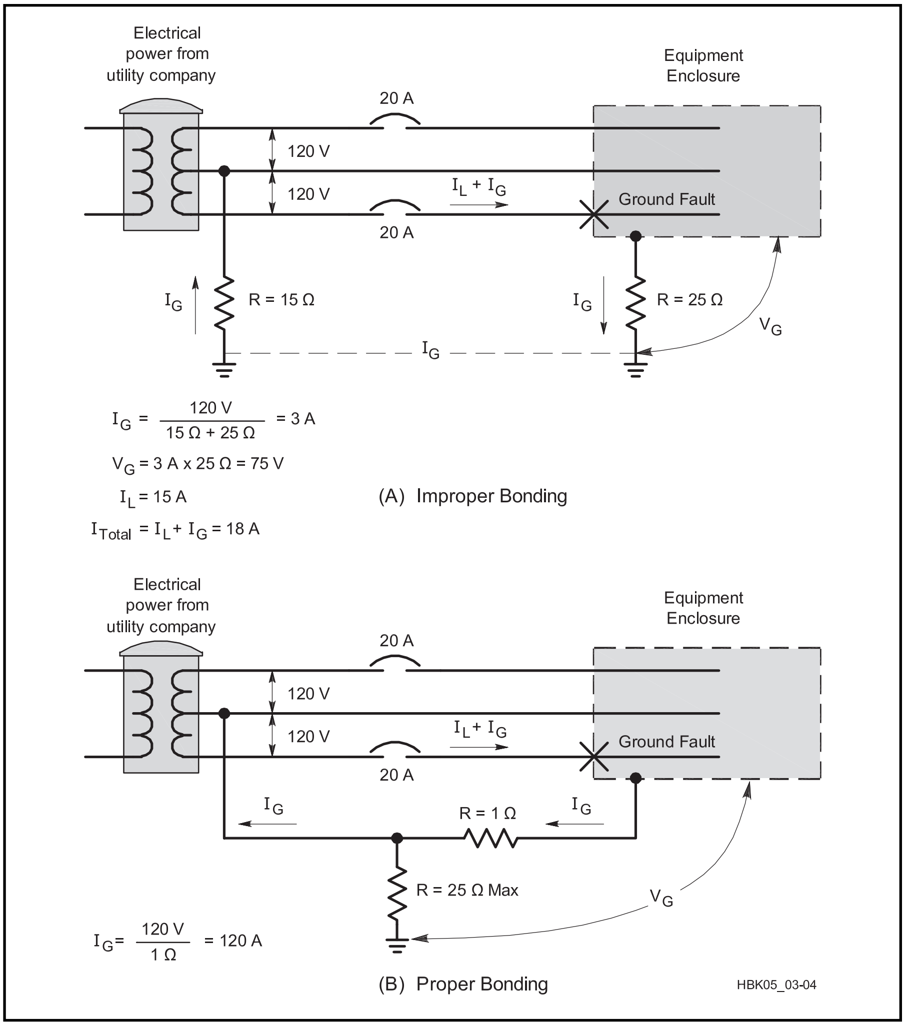

Figure 22.7 — These drawings show the importance of properly bonded ground rods. In the system shown in A, the 20-A breaker will not trip. In the system in B, the 20-A circuit breaker trips instantly. There is an equipment internal short to ground — the ground rod is properly bonded back to the power system ground. Of course, the main protection should be in a circuit ground wire in the equipment power cord itself!

Coax Shields as a Grounding Conductor

The importance of significant current-carrying capability in a grounding conductor is determined by your local circumstances. If lightning is a problem or contact with power-carrying conductors due to wind or ice is a possibility, the ability of the coax shield to carry a lot of current is important and a separate grounding conductor is a good idea. In areas where hazards are reduced, a smaller conductor may suffice. Contact a licensed electrician if you aren't sure about what is prudent for your area.

through libraries. Home wiring guides are also available at home improvement stores.

Additionally, the NEC covers safety inside the station. All grounding 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 insulator. Other code requirements include enclosing transmitters in metal cabinets that are bonded to the grounding system. Of course, conductive handles and knobs must be grounded as well.

22.1.10 Antennas

Article 810 of the NEC includes several requirements for wire antennas and feed lines that you should keep in mind when designing your antenna system. 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 AWG. The grounding conductor (used to bond equipment chassis together) must be at least #14 AWG.

The single most important thing to consider for safety is to address the potential for contact between the antenna system and power lines. As the code says, "One of the leading causes of electric shock and electrocution, according to statistical reports, is the accidental contact of radio, television, and amateur radio transmitting and receiving antennas and equipment with light or power conductors." (See Article 810.13, Fine Print Note.) The requirements in the code for wire sizes, bonding requirements, and installation practices are mostly aimed at preventing tragedy, by avoiding the contact in the first place, and by mitigating the effects of a contact if it occurs.

Article 820 of the NEC applies to cable TV installations, which almost always use coaxial cable, and which require wiring practices different from Article 810 (for instance, the coax shield can serve as the grounding conductor). Your inspector may look to Article 820 for guidance on a safe installation of coax, since there are many more satellite TV and cable TV installations than amateur radio. Ultimately, it is the inspector's call as to whether your installation is safe.

Article 830 applies to Network Powered Communication Systems, and as amateurs do things like install 802.11 wireless LAN equipment at the top of their tower, they'll have to pay attention to the requirements in this Article. The NEC requirements discussed in these sections are not adequate for lightning protection and high-voltage transient events. See the section "Lightning/Transient Protection" later in this chapter for more information.

ANTENNA CONDUCTORS

Transmitting antennas should use hard-drawn copper wire: #14 AWG for unsupported spans less than 150 feet, and #10 AWG for longer spans. Copper-clad steel, bronze or other high-strength conductors must be #14 AWG for spans less than 150 feet and #12 AWG for longer spans. Open-wire transmission line conductors must be at least as large as those specified for antennas. Stealth antennas made with light-gauge wire are not code-compliant but may be OK as a temporary installation since the NEC does not apply in such situations.

LEAD-INS

There are several NEC requirements for antenna lead-in conductors (transmission lines are lead-in conductors). For transmitting stations, their size must be equal to or greater than that of the antenna. Lead-ins attached to buildings must be firmly mounted at least 3 inches clear of the surface of the building on nonabsorbent insulators. Lead-in conductors must enter through rigid, noncombustible, nonabsorbent insulating tubes or bushings, through an opening provided for the purpose that provides a clearance of at least two inches;

or through a drilled windowpane. All lead-in conductors to transmitting equipment must be arranged so that accidental contact is difficult. As with stealth antennas, installations with feed lines smaller than RG-58 are likely not code compliant depending on how your local inspector interprets the code.

ANTENNA DISCHARGE UNITS (LIGHTNING ARRESTORS)

All antenna systems are required to have a means of draining static charges from the antenna system. A listed antenna discharge unit (lightning arrestor) must be installed on each lead-in conductor that is not protected by a permanently and effectively grounded metallic shield, unless the antenna itself is permanently and effectively grounded, such as for a shunt-fed vertical. Note that the usual transient protectors are *not* listed antenna discharge units.(The code exception for shielded lead-ins does *not* apply to coax, but to shields such as thin-wall conduit. Coaxial braid is neither "adequate" nor "effectively grounded" for lightning protection purposes.) An acceptable alternative to lightning arrestor installation is a switch (capable of withstanding many kilovolts) that connects the lead-in to ground when the transmitter is not in use. A garden-variety knife switch for household appliances is not adequately rated for this job.

ANTENNA BONDING (GROUNDING) CONDUCTORS

In general the code requires that the conductors used to bond the antenna system to ground be at least as big as the antenna conductors, but also at least #10 AWG in size. Note that the antenna grounding conductor rules are different from those for the regular electrical safety bonding, or lightning dissipation grounds, or even for CATV or telephone system grounds.

MOTORIZED CRANK-UP ANTENNA TOWERS

If you are using a motorized crank-up tower, the code has some requirements, particularly if there is a remote control. In general, there has to be a way to positively disconnect power to the motor that is within sight of the motorized device, so that someone working on it can be sure that it won't start moving unexpectedly. From a safety standpoint, as well, you should be able to see or monitor the antenna from the remote control point.

22.1.11 Lightning/Transient Protection

Nearly everyone recognizes the need to protect themselves from lightning. From miles away, the sight and sound of lightning boldly illustrates its destructive potential. Many people don't realize that destructive transients from lightning and other events can reach electronic equipment from many sources, such as outside antennas, power, telephone and cable TV installations. Many hams don't realize that the standard protection scheme of several decades, a ground rod and simple "lightning arrestor," is *not* adequate.

Lightning and transient high-voltage protection follows a familiar communications scenario: identify the unwanted signal, isolate it and dissipate it. The difference here is that the unwanted signal is many megavolts at possibly 200,000 A. What can we do?

Effective lightning protection system design is a complex topic. There are a variety of system tradeoffs which must be made and which determine the type and amount of protection needed. A amateur station in a home is a very different proposition from an air traffic control tower which must be available 24 hours a day, 7 days a week. Hams can easily follow some general guidelines that will protect their stations against high-voltage events that are induced by nearby lightning strikes or that arrive via utility lines. Let's talk about where to find professionals first, and then consider construction guidelines.

Manufacturers of Lightning Protection Equipment

For current vendor contact information, use your favorite internet search tool.

- Alpha Delta Communications: Coax lightning arrestors, coax switches with surge protectors.
- The Wireman: copper wire up to #4 AWG, 2-inch flat copper strap, 8-ft copper clad ground rods and 1 × ¼-inch buss bar.
- ERICO International Corporation: CadWeld bonding system and lightning protection equipment.
- Harger Lightning & Grounding: lightning protection components.
- Industrial Communication Engineers, Ltd (ICE): Coax lightning arrestors.
- KF7P Metalwerks: Entrance panels, lightning arrestors, surge protectors, grounding and bonding hardware, and so on.
- PolyPhaser Corporation: Many lightning protection products for feed lines, towers, equipment, and so on.
- Zero Surge Inc: Power line surge protector.

PROFESSIONAL HELP

Start with your local government. Find out what building codes apply in your area and have someone explain the regulations about antenna installation and safety. For more help, look in your telephone yellow pages for professional engineers, lightning protection suppliers and contractors.

Companies that sell lightning-protection products may offer considerable help to apply their products to specific installations. One such source is PolyPhaser Corporation. Look under "References" later in this chapter for a partial list of PolyPhaser's publications.

CONSTRUCTION GUIDELINES

Bonding Conductors

Copper strip (or *flashing*) comes in a number of sizes. The *minimum* recommended grounding conductor for lightning protection is 1.5 inches wide 20 gauge strap (0.032 inch (0.8 mm) thick) or #6 AWG stranded wire. The requirements for minimum size are driven by the need for mechanical durability.

Do not use braided strap outside or in wet areas because the individual strands oxidize over time, greatly reducing the effectiveness of braid as an ac conductor. Bear in mind that copper strap has about the same inductance as a wire of the same length. While strap may be easier to install and provides a lower RF loss (if it's part of a vertical antenna grounding system, for instance), it doesn't provide significant improvement over round wire for power line frequencies (the NEC's concern) or lightning (where inductance dominates the effects).

Use bare copper for buried ground wires. (There are some exceptions; seek an expert's advice if your soil is corrosive.) Exposed runs above ground that are subject to physical damage may require additional protection (a conduit) to meet code requirements. Wire size depends on the application, but never use anything smaller than #6 AWG for bonding earth electrodes. The NEC specifies conductors using wire gauge, and doesn't describe the use of flashing. Local lightning-protection experts or building inspectors can recommend sizes for each application.

Tower and Antennas

Because a tower is usually the highest metal object on the property, it is the most likely strike target. Proper tower grounding is essential to lightning protection. The goal is to establish short multiple paths to the Earth so that the strike energy is divided and dissipated.

Connect each tower leg and each fan of metal guy wires to a separate ground rod. Space the rods at least 6 feet apart. Bond the leg ground rods together with #6 AWG or larger copper bonding conductor (form a ring around the tower base, see **Figure 22.8**). Connect a continuous bonding conductor between the tower ring ground and the entrance panel. Make all connections with fittings approved for grounding applications. *Do not use solder for these connections.* Solder will be destroyed in the heat of a lightning strike.

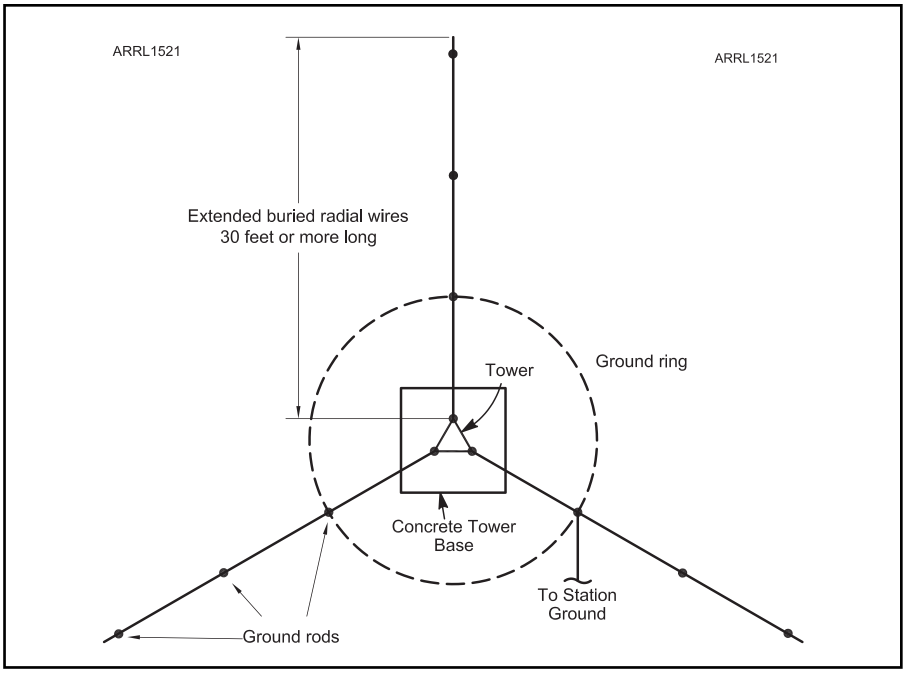

Figure 22.8 — Schematic of a properly grounded tower. A bonding conductor connects each tower leg to a ground rod and a buried (1 foot deep) bare, tinned copper ring (dashed line), which is also connected to the station ground and then to the ac safety ground. Make the ring diameter large enough that ground rods aligned with the tower legs will be approximately 6 feet apart. Buried radial wires extending beyond the ring are a common commercial practice and provide extra protection but are optional. All connectors should be compatible with the tower and conductor materials to prevent corrosion. See text for conductor sizes and details of lightning and voltage transient protection.

Because galvanized steel (which has a zinc coating) reacts with copper when combined with moisture, use stainless steel hardware between the galvanized metal and the copper grounding materials. Rohn and other manufacturers now offer ground clamps designing for connecting galvanized tower legs to copper ground conductors.

To prevent strike energy from entering a station via the feed line, ground the feed line *outside* the home. Ground the coax shield *to the tower* at the antenna and the base to keep the tower and line at the same potential. Several companies offer grounding blocks that make this job easy.

All grounding media at the home must be bonded together. This includes lightning-protection conductors, electrical service, telephone, antenna system grounds and underground metal pipes. Any ground rods used for lightning protection or entrance-panel grounding should be spaced at least 6 feet from each other and the electrical service or other utility grounds and then bonded to the ac system ground as required by the NEC.

A Single-Point Ground Panel (SPGP)

The basic concept with transient protection is to make sure that all the radio and other equipment is tied together and "moves together" in the presence of a transient voltage. It's not so important that the station be at "ground" potential, but, rather, that everything is at the *same* potential. For fast rise-time transients such as the individual strokes that make up a lightning strike, even a short wire has enough inductance that the voltage drop along the wire is significant, so whether you are on the ground floor, or the 10th floor of a building, your station is "far" from Earth potential.

The easiest way to ensure that everything is at the same potential is to tie all the signal ground connections to a common reference. In large facilities, this reference would be provided by a grid of large diameter cables under the floor, or by wide copper bars, or even a solid metal floor. A more practical approach for smaller facilities such as a ham station is to have a *single-point ground panel* (SPGP). The SPGP may be a separate metal panel or it can be enclosed in an electrical box. See the articles by Block in the References section for a complete discussion of the SPGP. The articles are available online through the ARRL's Radio Technology Topics website (**www.arrl.org/radio-technology-topics**) under Safety and in the ARRL book *Grounding and Bonding for the Radio Amateur*.

The SPGP should be mounted outside the building. The easiest way to do this is to install a large metal enclosure or a metal panel as a bulkhead and grounding block. The panel should be connected to the lightning dissipation ground with a short wide conductor (for minimum impedance), and, like all grounds, bonded to the electrical system's ground. Mount all protective devices, switches, and relay disconnects on the outside facing wall. The enclosure or panel should be installed in a way that if lightning currents cause a component to fail, the molten metal and flaming debris do not start a fire.

Every conductor that enters the structure, including antenna system control lines, telephone, and CATV cables, should have its own surge suppressor on an entrance panel. Suppressors are available from a number of manufacturers, including Industrial Communication Engineers (ICE) and PolyPhaser, as well as the usual electrical equipment suppliers such as Square-D.

We want to control the flow of the energy in a strike and eliminate any possible paths for surges to enter the building. Route feed lines, rotator control cables, and so on at least six feet away from other nearby grounded metal objects. Keep incoming, unprotected cables well away from cables on the protected side of any lightning arrestors, as well.

Voltage Rise On Wires With Fast Transients

A rule of thumb is that a single wire has an inductance of about 1 µH per meter of length. The voltage across an inductor $V = L\ \Delta i/\Delta t$. ($\Delta i/\Delta t$ is the change in current per unit of time.) A lightning stroke has a rise time of about 1-2 µs, so the current might go from zero to 10 kA in a microsecond or two, a $\Delta i/\Delta t$ of over 1 kA/µs (10^9 A/s). An inductance as low as 1 µH would create a voltage of 1000 volts from this current transient.

Lightning Arrestors

Feed line lightning arrestors are available for both coax cable and balanced line. Most of the balanced line arrestors use a simple spark gap arrangement, but a balanced line *impulse* suppressor is available from ICE.

DC blocking arrestors for coaxial cable have a fixed frequency range. They present a high-impedance to lightning (less than 1 MHz) while offering a low impedance to RF.

DC continuity arrestors (gas tubes and spark gaps) can be used over a wider frequency range than those that block dc. Where the coax carries supply voltages to remote devices (such as a mast-mounted preamp or remote coax switch), dc-continuous arrestors *must* be used.

22.1.12 Other Hazards in the Station

UPS AND ALTERNATE ENERGY SOURCES

Many hams have alternate energy sources for their equipment, or an uninterruptible power supply (UPS), so that they can keep operating during a utility power outage. This brings some additional safety concerns, because it means that the "turning off the breaker" approach to make sure that power is disconnected might not work.

In commercial installations, fire regulations or electrical codes often require that the emergency power off (EPO) system (the big red button next to the door) also disconnect the batteries of the UPS system, or at least, disable the ac output. This is so that firefighters who may be chopping holes with conductive tools or spraying conductive water don't face the risk of electrocution. (According to NEC, Articles 645-10 and 645-11, UPSs above 750 VA installed within information technology rooms must be provided with a means to disconnect power to all UPS supply and output circuits. This disconnecting means shall also disconnect the battery from its load. The code further requires that the control for these disconnecting means shall be grouped and identified and shall be readily accessible at the principal exit doors.)

A similar problem exists with solar panel installations. Just because the breaker is turned off doesn't mean that dangerous voltages don't exist on the solar panel. As long as light is falling on them, there is voltage present. With no load, even a relatively dim light falling on part of the panels might present a shock or equipment damage hazard. Modern grid-tie solar systems with no batteries often have the panels wired in series, so several hundred volts is not unusual.

Recent revisions of the NEC have addressed many of the aspects of photovoltaic (PV) installations that present problems with disconnects, bonding, and grounding. Consulting your local authorities is always wise, and there are several organizations such as the Southwest Technology Development Institute at New Mexico State University that have prepared useful information (see the references at the end of this section). In general, PV systems at 12 or 24 V aren't covered by the NEC.

Fire Extinguishers in the Amateur Station

Every amateur station should have a fire extinguisher at hand. Three classes of fire extinguishers are appropriate for amateur stations:

- Class A: Combustible solid materials such as wood or paper
- Class B: Combustible liquid or gases
- Class C: Energized electrical fire

A fixed or portable station should have "ABC" class extinguishers. Mobile stations are most likely to experience class B and C fires. Liquid water extinguishers or hoses should never be used on an electrical fire because most water is a conductor of electricity and creates an electrical shock hazard. For more information on fire extinguishers, see the chapter "Assembling a Station."

ENERGIZED CIRCUITS

Working with energized circuits can be very hazardous since, without measuring devices, we can't tell which circuits are live. The first thing we should ask ourselves when faced with troubleshooting, aligning or other "live" procedures is, "Is there a way to reduce the hazard of electrical shock?" Here are some ways of doing just that.

1) If at all possible, troubleshoot with an ohmmeter. With a reliable schematic diagram and careful consideration of how various circuit conditions may reflect resistance readings, it will often be unnecessary to do live testing.

2) Keep a fair distance from energized circuits. What is considered "good practice" in terms of distance? The NEC specifies minimum working space around electric equipment depending on the voltage level. The principle here is that a person doing live work needs adequate space so they are not forced to be dangerously close to energized equipment.

3) If you need to measure the voltage of a circuit, install the voltmeter with the power safely off, back up, and only then energize the circuit. Remove the power before disconnecting the meter.

4) If you are building equipment that has hinged or easily removable covers that could expose someone to an energized circuit, install interlock switches that safely remove power in the event that the enclosure is opened with the power still on. Interlock switches are generally not used if tools are required to open the enclosure.

Electrical Shock Hazards and Effects

What happens when someone receives an electrical shock?

Electrocutions (fatal electric shocks) usually are caused by the heart ceasing to beat in its normal rhythm. This condition, called ventricular fibrillation, causes the heart muscles to quiver and stop working in a coordinated pattern, in turn preventing the heart from pumping blood.

The current flow that results in ventricular fibrillation varies between individuals but may be in the range of 100 mA to 500 mA. At higher current levels the heart may have less tendency to fibrillate but serious damage would be expected. Studies have shown 60-Hz alternating current to be more hazardous than dc currents. Emphasis is placed on application of cardiopulmonary resuscitation (CPR), as this technique can provide mechanical flow of some blood until paramedics can "restart" the heart's normal beating pattern. Defibrillators actually apply a carefully controlled waveform to "shock" the heart back into a normal heartbeat. It doesn't always work but it's the best procedure available.

What are the most important factors associated with severe shocks?

You may have heard that the current that flows through the body is the most important factor, and this is generally true. The path that current takes through the body affects the outcome to a large degree. While simple application of Ohm's law tells us that the higher the voltage applied with a fixed resistance, the greater the current that will flow. Most electrical shocks involve skin contact. Skin, with its layer of dead cells and often fatty tissues, is a fair insulator. Nonetheless, as voltage increases the skin will reach a point where it breaks down. Then the lowered resistance of deeper tissues allows a greater current to flow. This is why electrical codes refer to the term "high voltage" as a voltage above 600 V.

How little voltage can be lethal?

This depends entirely on the resistance of the two contact points in the circuit, the internal resistance of the body, and the path the current travels through the body. Historically, reports of fatal shocks suggest that as little as 24 V *could* be fatal under extremely adverse conditions. To add some perspective, one standard used to prevent serious electrical shock in hospital operating rooms limits leakage flow from electronic instruments to only 50 µA due to the use of electrical devices and related conductors inside the patient's body.

5) Never assume that a circuit is at zero potential even if the power is switched off and the power cable disconnected. Capacitors can retain a charge for a considerable period of time and may even partially recharge after being discharged. Bleeder resistors should be installed, but don't assume they have discharged the voltage. Instead, after power is removed and disconnected use a "shorting stick" to ground all exposed conductors and terminals to ensure that voltage is not present. If you will be working with charged capacitors that store more than a few joules of energy, you should consider using a "discharging stick" with a high wattage, low value resistor in series to ground that limits the discharge current to around 5-10 A. A dead short across a large charged capacitor can damage the capacitor because of internal thermal and magnetic stress. Avoid using screwdrivers, as this brings the holder too close to the circuit and could ruin the screwdriver's blade. For maximum protection against accidentally energizing equipment, install a shorting lead between high-voltage circuits and ground while you are working on the equipment.

6) Shorting a series string of capacitors does not ensure that the capacitors are discharged. Consider two 400 μF capacitors in series, one charged to +300 V and the other to –300 V with the midpoint at ground. The net voltage across the series string is zero, yet each has significant (and lethal) energy stored in it. The proper practice is to discharge each capacitor in turn, putting a shorting jumper on it after discharge, and then moving to the next one.

7) If you must hold a probe to take a measurement, always keep one hand in your pocket. As mentioned in the sidebar on high-voltage hazards, the most dangerous path current could take through your body is from hand to hand since the flow would pass through the chest.

8) Make sure someone is in the room with you and that they know how to remove the power safely. If they grab you with the power still on they will be shocked as well.

9) Test equipment probes and their leads must be in very good condition and rated for the conditions they will encounter.

10) Be wary of the hazards of "floating" (ungrounded) test equipment. A number of options are available to avoid this hazard.

11) Ground-fault circuit interrupters can offer additional protection for stray currents that flow through the ground on 120-V circuits. Know their limitations. They cannot offer protection for the plate supply voltages in linear amplifiers, for example.

12) Older radio equipment containing ac/dc power supplies have their own hazards. If you are working on these live, use an isolation transformer, as the chassis may be connected directly to the hot or neutral power conductor.

13) Be aware of electrolytic capacitors that might fail if used outside their intended applications.

14) Replace fuses only with those having proper ratings. The rating is not just the current, but also takes into account the speed with which it opens, and whether it is rated for dc or ac. DC fuses are typically rated at lower voltages than those for ac, because the current in ac circuits goes through zero once every half cycle, giving an arc time to quench. Switches and fuses rated for 120 V ac duty are typically not appropriate for high-current dc applications (such as a main battery or solar panel disconnect).

22.1.13 Electrical Safety References

ARRL Technical Information Service Web page on electrical safety in the Technology area of the ARRL website.

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Federal Information Processing Standards (FIPS) publication 94: *Guideline on Electrical Power for ADP Installations.* FIPS are available from the National Technical Information Service.

IAEI: *Soares' Book on Grounding*, available from International Association of Electrical Inspectors (IAEI).

"IEEE Std 1100 - 2005 IEEE Recommended Practice for Powering and Grounding Electronic Equipment," *IEEE Std 1100-2005 (Revision of IEEE Std 1100-1999)*, pp 0_1-589, 2006. "This document presents recommended design, installation, and maintenance practices for electrical power and grounding (including both safety and noise control) and protection of electronic loads such as industrial controllers, computers, and other information technology equipment (ITE) used in commercial and industrial applications."

National Electrical Code Handbook 2017, NFPA 70, National Fire Protection Association, Quincy, MA (**www.nfpa.org**), also available through libraries.

Silver, W., Grounding and Bonding For the Radio Amateur, 2nd edition, ARRL, 2021.

Solar energy websites — **www.nmsu.edu/~tdi/PV=NEC_HTML/pv-nec/pv-nec.html** and **www.solarabcs.org**

Standard for the Installation of Lightning Protection Systems, NFPA 780, National Fire Protection Association, Quincy, MA (**www.nfpa.org**).

See the Protection Group's list of white papers contained in the Knowledge Base **www.protectiongroup.com**.

22.2 Antenna and Tower Safety

An antenna at height is a critical component of an effective amateur radio station. Hams have a long history of finding creative ways to get their antennas to the necessary height. We don't always think of safety first, but regardless of whether the chosen antenna support is as simple as a tree, or as sophisticated as a tall, purpose-built tower, every antenna project can present many potential risks to life and limb.

Whether the chosen antenna support is as simple as a tree, or as sophisticated as a tall, purpose-built tower, every antenna project can present risks to life and limb. Some of the hazards that may be encountered include:

- Electrical hazards
- Structural failures
- Hazards associated with lifting and lowering equipment
- Falls from substantial height
- Challenging weather
- Falling objects
- Equipment failure

The topic of antenna and tower safety is by no means an academic pursuit. In 2019 and 2020 alone, there were six recorded fatalities related to amateur radio tower work and serious injuries in other instances. The causes of these tragic incidents were all identifiable in advance and avoidable. With careful attention and care, no ham needs to lose their life or sustain serious injury in the course of working on an antenna system.

In the initial section, we introduce some important ways of preparation and working on antennas and their supports safer and easier. This material presents a good overview of safety issues and practices associated with antennas and supporting structures. The remainder of the sections focus primarily on safety issues encountered during tower construction and maintenance, although the techniques may also apply to other types of antenna supports.

The material in this section covers a lot of topics and should be treated as an overview. If you need more information about a particular piece of equipment or technique, see the Reference section for more articles and online information. The *ARRL Antenna Book* chapter on **Building Antenna Systems and Towers** goes into much more detail about these same topics and many others. There is sufficient information in these books, articles, and online so that no one needs to be uninformed about good practices for working on and building antenna systems.

22.2.1 Planning for Safety

Safety isn't something you can just *set-and-forget*. It's not just *buy-and-be-done*. It's a way of thinking; it's pervasive; it should be ingrained in everything you do. Done right, safety practices result in long-term benefits.

Every antenna project has a lifetime that comprises several important phases. Those phases include *Planning, Construction, Maintenance*, and *Removal*. Let's take a look at each of these phases and the safety practices that can be incorporated into each one.

THE PLANNING PHASE

Every antenna project starts with some sort of *Planning*. Whether it's a simple wire antenna or a much bigger installation in-volving a tower and rotatable antennas, you'll need to make a range of important decisions before you begin to build.

Design is perhaps the most critical part of the planning phase. In antenna system design, you will consider questions about the location of the antenna system; the size, weight and strength of the pieces and parts that will be employed; and the strength of all supporting components. Factors such as climate and weather, desired lifetime, maintenance requirements, budgets, and local regulations will all factor into your design. Getting the design right is particularly important because it sets the stage for what will happen throughout the full lifetime of the system. A good design is likely to result in a system that will be effective, reliable and safe over the course of its entire lifetime.

Conservativism is the watchword for a safe project. Maximum safety can best be ensured by creating the path forward from a conservative perspective. Conservative goals and specifications will not only increase safety margins for the project; they reduce the effort and cost associated with the later phases of construction, maintenance, and removal.

THE CONSTRUCTION PHASE

Construction describes the time during which the antenna or antenna support structure is erected, usually one or more days of concentrated effort by a team of hams. Construction is one of the two phases in the life of an antenna or tower during which risk of injury is highest. Some of those involved might have experience, while others are new to the process of antenna and tower construction. Fueled by excitement and anticipation of the moment when the project will be ready to test, the build team is often motivated to get the job done quickly. With pressure to complete any job in the least possible amount of time comes the temptation to cut corners or distractions from safe procedures. The best planning is easily compromised when team members decide to skip steps, work with insufficient skills or tools, or omit critical procedures. This is a period when everyone must be vigilant about keeping safe practices front-and-center.

THE MAINTENANCE PHASE

Once the new antenna or tower has been fully installed and tested, its service life begins. Every owner/operator of an antenna system hopes for a long lifetime of trouble-free operation. But wear-and-tear is a fact of life for all mechanical and electrical devices. Some forms of degradation are predictable, such as loosening of nuts and bolts, corrosion, and wear on ropes or cables exposed to friction. These can and should be addressed with *preventative maintenance* (PM) steps. Annual checkups of hardware are a must. Replace antenna support ropes before they fail, perhaps bi-annually. PM will prevent much bigger problems and help avoid the need for much bigger and riskier repair projects.

THE REMOVAL PHASE

The remaining risky phase in the life of an antenna project — particularly with respect to a tower —– is removal. A variety of risks present themselves during the take-down of an existing tower. Let's consider two of the most common safety risks related to removal of a tower.

Unknown Construction Materials and Methods

It is not uncommon for hams to assist in removal of a tower or other antenna structure when a ham is moving or is otherwise no longer able to use it. After asking the first few questions, it is very common to find that the original construction details were not documented. Is there concrete in the base and anchors of a guyed tower? How much? How is the roof tower attached to the roof? What material was used for the mast? Can it be identified simply by visual inspection? When the answers to these questions are unknown, workers face significant risks. If there isn't sufficient information to make a safety determination, there is only one correct plan of action — call in the professionals.

Old Installations

When an installation has been in place for many years, the risks increase. Corrosion is almost certain to have invaded the hardware. Frequently, the corrosion is invisible; even a trained professional may have difficulty detecting it. The opportunity to take on a removal project in exchange for the salvage value of a tower and antennas is a temptation that should be avoided. If you are not highly trained and experienced in working with tower and antenna installations, the right course of action is to call in the professionals.

22.2.2 Antenna Supports and Structures

TREES

The original antenna supports were trees: if you've got them, use them. They're free and unregulated, so it couldn't be easier. Single-trunked varieties such as fir and pine are easier to use than the multi-trunked varieties. Multi-trunked trees are not impossible to use but they require more work. For dipoles or other types of wire antennas, plan for the tree to support an end of the wire; trying to install a center-supported inverted V or similar configuration is almost impossible due to all of the intervening branches.

Even when working with trees, it's important to be aware of the potential for safety hazards. There are two primary safety risks associated with using trees as antenna supports:

Proximity to Power Lines

Antennas are metallic and must be kept a substantial distance from power lines. Any wire or tubing coming in accidental contact with a power line is a lethal hazard. Even antennas protected by non-conductive sleeves must be kept from contacting power lines. When you choose trees as your antenna supports, inspect the tree carefully. It is important to avoid using trees that are in close proximity to any power lines that may be difficult to see in or near the tree. Without expert knowledge, you should assume that any wires on utility poles and any wires entering your home at a service entry point are dangerous and must be avoided.

Climbing

In general, safely climbing a tree to install an antenna requires special equipment and training in techniques that protect both the tree and the climber. Professional arborists and tree services have all the necessary experience and equipment. Professional tree climbers are often willing to help out for a small fee.

There are quite a few options to support your antenna high in a tree without climbing. Rope saws, pole trimmers, ropes, pulleys, and other tools can establish a strong and secure support point for your antenna.

If you can safely gain access to the tree at the desired height, an effective method is to install a screw-eye with a pulley into the trunk or a strong branch, then trim enough limbs to create a "window" for the antenna through the branches. Finally, attach a rope halyard to the antenna insulator. Here's a useful tip: Make the *halyard* a continuous loop as shown in **Figure 22.9**. Since it's almost always the antenna wire that breaks, a continuous halyard makes it easy to reattach the wire and insulator. With just a single halyard, if the antenna breaks, the tree will have to be climbed to reach the pulley, then reinstall and attach the line.

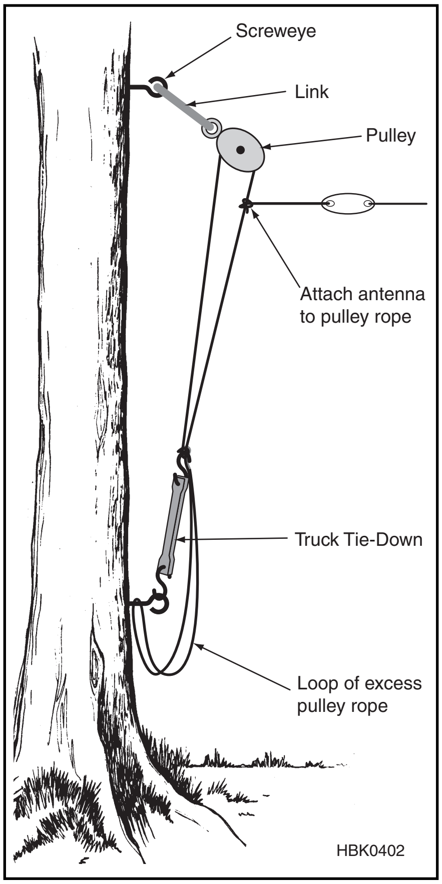


Figure 22.9 — Loop and halyard method of supporting wire antennas in trees. Should the antenna break, the continuous loop of rope allows antenna repair or replacement without climbing the tree.

Another popular option to get your wires high in the trees is by using some sort of launcher. Using a bow-and-arrow is a traditional method of shooting a fishing line over a tree to pull up a bigger line. Some use a slingshot or a fishing rod with a well-chosen weight to get the initial line over a high branch. There are commercial compressed-air launchers or "spud guns" that can reach heights of more than 200 feet! One of the secrets to success in all of these techniques is to start with a light fishing line holding a weight large enough to pull the line back to the ground through the tree. Then use the light line to pull a mid-weight line over the branch, and finally pull the heavy-duty rope into place. The initial weight should be brightly colored so you can find it either on the ground or in the tree.

Somewhat slower but a lot more controllable, a multi-rotor drone can lift light lines over the highest trees, although not through them. A light line is carried over the tree by the drone, and then the light line is used to pull a heavier line over the tree, just as when using a launcher. The process is described in a pair of QST articles: See the Reference section entries for articles by Kam Sirageldin, N3KS (better known as TI5W and TI7W), and by Michael Shandblatt, W3MAS, and Joe Warwick, KB3ZED.

MASTS AND POLES

Ground-mounted masts and poles come in a wide variety of sizes and strengths. Telescoping fiberglass poles are popular supports for wire antennas, particularly for portable and temporary use. Light-duty TV antenna push-up masts can support small beam antennas. AB-155 military surplus masts use stackable sections of fiberglass and aluminum tubing supported by guys and tripods. Another military-style mast, the AB-577 is an all-aluminum crank-up mask often called a "rocket launcher" that can support a medium-sized HF beam.

All types of masts present challenges; don't overload them. None of the choices listed here can be climbed, so antennas or mounting gear must be attached at ground level before the mast is raised. Masts with antennas installed can bend or break when being "walked up" to vertical from a horizontal position. Stackable sections require sturdy supports to hold the mast vertical as the mast is lifted to add more sections from the bottom. The mast manufacturer will provide directions and safe loading information. These instructions must be followed to avoid damaging the mast or causing injuries. It is also wise to have a supervisor or observer monitor progress and watch out for unsafe situations as the mast is being erected.

A mast's flexibility makes the side guys especially important since they keep it from bending sideways under load. Masts require extra care during installation to be sure they are kept straight. Once a curve develops, a collapse can occur very quickly. If a team is required to manage guys as the mast is raised, a practice session should be arranged so that everyone knows the procedure and coordinating instructions are followed.

Steel push-up masts are heavy, especially when raising the final sections that are carrying the full weight of the extended mast. A slipping section can seriously injure fingers and hands. Push-up masts can be walked up, but only with light antennas attached (the top section is likely to bend if loaded when it is not vertical).

Wooden utility poles, new or used, are very sturdy but are not cheap, require special installation with a pole-setting truck, and there is no commercial antenna mounting hardware available for them. That makes them a poor choice for most installations. Do not use existing utility poles as antenna supports if they support utility lines of any type.

TOWERS

Towers require a significant effort to design and install a safe, effective system but are the only viable choice for large, rotatable antennas and arrays. Along with being able to support the weight and torque of larger antennas and accessory equipment, the options offered by commercial tower manufacturers allow each individual tower installation to be purpose-built to suit the needs of the station owner. A wide variety of requirements can be satisfied with selection of the right tower type and proper construction. There are many safety issues involved that require careful planning and preparation. These are discussed in the following sections.

There are three basic types of towers commonly used by amateurs to support antennas: *roof-mounted*, *self-supporting*, and *guyed*. Each is described in the section below on Design Considerations.

Using towers for portable and temporary stations has its own set of safety challenges. It is common on Field Day, for example, to erect towers of 20 to 40 feet to support a small HF beam. The June 2013 *QST* article "Field Day Towers — Doing It Right" by Daso and Silver presents information about and guidelines for temporary tower installation.

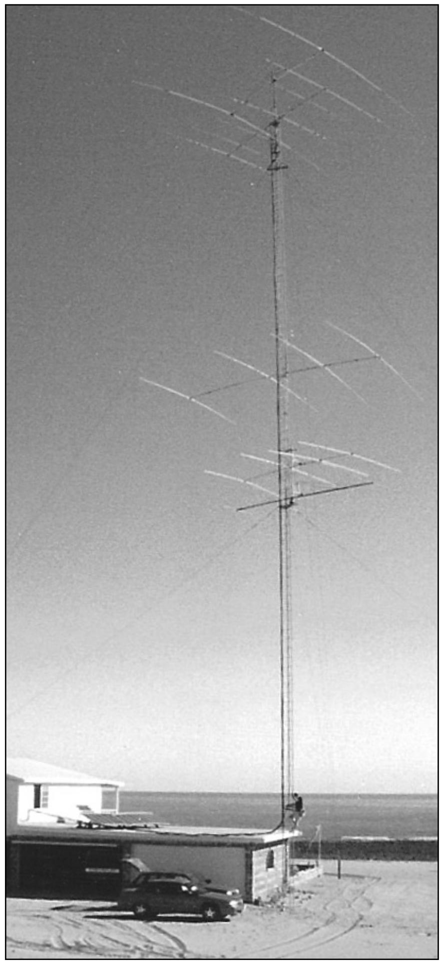


Figure 22.10 — A guyed tower with a good-sized load of antennas shown at the left. At the right, a Trylon Titan self-supporting tower. [Steve Morris, K7LXC, photos]

22.2.3 Build It by the Book

Every aspiring antenna system builder/owner needs to understand and follow two types of information that constrain or guide construction and installation:

Regulations

Most antenna support structures fall under local building regulations as well as neighborhood restrictions. Many housing developments have Homeowner's Associations (HOAs) as well as Covenants, Conditions and Restrictions (CC&Rs) that may have a direct bearing on whether a tower or similar structure can be erected at all, and if allowed, how it must be constructed for safety and other concerns. This is a broad topic with many facets. Detailed background on these topics is provided in *Antenna Zoning for the Radio Amateur* by Fred Hopengarten, K1VR, an attorney with extensive experience in towers and zoning. You may also want to contact one of the ARRL Field Organization's Volunteer Counsels.

Even without neighborhood restrictions, a building permit is likely to be required. With the proliferation of cellular and other commercial wireless devices and their attendant RF sites, many local governments now require that all antenna support structures meet local building codes. Again, K1VR's book is extremely helpful in sorting all this out. Building permit applications may also require Professional Engineer (PE) calculations and stamp (certification). The ARRL Field Organization's Volunteer Consulting Engineer program may be useful with the engineering side of your project.

It is important to understand that building regulations are the cumulative results of decades of experience — and that compliance with them will result in a structure that is both stronger and safer for you and your neighbors. Working closely with the local building department is often a source of useful knowledge and tips for a better installation. It also gives you permits and signoffs that can provide a level of liability protection in the event of a future incident.

Manufacturers' Guidelines

As you explore the various options in the world of commercial antenna supports, you will find that every manufacturer provides clear instructions on how their products should be installed and specifications of the minimum performance that should be expected when installed per the manufacturer's instructions. This information is developed by design engineers and is usually signed off by a registered Professional Engineer to certify that the design is in alignment with standard building codes, such as the International Building Code (IBC). The IBC is the base building code used by most jurisdictions in the United States. (See the sidebar on the NEC in the Electrical Safety section earlier in this chapter for more information on building codes.)

Former tower climber Steve Morris, K7LXC says it well in what is affectionately known in the amateur radio world as the K7LXC Prime Directive — "DO what the manufacturer says." Follow the corollary as well — "DON'T do what the manufacturer doesn't say to do." Professional engineers have analyzed and calculated the proper specifications and conditions for tower structures and their environment. Taking shortcuts or making different decisions will result in a less reliable installation. It is also important to note here that every installation is unique. Your analysis may reveal that even the manufacturer's recommendations are not conservative enough for your particular situation and needs.

DESIGN CONSIDERATIONS

Safety starts with design. Two critically important design parameters to consider when planning a tower installation are the maximum local *wind speed* and the proposed antenna *wind load*. Tower capacities are generally specified in square feet of antenna load. Check with your local building department to find out what the maximum wind speed is for your area. Another source is a list of maximum wind speeds for all counties in the US from the TIA-222, *Structural Standard for Antenna Supporting Structures and Antennas*. (TIA-222-H is the latest revision as of early 2021.) A list of wind speeds by county based on TIA-222-G is available online at **wirelessestimator.com/content/standards**.

Antenna wind load specifications are provided by the antenna manufacturer. It's important to note that when installing a mast with several antennas, the total effective wind load on the tower is not a simple sum of the wind loads of the various antennas. The true load of each antenna will increase with its height above the top of the tower. The forces on the top of the tower by A 10 sq. ft. antenna mounted 10 feet above the tower on a long mast will subject the tower to much greater forces than the same antenna mounted right at the top plate of the tower. A proper calculation of wind load should be done by a trained structural engineer. (A procedure for calculating load and mast strength is provided in the *ARRL Antenna Book*.)

Towers come in the guyed and self-supporting varieties shown in **Figure 22.10**. Each has its own safety issues. Guyed towers require a bigger footprint because the guys have to be anchored away from the tower — typically 80% of the tower height. Self-supporting towers need bigger bases to counteract the overturning moment and are more expensive than a guyed tower because there is more steel in them (the cost of a tower is largely determined by the cost of the steel).

The most popular guyed towers are the Rohn 25G and 45G. The 25G is a light-duty tower and the 45G is capable of carrying fairly large loads. The online Rohn catalog (see the References — the latest version 3 was released in 2015) has most of the information you'll need to plan an installation and is considered a "bible" of information for tower construction.

The primary risks associated with guyed towers are related to the guys themselves. Guy material, construction, termination, anchoring, and long-term maintenance must be done correctly to keep risks low. At the low end of the guyed tower category is the house-bracketed tower. In this case, the guyed tower sections are placed on a base immediately adjacent to a building, and specially designed brackets are used to support the tower. House brackets are required to be secured to the building in a structurally sound manner. Manufacturers can supply specifications. A local structural engineer can also provide custom plans designed specifically for the unique structure involved.

Fixed, self-supporting towers are made by several manufacturers and allow building a tower up to 100 feet or higher with a small footprint. Rohn, Trylon, and AN Wireless are popular vendors. In general, fixed self-supporting towers are reliable and long-lasting as long as the antenna load is kept well within the tower's specs and the tower is regularly inspected for corrosion. A self-supporting tower requires a substantial concrete base or footing.

Another type of self-supporting tower is the *crank-up*, shown in **Figure 22.11**. One large manufacturer of crank-up towers is US Towers. Using a system of cables, pulleys and winches, crank-up towers can extend from 20 feet to over 100 feet high. These are moderately complex devices, and as such, present certain risks. Because they consist of a variety of moving parts, crank-

Figure 22.11 — The bottom of a crank-up tower is shown at left. The motor drive mechanism is on the left and a fishing net on the right catches and coils the feed lines and control cables as the tower is lowered. On the right, a fully loaded crank-up extended to its maximum height of 90 feet. [Steve Morris, K7LXC, photos]

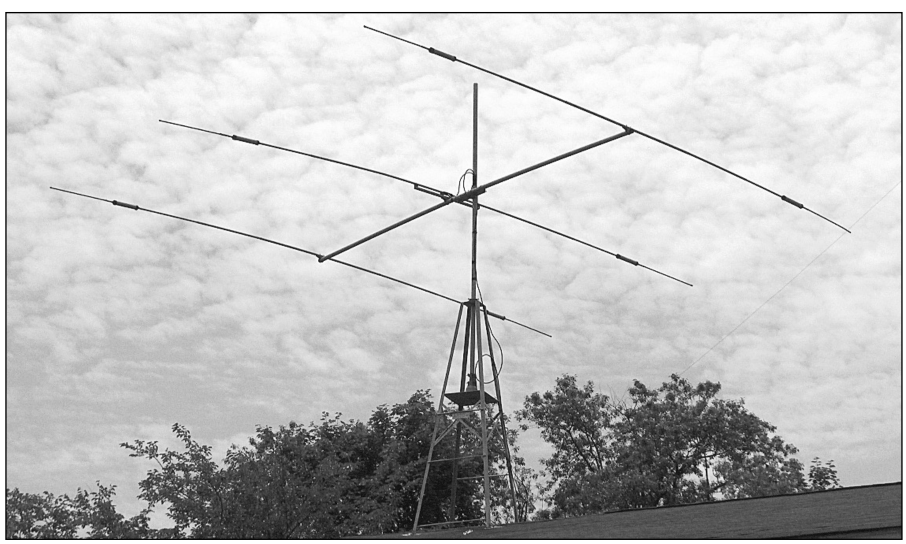


Figure 22.12 — A roof-mounted tower holding a mid-sized HF triband beam. [AA2OW photo]

Principles of Working Safely

The following safety tenets founded on three fundamental principles: Do it safely or not at all; There's always time to do it right; and If it's worth doing, do it better.

1. Never load or operate structures or equipment outside the design limits. Be careful with tools, ropes, pulleys, and other equipment that can cause injury or damage if they fail due to overload. Use the right stuff!
2. Always move to a safe, controlled condition and seek assistance when a situation is not understood. This is particularly important when working on towers and antennas. If something doesn't look right or isn't going according to plan, return to a safe state and figure out what to do.
3. Always operate with the safety mechanisms engaged. If a safety mechanism prevents you from doing something, either the task is unsafe or you may not be using the right equipment.
4. Always follow safe work practices and procedures. Make a plan before you start and don't do something you know is unsafe.
5. Act to stop unsafe practices. The team's safety depends on every team member. Do not hesitate to stop work if you see it is unsafe. Don't be afraid to speak up or ask for help! Regroup and do it right.
6. Clarify and understand procedures before proceeding. This is particularly important when working with a crew. Be sure everyone understands the procedure and how to communicate.
7. Involve people with expertise and firsthand knowledge in decisions and planning. Ask for advice and guidance from experienced hams when planning a task with which you are unfamiliar.

up towers require more maintenance than guyed or other self-supporting designs. As with the fixed, self-supporting tower, a crank-up tower requires a large concrete base.

Owners and climbers of crank-up towers must observe additional safety procedures to ensure that the mechanical state of the tower will not present risks during any operations that involve climbing. The tower sections should be fully nested and blocked ensuring there is no way for any of the sections to slip within the tower unexpectedly during work.

Antennas can also be installed on a *roof-mounted tower*, seen in **Figure 22.12**. These are four-legged aluminum structures of heights from four to more than 20 feet. While they are designed to be lag-screwed directly into the roof trusses, it is often preferable to through-bolt them into a long 2×4 or 2×6 that acts a backing plate, straddling and attached to three to four roof trusses. In any case, if it is not clear how best to install the tower on the structure, have a roofing professional or engineer provide advice. Working on a roof-mounted tower also requires extra caution because of climbing on a roof while also working on a tower. Many of these lightweight, aluminum towers cannot be climbed, so you must use a ladder to access the antenna. Again, extreme caution is required.

22.2.4 Tower Construction and Erection

THE BASE

Once all the necessary materials and the required approvals have been gathered, tower installation can begin. Let's assume you and your friends are going to install it. The first job is to construct the base. A base for a guyed tower can be hand-dug as can the guy anchors. For a self-supporting tower, renting an excavator of some sort will make it much easier to move the several cubic yards of dirt.

In the bottom of the hole, be sure to add several inches of gravel or crushed stone that will allow water to drain from the hollow tower legs. If the base section is not going to sit on the gravel, be sure to provide a drainage path for the legs. Water that builds up in the tower legs from condensation or leakage will rust out the steel from the inside where it is not visible until significant damage has been done, creating a severe safety hazard. Similarly, standing water in the legs may also freeze and split the tubing with the same effect on safety.

Next, some sort of rebar cage will be needed for the concrete. Guyed towers only require rudimentary rebar while a self-supporting tower will need a bigger, heavier and more elaborate cage. Consult the manufacturer's specifications for the exact materials and dimensions. As noted earlier, documentation of how the base is constructed is important for future reference when the tower is maintained or removed. It may also be necessary for a building permit and inspection along with home and liability insurance.

Typical tower concrete specs call for 3000 psi (minimum) compressive strength concrete and 28 days for a full cure. (See the manufacturer's specifications.) A local pre-mix concrete company can deliver it. Pouring the concrete is easiest if the concrete truck can back up to the hole. If that's not possible, a truck- or trailer-mounted line pump can pump it up to 400 feet at minimal expense if using a wheelbarrow is not possible or practical. Packaged concrete from the hardware store mixed manually may also be used, but the volume of concrete required will typically make this a very substantial job. Quikrete Mix #1101 is rated at 2500 psi after seven days and 4000 psi after 28 days.

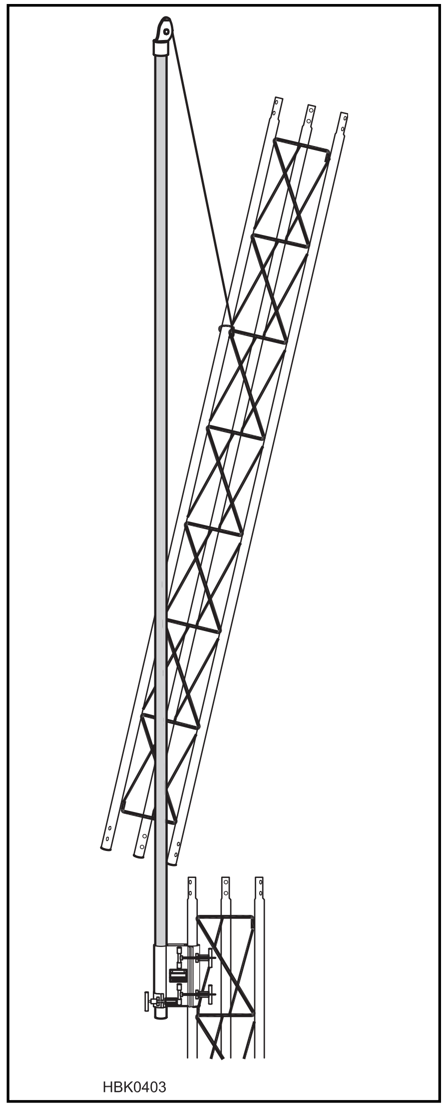
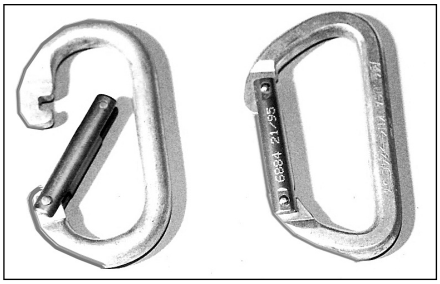


Figure 22.13 — A gin-pole consists of a leg clamp fixture, a section of aluminum mast and a pulley. It is used to lift the tower section high enough to be safely lowered into place and attached. (Based on Rohn EF2545.)

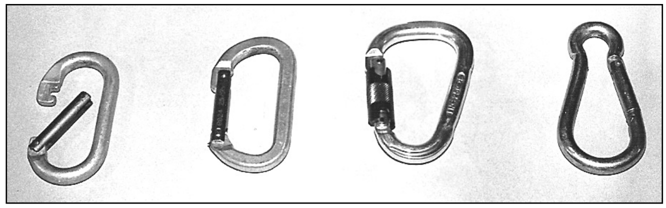
TOOLS

Once the base and anchors are finished and the concrete has cured, the tower can be constructed. There are several tools that will make the job easier and safer. Since most hams do not build or climb towers on a regular basis, practice using all of the tools and accessories before starting a tower project. Know how to tie and untie basic knots. Practice lifting and lowering operations at ground level before attempting them at height.

If the tower is a guyed tower, it can be erected either with a crane (discussed in the section below on installation) or a *gin-pole*. The gin-pole, shown in **Figure 22.13**, is a



(A)



(B)

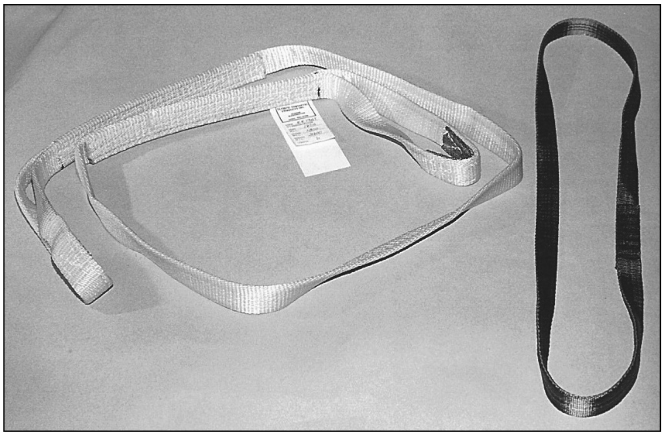


Figure 22.14 — (A) Oval, mountain climbing type carabiners are ideal for tower workloads and attachments. The gates are spring loaded — the open gate is shown for illustration. (B) An open aluminum oval carabiner; a closed oval carabiner; an aluminum locking carabiner; a steel snaplink. (C) A heavy duty nylon sling on the left for big jobs and a lighter-duty loop sling on the right for everything else. [Steve Morris, K7LXC, photos]

Figure 22.15 — Snatch blocks can be opened to place a rope directly on the sheave without having to thread it through the housing. A lightweight plastic block is shown at left, and two metal housing blocks at right.

pipe that attaches to the leg of the tower and has a pulley at the top for the haul rope. Use the gin-pole to pull up one section at a time (see below).

Another useful tool for rigging and hoisting is the *carabiner*. Shown in **Figure 22.14** (A and B), carabiners are oval steel or aluminum snap-links popularized by rock and mountain climbers. They have spring-loaded gates and can be used for many tower tasks. For instance, there should be one at the end of the haul rope for easy and quick attachment to rotators, parts, and tool buckets — virtually anything that needs to be raised or lowered. It can even act as a "third hand" on the tower. (Do not use light-duty carabiners marked "Not For Climbing.")

Pulleys ("blocks") are required for lifting and maneuvering loads with ropes. At a minimum, one pulley is needed for the haul rope at the top of the tower, and having two or more high-quality pulleys is usually required. Use pulleys rated for heavy loads such as for marine rigging and rock climbing. A *snatch block* is also useful; this is a pulley with one side that swivels so it can open up to "snatch" (attach to) the rope at any point without having to thread the rope through the pulley housing over the rotating sheave. **Figure 22.15** shows two snatch-block pulleys used for tower work.

Winches and come-along devices can make life a lot easier during certain operations. They provide mechanical advantage to reduce the human force required for lifting and other tasks. Winches can be manually operated or electric. Electric winches can dramatically reduce physical effort and they can cut hours out of a big tower job but powered winches come with increased risks. It is often very difficult to assess the tension being applied by a powered winch. Practice and extra care are required when using these powered tools.

ROPES AND SLINGS

The right number and types of ropes used in a tower project can have a dramatic impact on the time, effort and risks of a tower job. Experienced tower teams will employ several ropes to get the job done. It is quite common to use two ropes in most projects. The first is a utility rope. This rope goes straight up and down the tower through a pulley located at the location where work is being done. It is used to lift and lower tools and other small items.

The second rope is the haul rope. This rope will typically be one-half inch in diameter, or larger, and will afford a good grip for pulling and lifting the heavy items. **Table 22.2** shows the safe working load ratings for common types of rope.

There are several choices of rope material. The best choice is a synthetic material such as nylon or Dacron. A typical twisted rope is fine for most applications. A synthetic rope with a braid over the twisted core is known as *braid-on-braid* or *kernmantle*. While it's more expensive than twisted ropes, the outer braid provides better abrasion resistance.

The least expensive type of rope is polypropylene. While it is reasonably durable and cheap, it's a stiff rope that doesn't take a knot as well as other types. Polypropylene is also subject to breakdown over time due to exposure to natural ultraviolet in sunlight. These factors can present real safety risks; it's best to use a higher quality rope.

Table 22.2
Rope Sizes and Safe Working Load Ratings in Pounds

3-Strand Twisted Line

Diameter	*Manila*	*Nylon*	*Dacron*	*Polypropylene*
1/4	120	180	180	210
3/8	215	405	405	455
1/2	420	700	700	710
5/8	700	1140	1100	1050

Double-Braided Line

Diameter	*Nylon*	*Dacron*
1/4	420	350
3/8	960	750
1/2	1630	1400
5/8	2800	2400

Two factors that can come into play when selecting a rope are the elasticity and flexibility of the rope. A more elastic rope will stretch when under load. This can be a helpful characteristic when a shock-absorbing feel is desired. It is not helpful when it is important to maintain the rope's position. Flexibility is a generally good feature, allowing the rope to be more easily maneuvered and tied.

When doing tower work, being able to tie knots is required. Of all the knots, the *bowline* is the one to know for tower work. Most amateurs are knot-challenged so it's a great advantage to know at least the bowline and various hitches. You can learn how to tie many useful knots **www.animatedknots.com**.

The *loop sling* in Figure 22.14C can be wrapped around large or irregularly shaped objects such as antennas, masts or rotators, and attached to ropes with carabiners. For a complex job, a professional will often climb with eight to ten slings and use every one!

Web slings are typically made of nylon webbing and come in a variety of lengths and load ratings. The smallest are a few inches long, with 1/2-inch-wide webbing, and rated for a few hundred pounds. Large slings are several feet long and rated at a few thousand pounds. They are typically wrapped around the load, such as a mast, or through a hole or section of a load like a tower section. A carabiner around the webbing is used to create a lift point for the sling. There are a variety of "hitches" used for different load shapes and orientations.

INSTALLING TOWER SECTIONS

The easiest way to erect a tower is to use a crane or boom truck, such as used for putting up signs. It's fast and safe but more expensive than doing it in sections by hand. A crane or boom-truck from a sign company, for example, allows a tower to be constructed on the ground and lifted into place either in one piece or in sections. The crane can hold loads indefinitely while the climbers take as much time as needed to deal with the heavy sections. A crane can also lift an antenna clear of guys and other antennas, avoiding a lot of rope work by the climbers and ground crew.

The crane operator will need access to stable ground near the tower base and clearance to move the tower around. The tower is picked up or "picked" using a heavy web sling attached above the tower's center of gravity so that it will hang vertically in a stable configuration. Pre-assemble and install guys on the tower so they can be secured before the crane sling is released. A crew guides the bottom of the tower onto the base with the crane holding the weight, then secures the base followed by attaching the sets of guys.

To erect a tower by sections, a gin-pole is needed (see Figure 22.13). It consists of two pieces — a clamp or some device to attach it to the tower leg and a pole with a pulley at the top. The pole is typically longer than the work piece being hoisted, allowing it to be held above the tower top while being attached or manipulated.

With the gin-pole mounted on the tower, the haul rope runs up from the ground, through the gin-pole mast and pulley at the top of the gin-pole, and back down to the load. The haul rope has a knot (preferably a bowline) on the end for attaching things to be hauled up or down. A carabiner hooked into the bight of the knot can be attached to objects quickly so that you don't have to untie and re-tie the bowline with every use.

It's a good idea to pass the haul rope through a snatch-block at the bottom of the tower, changing the direction of the rope from vertical to horizontal. This allows the ground crew to pull horizontally. It also provides them an easier view up the tower and keeps them away from the tower base, in case the climbers accidently drop something.

GUYS

For guyed towers, it's the guys that do the work of keeping the tower where it should be under working load and the stresses of weather. Important construction parameters are *guy wire material* and *guy tension*. Do *not* use rope or any other material not rated for use as guy cable as tower guys — even during tower erection. Guyed towers for amateurs typically use either $^3/_{16}$-inch or $^1/_4$-inch *EHS* (extra high strength) steel guy cable.

There are also several commercially manufactured non-metallic cables designed to support towers. The most popular and well-tested in the amateur radio market is Phillystran, a lightweight cable made of Kevlar fibers. Phillystran is available with breaking strength similar to EHS cable. The advantage of Phillystran is that it is non-conducting and does not create unwanted electrical interaction with antennas on the tower. It is an excellent choice for towers supporting multiple Yagi and wire antennas and does not have to be broken up into short lengths with insulators.

EHS wire is very stiff — to cut it, use a hand-grinder with thin cutting blades or a circular saw with a metal-cutting aggregate blade. Wear safety glasses and gloves when cutting since there will be lots of sparks of burning steel being thrown off. Phillystran can be cut with a utility knife or a hot knife for cutting plastic. Because Phillystran can be melted or cut, if there is a risk of fire or vandalism, the bottom section of the guy should be EHS.

Guys should be tightened to the manufacturer's specifications. If the guys are too loose, the result will be wind-induced shock loading. Guys that are too tight exert extra compressive load on the tower legs, reducing the overall capacity and reliability of the tower. The proper tension for EHS or Phillystran guys is 10% of the material's *ultimate breaking strength*. For $^3/_{16}$-inch EHS the ultimate breaking strength is 4900 pounds, and

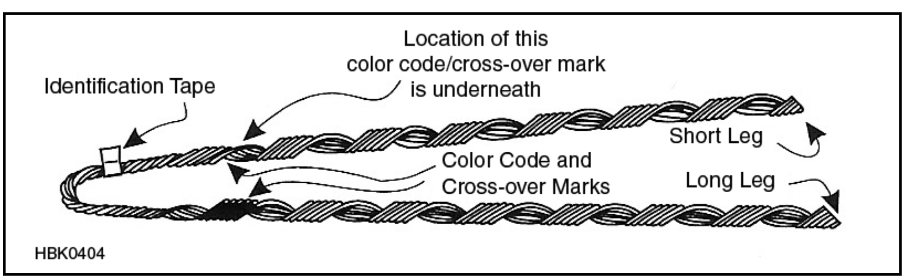
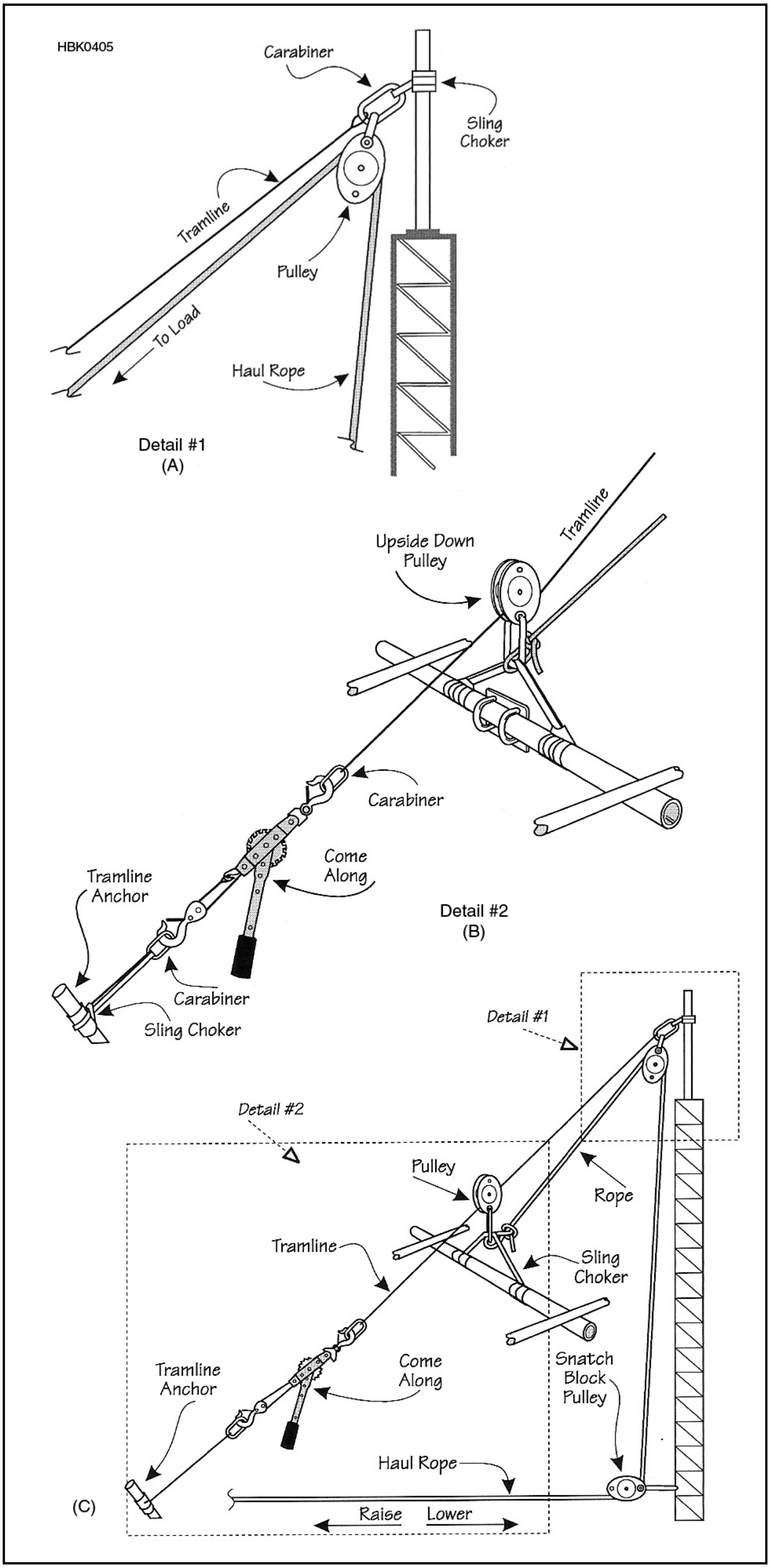


Figure 22.16 — A PreFormed Line Products Big Grip for guy wires.



for ¼-inch it's 6,000 pounds, so the respective guy tension should be 490 pounds and 600 pounds. The easiest to use, most accurate, and least expensive way to measure guy tension is by using a Loos tension gauge, developed for sailboat rigging (**loosnaples.com/products/tension-gauges/**).

Guy wires used to be terminated in a loop with cable clamps, but those have been largely replaced by pre-formed Big Grips, shown in **Figure 22.16**. These simply twist onto the guy wire and are very secure. They grip the guy cable by squeezing the cable as tension is applied. Be sure to use the right type of Big Grips for the thickness and material of the guy cable. It is also tempting to reuse Big Grips. A limited number of reapplications is permitted by the manufacturer before a grip should be taken out of service. Users should check manufacturer's guidelines for details.

22.2.5 Antenna Installation

Once the tower is up, it's time to install the antennas. VHF/UHF whips and HF wire antennas are pretty straightforward, but installing an HF Yagi is a more challenging project. With a self-supporting tower, there are no guy wires to contend with — generally, the antenna can just be hauled up the tower face. Sometimes it is simply that easy!

In most cases, short of hiring a crane, the preferred way to get a Yagi up and down a tower is to use the *tram* method. A single tramline above or between the top guys is suspended from the tower to the ground and the load is suspended under the tramline. **Figure 22.17** illustrates the tram method of raising antennas.

The tram line is typically attached to the mast above the top of the tower. In the case of a big load, the line may exert enough force to bend the mast. If in doubt, *back-guy* the mast with another line in the opposite direction for added support.

MASTS

A mast is a pipe that sticks out of the top of the tower and connects the rotator to the antenna. For small antenna loads and moderate wind speeds, any pipe will work. But as wind speed and wind load increase, more force will be exerted on the mast. Selecting a mast that's up to the job is an extremely important design consideration. There is no tower operation

Figure 22.17 — At A, rigging the top of the tower for tramming antennas. Note the use of a sling and carabiner. (B) Rigging the anchor of the tramline. A come-along is used to tension the tramline. (C) The tram system for getting antennas up and down. Run the antenna part way up the tramline for testing before installation. It just takes a couple of minutes to run an antenna up or down once the tramline is rigged.

more risky and potentially more expensive than recovering from a bent mast.

There are two materials used for masts — *pipe* and *tubing*. Tubing is designed to carry structural loads and should be used for large antennas or multiple antennas above the tower. Pipe can be water pipe or conduit (EMT). Pipe is a heavy material with not much strength since its job is just to carry water or wires. Pipe is acceptable as mast material for small loads only. Another problem is that 1.5-inch pipe (pipe is measured by its inside diameter or ID) is only 1.9-inches OD. Since most antenna boom-to-mast hardware is designed for a 2-inch mast, the less-than-perfect fit may lead to slippage.

For any larger load, carbon-alloy steel tubing rated for high strength is highly recommended. A moderate antenna installation in an 80 MPH wind might exert 40,000 to 50,000 pounds per square inch (psi) on the mast. Pipe has a yield strength of about 35,000 psi, so you can see that pipe is not adequately rated for this type of use. Chromoly (short for *chromium-molybdenum* alloy) steel tubing is available with yield strengths from 40,000 psi up to 115,000 psi but it is expensive. **Table 22.3** shows the ratings of several materials used as masts for amateur radio antennas.

Calculating the required mast strength can be done by using a software program such as the *Mast*, *Antenna and Rotator Calculator (MARC)* software. (See the References.) The software requires as inputs the local wind speed, antenna wind load, and placement on the mast. The software then calculates the mast bending moment and will recommend a suitable mast material.

Table 22.3
Yield Strengths of Mast Materials

Material	*Specification*	*Yield Strength (lb/in.^{2})*
Drawn aluminum tube	6063-T5	15,000
6063-T832	35,000	
6061-T6	35,000	
6063-T835	40,000	
2024-T3	42,000	
Aluminum pipe	6063-T6	25,000
6061-T6	35,000	
Extruded alum. Tube	7075-T6	70,000
Aluminum sheet and plate	3003-H14	17,000
5052-H32	22,000	
6061-T6	35,000	
Structural steel	A36	33,000
Carbon steel, cold drawn	1016	50,000
1022	58,000	
1027	70,000	
1041	87,000	
1144	90,000	
Alloy steel	2330 cold drawn	119,000
4130cold worked	75,000	
4340 1550 °F quench 1000 °F temper	162,000	
Stainless steel AISI	405 cold worked	70,000
AISI 440C heat-treated	275,000	

(From *Physical Design of Yagi Antennas* by David B. Leeson, W6NL)

22.2.6 Climbing Safety

Working at height is a potentially dangerous activity. As you think about climbing a roof or a tree or a tower, it is important to frame every decision in the context of safety. Continually asking the question, "Is this the safest way?" should become second nature. In the workplace this is known as developing a *safety mindset*. Mature organizations and teams build safety considerations into every project they undertake, fully recognizing the costs in time and resources that come with keeping people and property safe. The world of amateur radio is no different. Payback on investments in safety is returned over the long term, manifest in reduced rates of injury and fatalities. Developing a reputation as a safe pursuit also helps to foster the necessary trust for us to pursue the experimental aspects of amateur radio.

In this section, we will focus on tower climbing, but many of the concepts are transferable to other forms of work aloft such as on roofs and in trees which all have their own safety risks.

TAKE ADVANTAGE OF STANDARDS

Standards organizations provide a great deal of guidance in the area of safety equipment and technique. In the United States, OSHA, the Federal Occupational Safety and Health Administration, collects and analyzes real-world safety data. The agency then works with industry to create and publish high-level regulations for workplace safety. These rules include minimum standards for equipment and procedures. ANSI (American National Standards Institute) is an independent non-profit organization that encourages further development of detailed requirements for safety in many areas, including tower safety. The Telecommunication Industry Association (TIA) produces the most widely accepted standards package covering tower safety — currently at revision ANSI/TIA-222-H in early 2021.

Although amateurs working on their own non-commercial projects without compensation are not bound by these rules and recommendations, you'll be much better off by following them. There are many suppliers of excellent safety equipment that meets and exceeds the industry standards. As long as you choose compliant equipment and learn safe techniques, you will be on the path to a safe and successful project.

BEFORE YOU BEGIN: PREPARATION

As you contemplate any new project, you will need to define the scope of the entire job.

- What are your goals?
- How will you define success?
- What strategies could you use to achieve the goals?

Consider a job that's diagnostic. You believe there is a problem with a coaxial cable getting hung up on some tower hardware. The goal is to observe the coax as you turn the antenna rotator through 360 degrees of rotation. The traditional approach would be to send a climber up the tower for direct, close-up observation. But new technology can offer faster, easier, and safer options. Consider observing with binoculars from the safety of the ground or an upper floor in a nearby building. Or send a drone right to the location in question and capture recorded video through the full rotation.

Another concept that can greatly reduce risks and make a job go more smoothly is to break the work down into well-defined modules. Successful completion of one module should be required before proceeding to the next. When you break the work down this way, you gain the ability to manage your time more precisely and you have a built-in series of go/no-go decision points.

When you decide that climbing is the right approach, take stock of all elements of the job.

- Skills and experience
- Parts and supplies
- Safety equipment
- Tools
- People
- Time
- Conditions (weather, physical impediments, safety status)

One of the most important aspects of safety that you must assess is whether you have the knowledge and awareness to do a job safely and efficiently. You must have the mental ability to climb and work at altitude while constantly rethinking all connections, techniques and safety factors. Safely climbing and working on towers is 90% mental. Mental preparedness is something that must be learned. This is an occasion where there is no substitute for experience. Establishing and maintaining the right mental attitude is the hardest step for most people, but when safety gets the focus it deserves, tower work can be done safely and accidents are relatively rare.

Tower work is the easiest when the weather is nice and the sun is shining. For raising tower sections or antennas, a relatively windless day is preferred. Professional climbers usually do their trickiest lifts first thing in the morning when the chance of wind is the least. Don't push on in marginal conditions; you may wind up doing more harm than good. Obviously, you don't ever want to climb during a lightning storm. Don't hesitate to call off your project and wait for the right weather.

Figure 22.18 — Marty, NN1C (left) and Jim, K1IR are fully equipped with the right climbing gear and tools for tower and antenna work. (Jim Idelson, K1IR, photo)

PRE-CLIMB SAFETY INSPECTION

Before climbing any tower, perform a careful inspection of the base, anchors, and guys. A pair of binoculars allows inspection of the tower and guys above eye level. There should be no visible rust on the base section, especially where it contacts concrete. Look for splits from water freezing in the tower legs. If any of these are apparent, do not climb until further checks and any repairs are done. A small hole (⅛ inch typically) may be drilled in the bottom of a tower leg without compromising strength in order to drain any standing water. Guys should be correctly tensioned and all guy attachments and anchors secure and free of rust.

If the tower is a crank-up model, lower it completely until the lift cable is slack. Tower sections can bind and appear to be lowered completely but slip from a climber's weight, causing serious injury. Before climbing, block all tower sections with a 2×4 or heavier material through the tower so that no downward motion is possible. Never assume a crank-up tower is fully nested.

For tilt-over towers or tower-lowering fixtures, perform a careful inspection of the winch, cable, and fixture before raising or lowering the tower. When the tower is near horizontal, the tension in the cable can be thousands of pounds. Make sure no one is near the tower as it is raised or lowered and wear protective gear when operating the winch.

Figure 22.19 — Typical climbing equipment. From the top and left to-right, fall arrest lanyards with "gorilla hooks," hard hat and safety glasses, body harness, gloves, nylon sling, carabiners, and positioning lanyard. (Jim Idelson, K1IR, photo)

100% TIE-OFF: A RULE TO LIVE BY

Since its inception in the 1970s, OSHA has focused on workplace safety. In the 1980s, OSHA introduced the *100% tie-off* standard requiring a worker's body belt to be secured by at least two lanyards. This protection factor became an essential for employees who executed tasks at height. Fortunately, the body

(A) (B)

Figure 22.20 — The personal fall arrest system (PFAS) from the front (A) and back (B). Note that tools and slings are attached in the back where they will not interfere with the positioning lanyard. (Jim Idelson, K1IR, photos)

belt soon evolved into a full harness, which further protected workers from spinal and internal organ injuries.

OSHA's fall protection standards even cover fall protection for residential construction projects. Personal fall arrest systems must bring a worker to a complete and controlled stop, restrict workers from falling more than 6 feet, and have the strength necessary to endure twice the impact energy of the worker falling 6 feet.

Why is this type of system necessary? 100% tie-off is part of your plan to "expect the unexpected." While you can be in top physical condition, equipped with the most modern tools, and trained in the latest techniques, unexpected situations still arise. When everything is going well, there is no reason to expect to suddenly "just let go" when perched on the side of the tower. But, workers can and do experience sudden health emergencies. A heart attack or a fainting episode due to dehydration can render a worker unconscious. Unavoidable distractions can occur, as well. What if you were to accidentally disturb a bee or wasp nest and suddenly get stung while in your work position? Any of these situations could cause you to lose consciousness or the attention needed to maintain your footing. In moments like these, your 100% tie-off will save your life.

Fall protection is continuing to evolve in today's workplace, as employers and regulators seek new ways to protect workers. OSHA has ongoing research on how to identify hazards and is also improving current regulations. As a ham, if you know and take to heart the concept of 100% tie-off, you will be well on your way to making your tower work as safe as possible. Done right, climbing can be enjoyable, rewarding and safe as shown by Marty, NN1C and Jim, K1IR in **Figure 22.18**.

PERSONAL SAFETY EQUIPMENT

Check your safety equipment every time before you use it. Inspect it for any nicks or cuts to your belt and safety strap. Professional tower workers are required to check their safety equipment every day; follow their example.

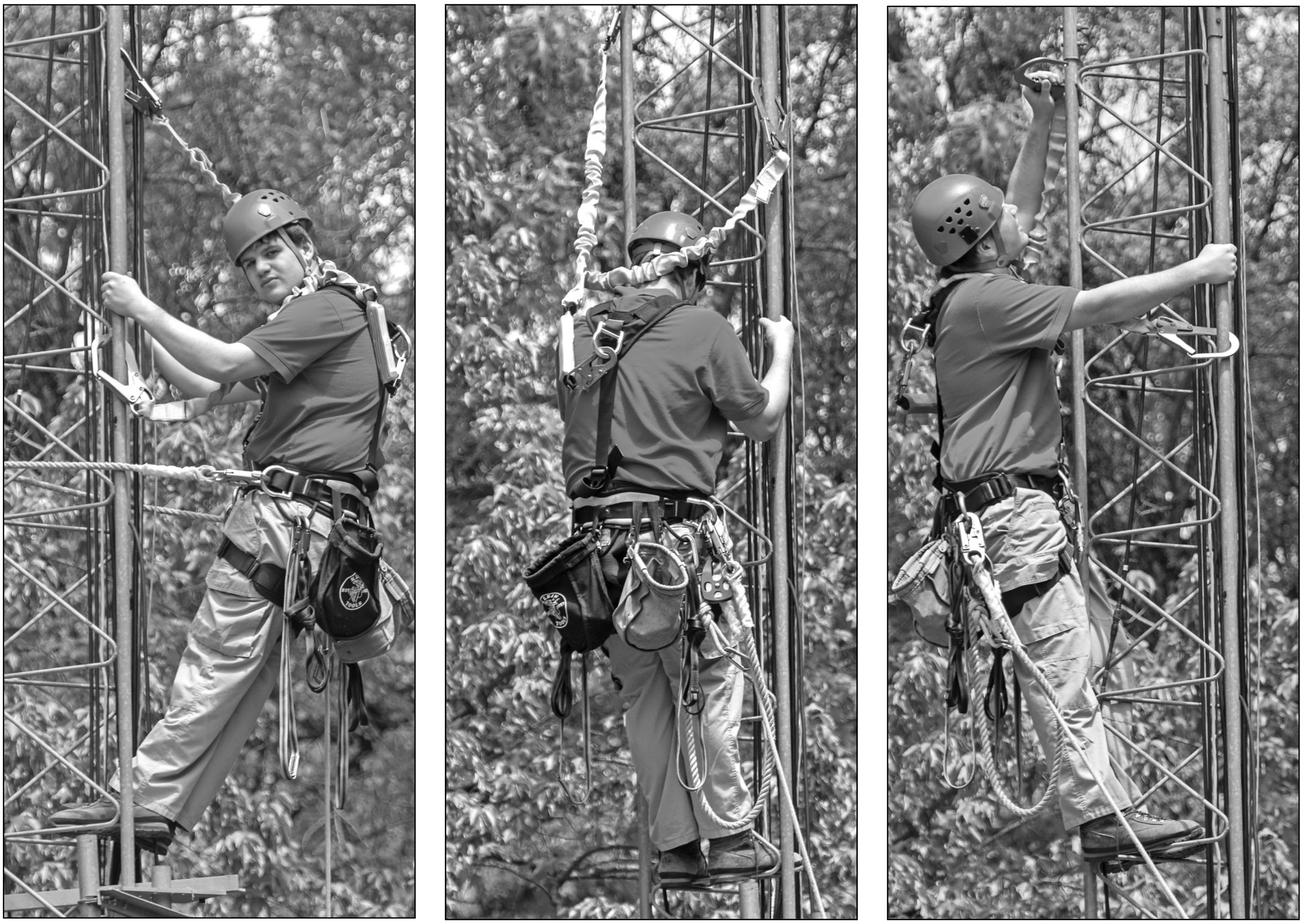
To implement 100% tie-off, you need the right equipment. OSHA specifies the equipment that must be used. Minimum requirements for Personal Protective Equipment (PPE) are given in OSHA Standard 1910.140 - Personal fall protection systems (**www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.140**). *DO NOT* cut corners on buying or using safety equipment; you bet your life on it every time you use it! **Figure 22.19** shows a typical set of climbing and safety gear used when working on towers.

The most important pieces of safety equipment are the *personal fall arrest system* (PFAS) you wear and the accompanying lanyards that attach to it. **Figures 22.20A** and **B** show a climber wearing a PFAS from the front and back. The body harness portion of the PFAS has leg loops and suspenders to help spread the fall forces over more of your body and has the ability to hold you in a natural position with your arms and legs hanging below you where you're able to breathe normally. (See the warning below about lineman belts.)

Two or more lanyards are used. The first is the fall arrest lanyard (top item in Figure 22.19) which attaches to a D-ring between your shoulder blades. The other ends are attached to large snap hooks ("gorilla hooks") that clip on to the tower above the work or climbing position. The proper choice is a dual shock absorbing lanyard with bar-tacked stitches that pull apart under force to catch and decelerate you in case of a fall A simple 6-foot rope lanyard is inexpensive but doesn't offer any shock absorption and does not provide 100% tie-off.

The second lanyard is a positioning lanyard (bottom item in Figure 22.19) that holds you in working position and attaches to the D-rings at your waist. It can be adjustable or fixed and may be made from different materials such as nylon rope, steel chain, or special synthetic materials. An adjustable positioning lanyard as shown in the figure will adjust to almost any situation, whereas a fixed-length one is typically either too long or too short. A rope lanyard is the least expensive. **Figure 22.21A** shows a climber with a positioning lanyard around the tower and the fall arrest lanyards both attached to the tower with one above him. This is a safe working position.

Hams should note that leather climbing equipment was outlawed some years ago by OSHA — so don't use it. This includes the old-fashioned safety belt that utility linemen used for years but which offers no fall protection capability. If you drop down while wearing a safety belt, your body weight can cause it to rise up from your waist to your ribcage where it could immobilize your diaphragm and suffocate you. On the other hand, you



(A) (B) (C)

Figure 22.21 — Proper 100% tie-off technique (see text). Lanyard attachment at the work position is shown in A. Getting ready to climb with both fall-arrest lanyards attached is shown at B. Moving one of the fall arrest lanyards while maintaining tie-off is shown at C. (Jim Idelson, K1IR, photos)

can use a safety belt for positioning when it's worn in conjunction with a compliant FAH. In fact, most modern fall arrest harnesses also incorporate a waist belt with positioning lanyard attachment rings for a single, convenient, comfortable climber safety package.

But having the right gear doesn't ensure it is in good working order. Take a page from the OSHA regulations: professional tower workers are required to check their safety equipment every day. Make it your habit to check your safety equipment before you use it every time. Inspect for any nicks or cuts to your harness and lanyards immediately prior to each use.

DRESS FOR SUCCESS

You'll want to equip yourself with some additional gear for a safe and compliant climb:

Boots should be leather with a steel or fiberglass shank. Diagonal bracing on Rohn 25G is only 5⁄16–inch rod — spending all day standing on that narrow support will take a toll on your feet. The stiff shank will support your weight and protect your feet; tennis shoes will not. Leather boots are mandatory on towers like Rohn BX that have sharp X-cross braces. Your feet are always on a slant and against a sharp angle of sheet metal — that is hard on feet.

A hard hat and safety goggles are both required and highly recommended. Make sure they are ANSI or OSHA approved and that you and your crew wear them. As you'll be looking up and down a lot, a chin strap is essential to keep the hard hat from falling or blowing off. You may not need the safety goggles until you are at the work position but have them available in your tool kit.

Tower work can be hard on hands, especially if you don't work on towers frequently. Gloves are essential — keep several spare pairs for ground crew members who show up without them. Cotton gloves are fine for gardening but not for tower work; they don't provide enough friction for climbing or working with a haul rope. Gloves designed for the job and the environment are the only kind to use. You will find a range of options made from leather and other synthetic materials that are up to the job. The softer the gloves, the more useful they'll be during intricate parts of the job. Framer's gloves with the tips of the thumb and first two fingers removed protect the palm and back of the hand while allowing fine fingertip control but expose fingers to cold weather. You will need warmer gloves if you are doing a job in cold weather. The bottom line is that you should maintain a selection of gloves that give you the right combination of gripping power, dexterity, and warmth to handle all the different jobs and weather you will encounter.

TOWER CLIMBING BEST PRACTICES

Just having the right gear does not ensure that it will save your life; you have to use it correctly. The most important rule for using a full body harness and dual fall arrest lanyard is to follow these 100% tie-off steps as you climb. Figures 22.21B and C show the proper way to climb while maintaining 100% tie-off.

1) Attach one lanyard hook above you as you start your ascent.

2) In the case of most ham towers, attach to

a tower leg, as the leg provides the strongest anchor point. A tower rung may not be strong enough to sustain the downward force of a fall as specified in the OSHA requirements.

3) As you climb, attach the second lanyard hook to a tower leg a few feet above the first. It helps to repeat "On before off" so you reinforce doing things in the proper order.

4) Disconnect the lower hook and continue to climb.

5) As you climb, alternately place the hooks such that you are always securely connected by one of the lanyard ends and try to keep your attachment point above you as much as possible. This will limit the maximum distance you can fall at any moment.

6) When you reach your work position, attach both lanyards above you for redundant fall protection while you do the job.

7) Reverse these steps as you descend.

Note that the sequence described above does not call for use of a positioning lanyard. That is because, while a positioning lanyard is helpful in providing comfort while climbing or while working, it does not meet the stringent requirements for fall arrest. So, you can — and should — use positioning lanyards to make your work easier, but don't depend on them for fall protection.

Many climbers have developed ways of thinking about movement on a tower that force safer behavior. One such model is the concept of having four points of attachment and security — two hands and two feet. When climbing, move only one point at a time. That leaves you with three points of contact and a wide margin of safety if you ever need it. This is in addition to having your fall-arrest lanyard connected at all times.

Another recommended technique is to always do everything the same way every time. That is, always wear your positioning lanyard on the same D-ring and always connect it in the same way. Always look at your belt D-ring while clipping in with your safety strap to confirm that you're securely attached. A visual check helps ensure you are connected to a D-ring and not some other piece of gear. Always look!

Safety Tips

1) Don't climb with anything in your hands; attach it to your safety belt if you must climb with it, or have your ground crew send it up to you in a bucket.

2) Don't put any hardware in your mouth; it can easily be swallowed.

3) Don't climb while wearing rings and/or neck chains; they can get hooked on things. Long hair should be secured.

4) Be on the lookout for bees, wasps, hornets, and their nests. If you do run into a stinging insect, use Adolph's Meat Tenderizer on the sting — it contains the enzyme papain which neutralizes the venom. Have a small jar in your tool kit.

5) Don't climb when tired; that's when most accidents occur.

6) Don't try to lift anything by yourself; one person on a tower has very little leverage or strength. Let the ground crew use their strength; save yours for when you really need it.

7) If a procedure doesn't work, assess the situation and re-rig, if necessary, before trying again.

A TEAM EFFORT: CLIMBERS + GROUND CREW

Every antenna or tower project is a team effort, and the ground crew is critical to a successful outcome. Don't underestimate the impact the ground crew will have on your project. Consider these points when you put together your support team.

1) Put together a team that has the right mix of skills. If you are going to be tramming an antenna, the ground crew should know how to do it.

2) Make sure the team is committed to the job. Commitment means staying for the duration and not being distracted while the job is under way.

3) Communication is critical. The ground crew should be equipped to communicate with the tower climber(s) with appropriate gear. Many teams use handheld VHF or FRS radios for this purpose.

4) Tools are a major responsibility for the ground crew. Climbers should only need to do the minimum amount of climbing necessary to get the job done. Ground crew need to know where to find a needed tool and have a way to get it into the hands of a climber quickly. Ground crew will also need to be fully up-to-speed on operation of specialized tools like the gin pole, come-along, and winches.

WORKING AS A TEAM

Before tower work starts, have a safety meeting with the ground crew. This "tailgate" meeting is important to get everyone on the same page, work-wise, detailing the work to be done and how to do it. This also the time and place to introduce the ground crew to gear or hardware they may be unfamiliar with such as a capstan winch, carabiners, rock climbing gear, special tools, and so on. Explain what is going to be done and how to do it.

The climber(s) are frequently the most experienced members of the tower team. As such, one of the climbers is usually designated to be the team leader. This leadership role is critical for everyone to understand. The climber(s) are most at risk and often have a unique visual perspective on what's happening at any moment. It's very important for the team to stay focused on the job and to be actively listening for instruction from the climbers. There can be long stretches of work that only involves the climbers, but a need for ground crew support can arise in an instant and the team needs to be ready to respond immediately. Remember, don't do anything unless directed by the leader in charge. This includes handling ropes, tidying up, moving hardware, and so on.

Another important role for the ground crew is to communicate updates and any other information that can be helpful to the team on the tower. As a climber, it is very helpful to hear about anything that might affect upcoming actions or decisions. This might include notifications about changing weather, changes in the ground crew, updates regarding supplies or parts of the project being handled on the ground. Let the tower crew know when it's time to break for lunch!

If radios are not being used to communicate, when talking to the climber on the tower, look up and talk directly to them in a loud voice. The ambient noise level is significantly higher up on the tower because of traffic, wind and nearby equipment. Have an agreed-on set of hand signals for raising, lowering, holding, starting and stopping, etc.

While leadership generally comes from the climber, it is very important for all team members to understand that responsibility for watching for safety issues belongs to everyone. Any team member who senses an impending safety risk should raise the issue right away. The team should respect any safety-related observation, pause, and evaluate the situation. The team should then decide what to do. Action should only be taken when the team has determined best right course to pursue.

Be conservative throughout the course of the job. Operate slowly; trying to go too fast can result in poor work and cutting corners on safety.

WRAPPING UP

When is it time to quit? We start all these projects with the goal of finishing up when the job is done, when the project goals have been met, and all within the planned time frame. But, despite the best of planning, complex jobs often take longer than expected. The question every antenna team will invariably face is what to do when it is becoming clear that the project can't be completed as planned. Sometimes it's a matter of running out of daylight. Or the weather is changing. Perhaps some members of the team have to leave. Or fatigue is setting in after a long day of work. Decisions made in these moments can be the difference between success and disaster.

The temptation is to work faster, to try to squeeze the rest of the job into the allotted time. This is a recipe for failure. Many accidents happen during just these circumstances.

It is far better to choose a path that allows for securing the site in a safe state, getting the climbing team safely back on the ground and preparing to complete the job at the next opportunity. All this wind-down effort takes time, so the experienced crew should be anticipating the best point to suspend work, leaving sufficient time to wrap things up.

22.2.7 Antenna and Tower Safety References

ORGANIZATIONS AND STANDARDS

ANSI/ASSP

Fall Protection and Fall Restraint Code Z359 — **www.assp.org/standards/standards-topics/fall-protection-and-fall-restraint-z359**

ANSI/TIA

Structural Standards for Antenna Supporting Structures and Antennas TIA-222-G/H — **tiaonline.org/press-release/tia-announces-publication-of-tia-222-h-standard-for-antennas-and-the-supporting-structures-for-antennas-and-small-wind-turbines**

OSHA (Occupational Health and Safety Administration)

Fall Protection Standards — **www.osha.gov/fall-protection/standards**

Personal Protective Equipment — **www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.140**

ARRL Resources

ARRL Volunteer Counsel program — **www.arrl.org/volunteer-counsel-program**

ARRL Volunteer Consulting Engineer program — **www.arrl.org/volunteer-consulting-engineer-program**

Amateur Publications

Publications listed here may not include current safety practices but include much useful information on techniques, tools, and materials.

Brede, D., W3AS, "The Care and Feeding of an Amateur's Favorite Antenna Support — the Tree," *QST*, Sep 1989, pp. 26 – 28, 40.

Daso, D., K4ZA *Antenna Towers for Radio Amateurs* (ARRL, 2010).

Daso, D., K4ZA, "Workshop Chronicles" (column), *National Contest Journal.*

Daso, D., K4ZA, and W. Silver, NØAX, "Field Day Towers — Doing It Right," *QST*, June 2013, pp. 67 – 69.

Hopengarten, F., K1VR, *Antenna Zoning for the Radio Amateur* (ARRL, 2002).

Morris, S., K7LXC, *Up the Tower: The Complete Guide to Tower Construction* (Champion Radio Products, 2009).

M. Shanblatt and J. Warwick, "Hanging a Treetop Antenna with a Drone," *QST*, Mar. 2018, pp 67-68.

Silver, H., NØAX, ed., *The ARRL Antenna Book*, 24th Edition (ARRL, 2019).

Sirageldin, K., "Using a Drone for Antenna Installation at TI5W," *QST*, Nov. 2017, pp. 85 – 86.

ONLINE RESOURCES

Champion Radio Products (a useful resource for tower construction and safety products) — **www.championradio.com**

Knot-tying website (tie the right knot for any antenna system application) — **www.animatedknots.com**

NATE: The Communications Infrastructure Contractors Association Safety Resources — **natehome.com/safety-education/safety-resources**

Wireless Estimator (commercial tower safety and standards and incident reporting) — **www.wirelessestimator.com**

Zero Falls Alliance (repository of amateur radio tower safety statistics, root causes, equipment and techniques) — **www.zerofalls.org**

22.3 RF Safety

This section was written by Gregory Lapin, PhD, PE, N9GL, chair of the ARRL RF Safety Committee. The ARRL's RF Safety Committee reviewed this content. Additional material is available as supplemental information on the ARRL's RF Exposure web page at **www.arrl.org/rf-exposure**.

22.3.1 The Need for an RF Safety Program

We have all seen water boiling in a microwave oven. Microwaves are a type of RF energy that can harm our bodies if we are exposed to it at sufficiently high levels. This is why reasonable precautions are taken so that RF energy at the frequencies and levels used by amateur radio stations are safe.

Based on over 100 years of experience in amateur radio, operators who are regularly exposed to lower levels of RF energy have similar, and sometimes less, disease than the general population (see the sidebar "Standards, Science, and the Community"). Similar encouraging health outcomes from the vast majority of people on Earth who use cellular telephones on a regular basis indicate that when properly controlled, exposure to RF energy does not need to be a concern. Clearly, RF can be used safely.

To be dangerous, RF must be absorbed into tissue with sufficient power to cause heating for which the body cannot compensate. As licensed radio amateurs, we all need to ensure that our transmissions do not expose any people beyond the levels that have been deemed to be safe. Standards organizations have reviewed and analyzed scientific research that has been performed for over 60 years and derived safe levels of exposure for people. Regulatory agencies, such as the FCC in the United States, have developed regulations that require all operators of RF transmitters to maintain exposure levels below specified limits.

Modern research into the biological effects of exposure to electromagnetic energy has been taking place since the 1950s. The United States Navy sponsored much of the early research and, together with academics and the IEEE, formed the first electromagnetic exposure safety committee. This later evolved into the IEEE C95 family of standards on electromagnetic safety that include both recommended safety levels for exposure as well as recommendations for establishing RF safety programs.

An RF safety program should be developed for each amateur radio station. The program consists of an analysis of potential exposure levels around the station. If overexposure of people is possible, the program determines what forms of mitigation will be necessary to prevent anyone's exposure from exceeding the regulatory thresholds. Although not required by the FCC, documentation of the

The ARRL RF Safety Committee

The ARRL maintains an RF Safety Committee that is composed of scientific and medical experts in the many aspects of the study of RF safety. The RFSC serves as a resource to the ARRL Board of Directors, the ARRL Laboratory, and to the amateur community. It regularly monitors new scientific research and many of its members participate in the scientific committees that write safety standards for RF exposure. The RFSC participates in generating the RF safety questions for FCC amateur question pools and works with the FCC in developing its environmental regulations. For more information about the RFSC, see **arrl.org/arrl-rf-safety-committee**.

Standards, Studies, and the Community

You or your neighbors are likely to have questions about where standards for RF Exposure come from or how science evaluates the effect of RF on people. There are two papers on the **www.arrl.org/rf-exposure** web page and in this book's online information to help understand these questions: "RF Safety Standard Development" and "Types of Scientific Studies." To help you explain to your neighbors that amateur radio is safe because you operate your equipment safely, the discussion "How to Interact With a Concerned Neighbor" can make the conversation easier for everyone. Finally, there is so much information online with more coming out every day. "Interpreting the News About RF Exposure "Discoveries"" will help you deal with information that might be out of context or simply untrue. These documents will be helpful as you navigate questions about RF and amateur radio transmissions.

RF safety program should be filed away so that it can be referred to if there is ever any question about RF exposure from that station.

Part of RF safety is recognizing that non-ham acquaintances and family members may have concerns about RF exposure. The material in this section will help you explain what hazards exist and what steps you have taken to ensure that you are operating safely. Some people may have concerns that are difficult to address. For such cases, the ARRL provides "How to Interact With a Concerned Neighbor," which provides some guidance in responding. In addition, the Internet is a frequent source of information that is taken out of context or is simply false, which can also raise unwarranted concerns. The paper "Interpreting the News About RF Exposure "Discoveries" may be helpful when such issues are brought to you. Both papers are available at the ARRL's RF Exposure website, **www.arrl.org/rf-exposure**.

22.3.2 Effects of RF On the Body

NON-IONIZING RADIATION

When we speak of *radiation*, we are referring to the property of energy to move from one place to another, or radiate. The terminology has unfortunately been associated by the public with the energy that comes from radioactive devices, such as nuclear bombs, X-ray machines and other sources of ionizing radiation. When members of the public hear the word, *radiation*, they often think of danger.

There are two distinct types of photon energy that radiate: *Non-ionizing* and *Ionizing radiation*. These phrases refer to the ability of the energy contained in a photon to push electrons out of their orbits and ionize chemical compounds. When the chemicals in biological tissue are ionized, generally the tissue no longer functions properly. The photon energy of the radiation is what determines its potential to cause ionization; photon energy is directly proportional to frequency. Thus, electromagnetic energy with frequencies above the ionization limit are far more dangerous than photons at lower frequencies. The division between non-ionizing and ionizing radiation is in the ultraviolet light spectrum, with ionizing radiation having frequencies above 8×10^{14} Hz (800 THz).

The highest RF communications frequencies in use today are below 500×10^{9} Hz (500 GHz) and most amateur operations occur at frequencies far below that. Thus, amateur radio makes use of non-ionizing radiation that is thousands or millions of times below the frequency that would cause it to ionize tissue. This is significant since amateur radio transmissions have insufficient energy to ionize, or alter, DNA molecules in our tissue. Alteration of DNA molecules by ionization, such as with ultraviolet light, is generally believed to have the potential for causing cancer (which is why we wear sunscreen to filter out UV light from the sun in order to avoid skin cancer).

TISSUE HEATING

Even though non-ionizing radiation cannot alter tissue by rearranging its electrons, it can still cause damage with heat. The heat generated in tissue is proportional to the rate of RF energy absorption in the tissue; the rate of energy absorption is determined by the incident power density of the electromagnetic waves and the electrical properties of the tissue. Radiation interacts with any substance in three ways: it can reflect from its surface, it can pass through, and it can be absorbed. The portion that is absorbed is generally converted to heat. The human body core is referred to as *homeothermic*, meaning that body temperature is relatively uniform throughout the body and remains within a relatively narrow range. Your core body temperature is typically 98.6°F (37°C) and if your core temperature rises to be in excess of 104°F (40°C) your life could be danger.

The body has developed efficient methods to remove excess heat. Control of blood flow through tissue, sweating and breathing all are used in the tight control of tissue temperature. As long as the combined heat load resulting from the body's metabolic rate, heat absorbed from the environment and any heat generated by absorbed RF can be quickly and effectively removed by the body there is no danger of adverse health effects from the exposure. When the additional heat load from RF energy absorption exceeds the ability of the body to remove it, health can be compromised.

Heating vs Non-thermal RF Safety

RF safety exposure standards were originally based solely on the generation of heat from absorbed RF energy. The initial standards were derived from a single incident exposure limit of 10 mW/cm^2 for the entire spectrum of RF frequencies and assuming the body was exposed to a uniform field. Over time, this limit was revised to account for how the body absorbs RF energy differently at different frequencies, analogous to an antenna capturing more power from an RF field at its resonant frequency and less at non-resonant frequencies.

While the effects of heating from absorption of RF energy are easily calculated, there have been a number of demonstrations of biological effects from exposure to electromagnetic energy. For instance, in the laboratory, change of the operation of calcium channels in isolated cells exposed to levels of electromagnetic energy too low to cause measurable heating has been demonstrated. A number of other non-thermal effects have been demonstrated in the laboratory.

Although reports of RF effects in isolated cells in the laboratory is of interest to the scientific understanding of biological effects of electromagnetic energy exposure, such reports remain inconclusive as to the potential for causing adverse health effects in humans. To address this, the standards bodies have based their decisions about safe exposure levels on scientific studies that demonstrate deleterious effects on animals or on calculated body and tissue temperature increases presumed to be unsafe. Once the thresholds of potentially adverse effects have been determined, safety factors have been applied to arrive at acceptable exposure limits that include a margin of safety.

22.3.3 RF Safety Standard Development

Most of what we know about operating with safe exposure levels comes from over 60 years of scientific study of how electromagnetic energy affects biological tissue. Thousands of studies have been summarized by standards bodies that then identified levels of exposure considered to be safe. The two most recognized standards bodies are the IEEE International Committee on Electromagnetic Safety, ICES, and the International Commission on Non-Ionizing Radiation Protection, ICNIRP. The FCC has based its exposure regulations on both the IEEE C95.1-1991 standard and recommendations from a scientific group chartered by the U.S. Congress, the National Council on Radiation Protection (NCRP), in their NCRP Report #86. To read more about the history of electromagnetic standards development see RF Safety Standard Development on the ARRL's RF Exposure web page (**www.arrl.org/rf-exposure**).

TYPES OF SCIENTIFIC STUDIES

There are two basic types of scientific studies that are used to determine the limits of safe exposure to electromagnetic energy. Laboratory studies use either isolated cells or animals to test for effects of highly controlled exposures. Epidemiological studies focus on the incidence of adverse effects or diseases in the population to try to identify trends that may be related to some type of exposure. All scientific studies must deal with the biological variations between various individuals. Natural variations are separated from the effects of the stimulus under examination by examining large populations of subjects that have been exposed to the stimulus (study population) and those that have not (control population). If the number of subjects studied is large enough and all variables and stimuli except the stimulus under study are identical between the study and control populations, statistical analysis will point to any effects that are associated with the stimulus in question. To read more about scientific studies, including epidemiological studies of amateur radio operators, see Types of Scientific Studies on the ARRL's RF Exposure web page (**www.arrl.org/rf-exposure**).

Neither type of study can be conclusive as to the formation of a disease or production of some form of adverse reaction. An epidemiological study can indicate an association between a given stimulus and disease. Laboratory experimentation can shed light on the mechanisms that may cause disease, but neither type of study on its own is capable of proving a causal link between RF exposure and human disease.

All scientific studies are made public through the process of peer review. The results of a study are written as a scientific article, which briefly reviews previous work on that subject, specifies the methods that were used to obtain the reported results, presents the results and then includes an interpretation of the results. The written report of a study is submitted to a scientific journal, generally which specializes in the topic of the current study. The journal sends copies of the report to a number of peer reviewers, who use their expertise in the subject to critique the study and, after it is acceptable to the peer experts, is then published in the journal. The process of peer review has been widely considered an acceptable gate keeper that separates good from bad science.

In recent years, there has been evidence that the peer review process is not infallible. Many scientific publications that clearly do not have the scientific basis to make the claims that they do have been published as having been peer reviewed but appear to have bypassed the process. There are several ways that this has been done. For instance, papers that are not accepted by journals in their field are sometimes resubmitted to journals in other fields where the peers are not experts in the topic of the paper.

The scientific publication process also includes the ability for other peers, who were not asked to review a paper, to comment on science that they do not agree with. The comments are published in future editions of the journal and the original authors are given the opportunity to reply. Often, the comment and reply process is not followed with the original paper that is being challenged.

As weaknesses in the peer review process have become more evident, one tool that the scientific community has come to rely on is independent replication of results. If a scientific study provides results that contradict what has been seen in the past, it is important that the new results be confirmed by an independent laboratory that follows that first study's procedures. Often, independent replication is able to identify errors in the original study that led to the unique results.

22.3.4 FCC RF Exposure Requirements

The FCC is given the responsibility under the National Environmental Policy Act of 1969 to control the operations of stations that it regulates to prevent adverse effects on the environment. In 1996, this duty was expanded to prevent the signals from all transmitters, including those of the Amateur Radio Service, from causing excessive human exposure. Since the FCC is not a health and safety agency, it relied on accepted RF safety standards and advice from the FDA to develop its rules. The bases of the FCC safety thresholds were NCRP Report #86 and ANSI/IEEE C95.1-1992, which were discussed earlier.

SAR vs MPE

As per the safety standards, the FCC defined *maximum permissible exposure* (MPE) limits in terms of the power absorbed in tissue, the *specific absorption rate* (SAR). A fixed, safe SAR value applies across the frequency spectrum and is defined for exposure of the whole body or of a specific area (local exposure); at lower frequencies in the range of whole-body resonance, the whole body averaged SAR (in watts per kilogram of body mass) is the appropriate limit. At higher frequencies with exposures from antennas that are close to the body, localized SAR (in watts per kilogram of tissue, measured in a small amount of tissue, either a single gram or ten grams in size) becomes a more important measure of exposure.

It is very difficult to measure or model SAR. To measure SAR, one would have to place a probe directly in the tissue at many locations and monitor the rate of absorbed electromagnetic energy over time. Modeling SAR is also complicated, since the varying shapes of anatomical structures and their electromagnetic properties have to be modeled over the entire body. While these tasks are not impossible, they are complex enough that few amateur licensees would have the ability or means to determine if exposure from their stations exceeds the FCC limits.

In contrast to determining SAR, electromagnetic energy in the air is much easier to either measure or model. To make the exposure limits easier to follow, the standards bodies developed equivalences between electromagnetic energy incident on the surface of the body and the whole-body SAR that would result. Even though the safe SAR limit is fixed across the spectrum, the actual SAR that results from exposure, both within the body as a whole and within different organs, depends on frequency.

The relationship between wavelength and the sizes and shapes of the body and its organs causes resonances in some frequency ranges that result in more energy being absorbed. In **Figure 22.22**, which represents MPEs recommended by the ANSI/IEEE C95.1-1992 standard, this effect is clear. The average human body and its larger structures are most resonant to frequencies in the VHF range, and because of this the MPEs in that frequency range are the lowest. Where the difference between wavelength and the size of body structures is greater, both at VLF, LF and low HF frequencies, and at microwave and

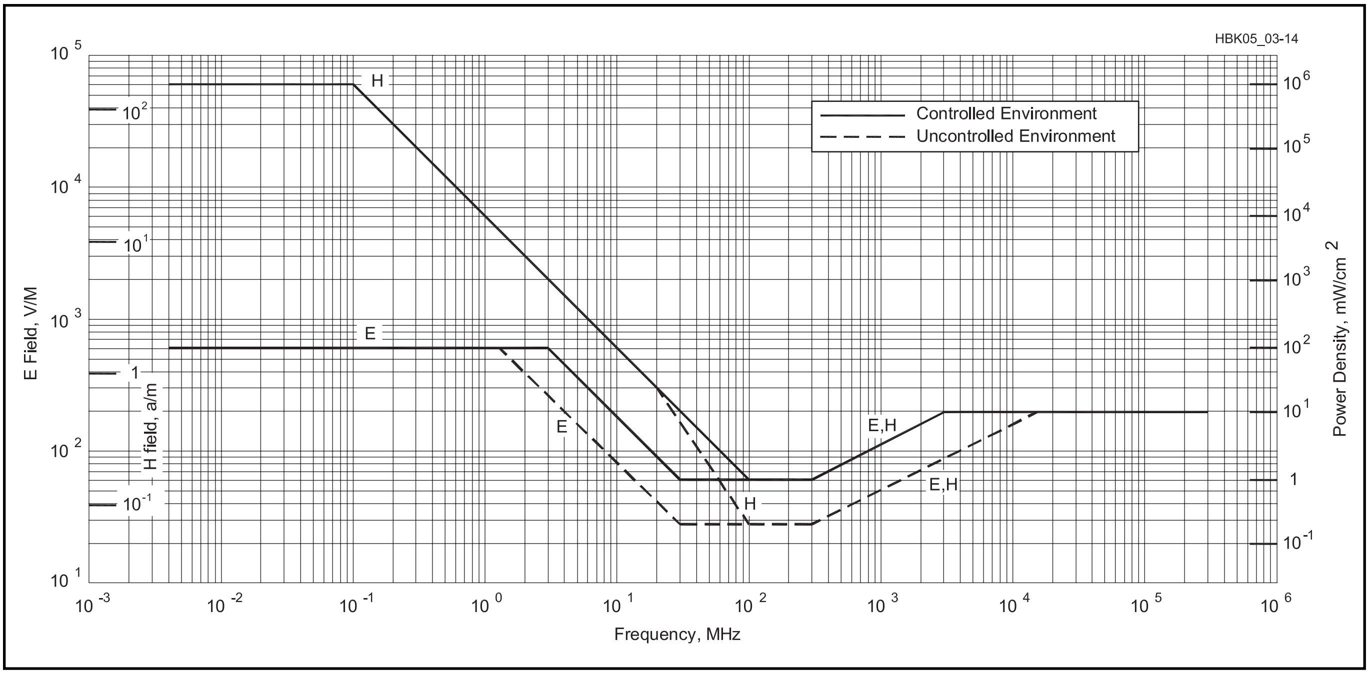


Figure 22.22 — 1991 RF protection guidelines for body exposure of humans. It is known officially as the "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz."

higher frequencies, absorption is less and the MPEs are higher.

At lower frequencies the interaction between electromagnetic energy and the human body differs for the electric and magnetic components of the energy. Because of this, different MPEs exist for the electric (E) field (in V/m) and the magnetic (H) field (in A/m) up to 300 MHz and both limits must be met. Above 300 MHz the MPE limits are expressed only by the power density (in mW/cm^2). It is common to measure or model power density at frequencies below 300 MHz but in doing so, one must be careful to obtain plane-wave equivalent power density. In the far-field, the power density at all frequencies is determined from a plane-wave but in the near-field, before the energy resolves into a plane-wave, the power density must be derived from both the E- and the H-fields at any location.

The graph in Figure 22.22 is also expressed in tabular form, as in **Table 22.4**. The FCC has published their MPE limits in that form in their rules, in §1.1310(e). Unlike the plots in Figure 22.22, power density is also shown in the table for frequencies below 30 MHz, under the condition that it be plane-wave equivalent power density.

Table 22.4

(From §1.1310) Limits for Maximum Permissible Exposure (MPE)

Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm2)*	*Averaging Time (minutes)*
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	(900/f2)*	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 Notes 1 and 2 in Table 22.5).

LOCALIZED EXPOSURE

The MPEs in the FCC rules presume uniform whole-body exposure. This may or may not be the case for typical amateur radio stations. In some circumstances, exposure is mainly limited to a portion of the body. Handheld radios are an example of this. When you hold a handheld radio in front of your face, most of the exposure from its antenna is to your head. The FCC uses a distance of 20 cm (about 8 inches) between the antenna and any portion of a person's body to distinguish between whether whole body MPE can be used for assessing compliance with their rules, or if a localized SAR determination must be made. For any antenna that is used less than 20 cm from a person, the only acceptable form of exposure determination is SAR.

Since SAR determination is beyond the capabilities of most radio amateurs, it is expected that manufacturers of handheld radios will perform that test and provide the results to the amateur, who will be able to use those data to comply with the FCC exposure requirements. This requirement became official on May 3, 2021, and any handheld radios manufactured before that time are assumed to meet the exposure requirements even without SAR testing by the manufacturer. In support of this supposition, a survey study of the FCC equipment database to see what SAR measurements have revealed for commercial handheld devices that are similar to amateur radio handhelds found that commonly used handheld transmitter power levels did not cause overexposure. This limited study showed that in commercial handheld devices at frequencies just above the amateur 2-meter band with similar power output and rubber duck antennas the SAR measurements were below the FCC SAR limits. Similar results were seen for devices that operated at frequencies just above the amateur 70 cm band.

Occupational vs General Population

The ANSI/IEEE C95.1-1992 standard makes a distinction between what is termed the occupational population, or *controlled environment*, and the general public, or *un-*

controlled environment. The reasoning for creating two sets of safety limits was to provide an additional margin of safety for people who were unaware of their exposure. The use of controlled and uncontrolled environments in the IEEE standard also helps emphasize that the IEEE standard does not restrict the higher set of exposure limits only to those who may be occupationally exposed. For example, the IEEE context is that the upper set of exposure limits, those for controlled environments, apply to anyone who is aware of the potential for exposure, not just to those who may be exposed because of their occupation.

This is in contrast to the FCC exposure rules wherein controlled exposures generally apply only to exposure encountered as a result of one's occupation, with the caveat that anyone considered to be in the occupational population must also be trained about RF safety.

The additional safety margins for general population/uncontrolled exposures are generally 5-times greater than those applicable to the controlled environment, which themselves already result in exposures that are 10-times lower than the exposure levels at which any deleterious effect had been detected in scientific studies. Thus, those individuals in uncontrolled environments are protected by limits that are 50-times lower than exposures at which deleterious effects have been demonstrated in scientific studies.

Radio amateurs and the people living in their households were included in the FCC rules to be considered part of the occupational population subject to the more permissive exposure limits. This gives amateurs more leeway in designing their RF safety programs, since the people living in their houses are subject to the higher MPE values. Questions on RF exposure were added to each of the amateur radio licensing exam question pools as evidence of training for licensed amateurs. Radio amateurs are expected to educate the people living in their homes about the potential for RF exposure caused by operation of their stations and how to reduce exposure if they so desire.

TIME AVERAGING

The MPEs are based on eliminating the whole-body heating effects caused by RF exposure. Because of the thermal time constant of the body, exposures are averaged over any six-minute period. This process results in controlling the approximate average level of thermal load imposed on the body. The time averaging permits short exposure to very high-power signals followed by very low exposure, which has the same effect on the body as a continuous lower exposure, as long as the average does not exceed the MPE over the designated averaging time. For the occupational population the averaging time is 6 minutes; for the general population it is 30 minutes.

MODULATION DUTY CYCLE

Averaging is defined in two ways for amateur radio operations. Many forms of modulation cause the peak power of the carrier to vary over time, and the average of those variations is lower than the exposure that would be caused by the unmodulated carrier. Some common averaging duty cycles for typical amateur radio modulation types are shown in **Table 22.5**.

TRANSMIT-RECEIVE DUTY CYCLE

During the exposure averaging times of 6- or 30 minutes, typical amateur communication switches from transmit-to-receive several times. Since exposure occurs only during the transmit portion of the conversation, that represents another duty cycle that can be combined with the modulation duty cycle to determine the overall time-averaged value of exposure. A typical voice conversation between two radio amateurs would have each station transmitting for 50% of the time. In a contesting situation, the transmit duty cycle could either be much less, with short calls and longer times listening or higher with frequent CQ calls and short pauses for a reply. Each amateur should make a best estimate of the duty cycle of transmission in their form of operating.

The transmit-receive duty cycle has meaning only in situations where transmissions are significantly shorter than the averaging period. For instance, if an amateur transmits continuously for 6 minutes and then listens for 6 minutes, the duty cycle for assessing the occupational exposure, with a 6-minute averaging time, is 100%, since the full averaging time can be used during one transmission. However, for this same transmit-receive timing in calculations for exposure of the general population, with a 30-minute averaging period, the duty cycle is 50%.

ACTUAL EXPOSURE AFTER AVERAGING

The exposure that is calculated for a person standing near an antenna can be lowered by factoring in both the modulation duty cycle and the transmit-receive duty cycle. For instance, if you calculate that when standing in a certain location near a 10-meter dipole, a person in the general public could be exposed to the equivalent of 1.0 mW/cm^2, a power density that exceeds the FCC MPE of 0.2 mW/cm^2 by a large margin, you may then apply the duty cycles of your operation. In this example, you normally operate with uncompressed SSB and converse with a friend where you each talk for one minute and listen for one minute. Your modulation duty cycle in this case is 20% (factor of 0.2) and your transmit-receive duty cycle is 50% (factor of 0.5). The averaged exposure of the person in question would then be:

$$1.0 \text{ mW/cm}^2 \times 0.2 \times 0.5 = 0.1 \text{ mW/cm}^2$$

Therefore, this location meets the FCC MPE for the general population when the station is operated as described. However, if you were to switch your modulation from SSB to FM, the average exposure would change markedly. Frequency modulation has a modulation duty cycle of 100% (factor of 1.0) and, with all other operating parameters being the same, the averaged exposure of the person in question would become:

$$1.0 \text{ mW/cm}^2 \times 1.0 \times 0.5 = 0.5 \text{ mW/cm}^2$$

which is more than double the FCC MPE for the general population.

22.3.5 Responsibilities of the Radio Amateur

The FCC expects every amateur radio licensee to abide by its exposure rules. Even when you are not required to perform a complicated analysis, it is your responsibility to make sure that no person is ever exposed above the MPE listed in the FCC rules, with

Table 22.5
Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm²)*	*Averaging Time (minutes)*
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f2)*	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 Notes 1 and 2).
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:
Pd = |Etotal|2 / 3770 mW/cm^2 or from $P_d = |H_{total}|^2 \times 37.7$ mW/cm^2.
Note 2: $|E_{total}|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2$, and $|H_{total}|^2 = |H_x|^2 + |H_y|^2 + |H_z|^2$

the understanding that the MPE table refers to values of plane wave equivalent power density that are averaged over applicable times and spatially averaged over the dimensions of the body.

There are several ways to evaluate the exposure from your amateur radio station. The simplest forms of evaluation are designed to be highly conservative so that any operation passing the evaluation is highly unlikely to ever cause overexposure to any person near the antennas. However, this conservatism may cause one to think that their operating parameters need to be changed while a more exact analysis may show that no overexposure would occur. For instance, the FCC provides exemptions from more detailed analysis applying calculations that indicate what the maximum transmitted power must be for a person standing a given distance from an antenna. In a given situation, the exemption formulae may tell you that you need to reduce power from what you planned to use. If that occurs, a more detailed form of analysis might show that your power setting would not actually cause overexposure and your planned power level will be permitted.

For the purposes of exposure analysis, it is not necessary to determine the exact levels to which people might be exposed. It is only necessary to affirm that any exposure will less than the FCC MPE thresholds. Any assessment method that provides credible confirmation without determining the exact exposure is perfectly acceptable when demonstrating compliance with the FCC human exposure rules.

Most stations will require multiple analyses to account for differences in operating modes, antennas, transmitters, and frequency bands. It is not necessary to use the same analysis methods for each set of operating parameters and, generally, the simplest method that shows compliance with the FCC MPEs is the best to use.

The FCC does not require that amateurs submit the results of their exposure assessments to the commission. However, it is wise to document the assessments and file them so that if there is ever a question about overexposure from your station, you will be able to provide documentation to show why that is not the case.

Many radio amateurs will find that the simplest forms of exposure assessment are satisfactory for their station's operations. Descriptions of the two most common methods are found below. More complicated assessments are beyond the scope of this discussion. If they should become necessary, other documents, including some that are referenced here, can provide appropriate guidance that you will need.

As you read this chapter about the federal regulations and requirements for compliance with RF exposure rules, it may seem a bit overwhelming in terms of both regulatory and technical detail. Perhaps the most useful guidance to new amateur radio licensees is to design your station to comply with these rules in the first place and choose conservative operational practices will help you avoid unnecessary trouble in the future. If you are a seasoned amateur licensee with a long-established station that may have never given any serious attention to RF safety in the past, now is the time to use the information in this chapter to help you review all aspects of your station that could lead to excessive RF exposures and, where appropriate, take those steps that will get your station into compliance.

PERFORMING AN EXPOSURE ASSESSMENT

Before choosing what type of exposure assessment is needed, there is certain information that must be gathered, which will be used with any assessment. These are:

1. The amount of power that will be emitted from the antenna

The measure of power that is important in the analysis of exposure is the amount that is emitted from the antenna. You need to know the output power of the transmitter, the loss in your feed line and the gain of your antenna. The FCC has standardized on effective radiated power (ERP) to define emitted power; ERP is the net power delivered to the antenna multiplied by the power gain of the antenna relative to a half wave dipole in free space. The simplest way to calculate ERP is to first convert transmitter output power to dBW (dB with respect to a watt, e.g., 100 watts = 20 dBW). Next subtract the feed line loss, which is reported by coaxial cable manufacturers in dB/100 feet at various frequencies. Choose the closest frequency that is reported by the manufacturer and factor in the length of your coaxial cable. Finally, add the gain of the antenna in dBd (dB with respect to a half wave dipole). Some antenna manufacturers report the gains of their antennas in dBi, the gain with respect to an isotropic radiator. To convert from dBi to dBd, subtract 2.15 dB (i.e., dBd = dBi - 2.15).

If you have a power amplifier that you use occasionally, try using that high power output in the analysis. If the method you are using suggests that exposure may not comply with the MPE, you can analyze with and without the amplifier separately. Clearly, if analysis with the higher transmit power indicates no potential exposure problems, then it is not necessary to repeat the analysis with the barefoot power level.

2. The shortest distance there will ever be between any part of the antenna and a person

Some methods of exposure assessment distinguish between exposure to people in the occupational population and exposure to the general population. This can be important for some stations since the FCC MPE values for the occupational population are significantly less stringent. The FCC has designated licensed radio amateurs and the members of their households as members of the occupational population, so it may be necessary to perform two analyses for each antenna on each band, with the distance from the antenna to the nearest people in the occupational population used in one calculation and the distance from the antenna to the nearest people in the general population used in the other calculation.

FCC EXEMPTIONS

The current FCC rules allow for "exemptions" from performing more detailed exposure evaluations. As mentioned earlier, however, there is no exemption from complying with the FCC exposure regulations!

The first requirement for the use of FCC exemptions is that the distance between a person and the nearest point of the antenna be outside the reactive field region of the antenna, which is greater than $\lambda/2\pi$, where λ represents the wavelength of the signal being transmitted. **Table 22.6** gives the minimum distances from the antenna for which the FCC exemptions can be used for most amateur bands.

If the shortest distance between a person and any part of the antenna (R), expressed in meters, will be less than the values on Table 22.6, then a different exposure evaluation method must be used. To determine if you are exempt from further, more detailed, evaluation, you can use the expressions in **Table 22.7** for your frequency range of interest to calculate the threshold ERP that will ensure compliance with the exposure rules. The calculation result tells you the maximum power that can be emitted from the antenna (ERP) in order to maintain the exemption. Take care to match your units. The FCC exemption formulas are based on distances in meters, while you may have made your measurements in feet. The result of the exemption is ERP in watts, while you may have calculated your ERP in dBW.

Table 22.6
Minimum Exemption Distances ($\lambda/2\pi$)

Band *(MHz)*	Distance	Band *(MHz)*	Distance
1.8	87.0 ft	24.9	6.3 ft
3.6	43.5 ft	28.2	5.6 ft
3.9	40.2 ft	50.1	3.1 ft
7.1	22.1 ft	146	1.1 ft
10.1	15.5 ft	223	8.4 in
14.1	11.1 ft	440	4.3 in
18.1	8.7 ft	902	2.1 in
21.2	7.4 ft	1296	1.5 in

Table 22.7
Maximum Exempt ERP

	Frequency (MHz)	*Maximum ERP (Watts)*
VLF	0.3 – 1.34	$1920 \times R^2$
HF	1.34 – 30	$3450 \times R^2 / f^2$
VHF	30 – 300	$3.83 \times R^2$
UHF	300 – 1500	$0.0128 \times R^2 \times f$
MW	1500 – 100,000	$19.2 \times R^2$

Note: R is distance in meters and f is frequency in MHz.

Example Calculations:

On 14.1 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 14.1^2 = 1735$ W.

On 22.2 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 22.2^2 = 433$ W.

On 50.1 MHz at 5 meters from the antenna, the maximum exempt ERP is $3.83 \times 5^2 = 96$ W.

On 146 MHz at 0.5 meters from the antenna, the maximum exempt ERP is $3.83 \times 0.5^2 = 0.96$ W.

Normally, FCC exemptions must be recalculated for each frequency band that will be used by a station. Some peculiarities of the equations allow you to decrease the number of calculations. For instance, in the equation for the HF bands (1.34–30 MHz) the frequency parameter is in the denominator. If you are using the same multiband antenna for several HF bands, by calculating the threshold ERP for the 10 meter band, as the frequency decreases for the other HF bands then the threshold ERP will only get larger. Calculation at the highest frequency used by an antenna in the HF bands gives the worst case, or lowest allowable threshold ERP. No additional calculations are necessary for lower frequencies on the same antenna as long as the exemption is valid for the highest frequency used and the minimum exposure distance remains greater than $\lambda/2\pi$ for all lower frequency bands being considered.

For VHF bands (30 – 300 MHz) the exemption formula does not vary with frequency, so you need only perform one calculation per antenna (with unchanging power levels), no matter how many VHF bands are transmitted by that antenna.

On UHF bands (300 – 1500 MHz) the exemption formula is proportional to frequency so a calculation at the lowest frequency in that range for an antenna is the only one needed for all frequencies transmitted from that antenna. In these bands, an exposure distance greater than $\lambda/2\pi$ could still be less than 20 cm. Recall that any exposure distance less than 20 cm must be evaluated with SAR, and these exemption formulae would not apply (see the note near the bottom of Table 22.7).

DISADVANTAGES OF USING EXEMPTIONS

Even though determining if you qualify for the exemption from more detailed evaluation is easy, the analysis process makes certain assumptions that tend to overestimate exposure. If the calculations with the exemption criteria yield acceptable ERP values for your station, then there is nothing else to do and your exposure analysis is complete. You can presume that operation of your station will comply with the FCC RF exposure rules.

If, however, the application of the exemption criteria indicates that you must decrease your ERP below what you planned to transmit, then the highly conservative assumptions associated with the process may be the culprit and not the potential exposure that would result from your station's operation. When an exemption calculation specifies a maximum allowable ERP, the assumption is that the antenna gain is equal in all directions. Even though a directional antenna is often rotated through a full circle, the regions above and below the antenna are never subject to that much gain, and there can be significant attenuation in the transmitted pattern that is not accounted for with this analysis method.

The exemption process assumes that members of the general population will be exposed at the previously determined shortest access distance to the antenna and applies the more restrictive general population MPE for finding a compliant ERP. It could be that only the amateur and/or members of the household will have such access and, in this case, the less stringent occupational/controlled exposure MPEs are actually applicable.

Further, the exemption determination does not factor in the modulation and transmit-receive duty cycles, which usually decreases the actual averaged exposure.

Finally, the exemption criteria also make the generally unrealistic assumption that perfect reflection of RF fields from the ground occur as if it was a perfectly conducting surface. This assumption, by itself, increases the potential exposure field power density by up to a factor of four. Hence, the exemption criteria represent a highly conservative approach that will in most cases overestimate potential exposure levels but can be regarded as a fail-safe approach for compliance assessment.

If the exemption process indicates that your station needs to decrease power to operate below the general population MPE, you should consider a more accurate form of analysis (see below) and confirm whether the individuals who have access to your antenna at the distance you determined will be members of the general population or just the licensed operator and members of the operator's household for which the less restrictive MPEs apply.

ONLINE CALCULATORS

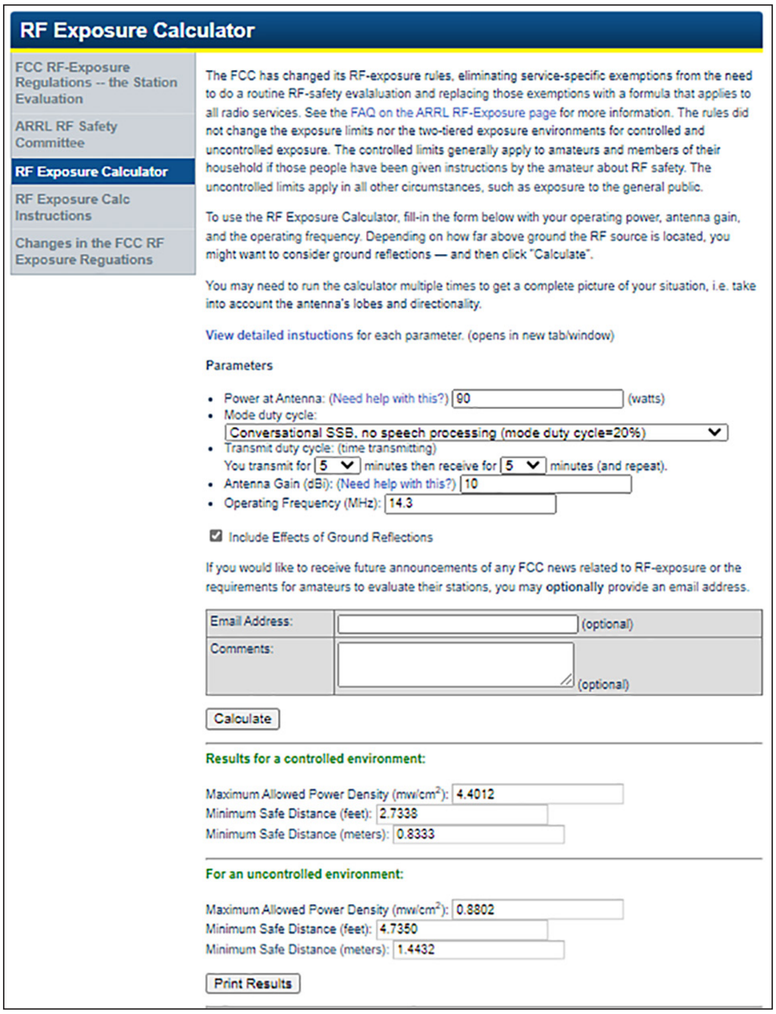
Several RF field calculators for estimating potential exposure are available on the Internet. Most are based on calculation in the far-field; some assume a free space environment while others permit inclusion of a ground reflection factor that increases the calculated field strength or power density. It is important to use a known online calculator. The calculations performed in the background of an online calculator may contain unwarranted assumptions or even outright errors that are invisible to the user. The calculator must compare the results of its power density calculations to the proper exposure limits; in the United States that must be the current FCC MPEs and, if they are ever changed, the calculator must be modified to produce the correct results. The calculator that you use should explicitly state which thresholds are being used with its calculations.

Even though the calculation is based on an equation for far-field power densities, the results for simple antennas are applicable in the near-field and even in the reactive near-field, which is not valid for FCC exemptions and may still be overly conservative. Other assumptions used in the FCC exemptions are also true for most online calculators, mainly that the antenna gain can occur in all directions. However, most online calculators will distinguish between the exposure distances for the occupational population and the general population.

A good example of an online RF exposure calculator can be found on the ARRL website at **arrl.org/rf-exposure-calculator**. A sample calculation is shown in **Figure 22.23**. This calculator requires that you determine the feed line loss and enter the power at the antenna. However, for simplicity, you may want to first perform the calculations as if there was no feed line loss and see if it gives favorable results. If not, then you can go to the additional work of calculating the feed line loss to see if that makes an important difference for your station's exposure calculation.

This calculator factors in the modulation and transmit-receive duty cycles. It asks for antenna gain in dBi. The results are the minimum compliance distances from the antenna to people in the occupational population and to people in the general population in both feet and meters. Remember that the averaging times for the FCC MPEs are different for the two different population groups and that the averaging times refer to either a six-minute or 30-minute "sliding window" of time. Thus, the transmit-receive duty cycle must take into account the ratio of the maximum transmit time during any six-minute or 30-minute period to the averaging time period.

The ARRL online calculator also allows for applying a realistic ground reflection factor


RF Exposure Calculator

FCC RF-Exposure Regulations -- the Station Evaluation
ARRL RF Safety Committee
RF Exposure Calculator
RF Exposure Calc Instructions
Changes in the FCC RF Exposure Reguations

The FCC has changed its RF-exposure rules, eliminating service-specific exemptions from the need to do a routine RF-safety evalaluation and replacing those exemptions with a formula that applies to all radio services. See the FAQ on the ARRL RF-Exposure page for more information. The rules did not change the exposure limits nor the two-tiered exposure environments for controlled and uncontrolled exposure. The controlled limits generally apply to amateurs and members of their household if those people have been given instructions by the amateur about RF safety. The uncontrolled limits apply in all other circumstances, such as exposure to the general public.

To use the RF Exposure Calculator, fill-in the form below with your operating power, antenna gain, and the operating frequency. Depending on how far above ground the RF source is located, you might want to consider ground reflections — and then click "Calculate".

You may need to run the calculator multiple times to get a complete picture of your situation, i.e. take into account the antenna's lobes and directionality.

View detailed instuctions for each parameter. (opens in new tab/window)

Parameters

- Power at Antenna: (Need help with this?) 90 (watts)
- Mode duty cycle: Conversational SSB, no speech processing (mode duty cycle=20%)
- Transmit duty cycle: (time transmitting) You transmit for 5 minutes then receive for 5 minutes (and repeat).
- Antenna Gain (dBi): (Need help with this?) 10
- Operating Frequency (MHz): 14.3

☑ Include Effects of Ground Reflections

If you would like to receive future announcements of any FCC news related to RF-exposure or the requirements for amateurs to evaluate their stations, you may **optionally** provide an email address.

Email Address:	(optional)
Comments:	(optional)

Calculate

Results for a controlled environment:

Maximum Allowed Power Density (mw/cm²): 4.4012
Minimum Safe Distance (feet): 2.7338
Minimum Safe Distance (meters): 0.8333

For an uncontrolled environment:

Maximum Allowed Power Density (mw/cm²): 0.8802
Minimum Safe Distance (feet): 4.7350
Minimum Safe Distance (meters): 1.4432

Print Results

Figure 22.23 — ARRL RF Exposure Calculator.

of 2.56 when calculating power density or no reflection factor at all (as in free space). This means that the calculator is intended for more realistic estimation of expected RF field power density, which is suitable for certifying compliance with the FCC MPEs. This is in contrast to applying the FCC exemption criteria proposed for an initial go/no go indication as to whether additional evaluation effort will be necessary.

WHEN SHOULD ONLINE CALCULATORS NOT BE USED?

Online calculators that are based on the far-field equation also give accurate exposure results as close as the surface of the antenna for some simple antenna types. It is important, however, to not use this form of analysis too close to more complex antennas. The exposure calculator does not ask you what type of antenna you are using and if it reports a short compliance distance, that would only be accurate for a simple wire antenna. If the shortest distance between a person and the antenna is much larger than the calculated compliance distance, the result may still be valid. A good distance to use for this determination is the same one that is used by the FCC exemptions, the reactive near-field, or $\lambda/2\pi$, as shown in Table 22.6. If the distance to the nearest person is greater than the value in that table and the calculator gives a compliance distance less than that, it can still be used even for a complex antenna.

22.3.6 RF Exposure Mitigation

It is not the purpose of the FCC human exposure regulations to keep you off the air. The goal is preventing overexposure of anyone while you are operating. If your calculations indicate that locations at which people may be present could cause exposure exceeding the FCC MPE (an overexposure), you must perform some type of mitigation to prevent that occurrence. There are many ways that you can mitigate an overexposure situation, some of which may actually improve the performance of your station.

If possible, when areas in which an overexposure could occur exist on the ground, raising the antenna could do away with the problem. For antennas that have sections mounted close to the ground, such as the ends of an inverted-V, raising those ends by even a few feet could convert a noncompliant station into one meeting the FCC MPEs.

POSITIVE ACCESS CONTROL

The FCC requires *positive access control* (PAC) to prevent people from accessing areas in which they might be overexposed. PAC is a general term that refers to an active measure that keeps people from entering overexposure areas. PAC can be as simple as a locked door to a rooftop on which antennas are located. A common way to achieve PAC is to place effective fencing around the areas where access must be controlled.

Wherever PAC is used, the FCC requires that signs be posted to warn about the possibility of overexposure. Signs must be large enough to be read from a distance at which overexposure cannot occur. The content of the sign is specified in the FCC rules, and, for areas in which the FCC general population MPE may be exceeded, must have the word "NOTICE" in white letters on a blue banner along with a description of the hazard and your contact information. If exposure to RF fields within the controlled area have the potential to exceed the FCC occupational population MPE, then the sign must have the word "CAUTION" in black letters on a yellow banner along with similar text as the "NOTICE" sign.

OPERATING MODIFICATIONS

Two conditions must be met to cause exposure: the station must be transmitting and there must be a person present in a potential overexposure area. PAC is a means of preventing the latter. However, control of the former can also satisfy the requirement that no person be exposed to electromagnetic energy exceeding the MPEs.

The FCC writes its regulations to cover all forms of radio transmission that they regulate. Some of these include broadcast transmitters and cellular base stations. Both of these differ from amateur radio in two ways: they transmit during all hours of every day of the year and, most importantly, they are usually unattended. In contrast, amateur radio transmissions are generally intermittent, and the amateur radio operator is usually present at the transmitter while it is operating.

If a person enters a potential overexposure area and the amateur radio operator then stops operating, no hazard exists, and the station remains compliant with the FCC rules on exposure. Similarly, the amateur radio operator may determine that a lower transmit power removes the hazard, and then decreases the power any time a person is seen to enter the overexposure area.

Amateur radio stations that are remotely controlled require special considerations when identifying areas in which individuals might be exposed above the FCC MPEs. For remote operations, the best approach is to design the transmitting site to be inherently compliant with the MPEs without need for real time monitoring of activity within the area.

22.3.7 RF Safety References

The preceding section has presented an introduction to the reasons for developing an RF Safety program for your station and some basic procedures to help determine what areas around your station may be a cause for concern that a person might be exposed to your transmitted signals beyond the limits that the FCC has set. To perform more exact exposure analyses, which may be necessary if your station has marginal exposure results from the more common methods, you can look to the following references:

FCC OET Bulletin 65

The FCC has provided guidance for complying with their rules on human exposure to electromagnetic energy in their OET Bulletin 65. OET Bulletin 65 Supplement B, which was principally written by members of the ARRL RF Safety Committee, provides more specialized information that applies to the operation of an amateur radio station. Both of these documents are available for free download from the FCC website: **www.fcc.gov/general/oet-bulletins-line**.

ARRL Antenna Book

The *ARRL Antenna Book* has an RF Safety section that builds on the information provided here. Additional information is provided to help perform more exact exposure modeling with the Numerical Electromagnetic Code (NEC), with a discussion of the importance of ground reflections and spatial averaging. A discussion of the use of Pre-Assessed Configurations (PACs) to more accurately estimate the potential RF exposure around specific antenna types and installations is also included. That section discusses specialized antennas that are more difficult to assess and how to handle exposure around unattended repeaters and other remote stations. Finally, the subject of VLF transmissions and induced limb currents is discussed in the anticipation that this additional measure of exposure may be added to the FCC regulations in the future.

RF Exposure and You

The ARRL has published a book entitled *RF Exposure and You*, which delves into all aspects of RF exposure and how to comply with FCC regulations.

SCIENTIFIC REPORTS AND STUDIES

ANSI/IEEE C95.1-1992: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. Note: The IEEE C95.1-1991 standard was adopted by the American National Standards Institute, ANSI, in 1992.

NCRP Report #86: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, 1986.

Tell, R., "Amateur portable radios (handheld transceivers): exposure considerations based on SAR." *QEX*, Jul./Aug. 2021, pp. 11 – 15.

Jordan, E., and Balmain, K., *Electromagnetic waves and Radiating Systems,* 2nd Edition (Prentiss-Hall, 1968) pp. 333 – 338.