TABLE OF CONTENTS

Chapter 26 — CD-ROM Content

Supplemental Articles
- “A One Person, Safe, Portable and Easy to Erect Antenna Mast” by Bob Dixon, W8ERD
- “Antenna Feed Line Control Box” by Phil Salas, AD5X
- “Homeowners Insurance and Your Antenna System” by Ray Fallen, ND8L
- “Installing Yagis in Trees” by Steve Morris, K7LXC
- “Is Your Tower Still Safe?” by Tony Brock-Fisher, K1KP
- Ladder Mast and PVRC Mount
- “Lightning Protection for the Amateur Station, Parts 1, 2 and 3” by Ron Block, KB2UYT
- “Removing and Refurbishing Towers” by Steve Morris, K7LXC
- Rotator Specifications
- “The Care and Feeding of an Amateur’s Favorite Antenna Support — The Tree” by Doug Brede, W3AS
- “The Tower Shield” by Baker Springfield, W4HYY and Richard Ely, WA4VHM

Chapter 26

Building Antenna Systems and Towers

Getting an antenna in the air and keeping it there requires decisions and challenges. For example, what kind of antenna support? How do you build it? What tools and techniques should be used? There are many other questions. In this chapter, experienced tower climber Don Daso, K4ZA, updates and expands the material from previous editions, including content from K7LXC. (Unless otherwise noted, photos were provided by K4ZA and K7LXC)

The information here is by no means exhaustive. For a more complete treatment, the reader is directed to two books written specifically for the ham installing or working on towers and antennas:

■ *Antenna Towers for Radio Amateurs: A Guide for Design, Installation and Construction* by Don Daso, K4ZA, and published by ARRL.

■ *Up the Tower: The Complete Guide to Tower Construction* by Steve Morris, K7LXC, and published by Champion Radio Products (**www.championradio.com**).

These books are great tutorials on working successfully and safely with towers and antennas. They also provide information for working with masts and trees. The two books provide complementary perspectives on many subjects, and reinforcing views on many others. If you are contemplating either a simple or significant tower or antenna project, you should read either or both of these books before beginning. You are also encouraged to read the articles listed in the Bibliography and to attend presentations by experienced individuals. Consider hiring professional assistance if you are not comfortable with doing such work yourself.

Many of the safety and tower work products mentioned in this chapter are available from numerous *QST* advertisers.. The CD-ROM supplied with this book also includes a directory of manufacturers and distributors for all manner of antenna-related products. You should be able to find everything you need in order to do the job safely and correctly, resulting in years of trouble-free service at the least possible risk.

Learning and practicing the right way to do things will save you time, money and worries. Let's start with safety!

Equipment and Materials

A list of vendors for equipment and materials for antennas and towers is available on the CD-ROM that comes with this book. Printed in previous editions, the list is now changed to electronic form in order to allow more frequent updates.

26.1 SAFETY AND SAFETY EQUIPMENT

Working aloft is dangerous, pure and simple. Whether it's 20 or 200 feet tall, climbing towers is dangerous. You're always at risk. Fear of heights is one of the most common phobias, affecting an estimated 3 to 5 percent of the population.

Due to the dangers inherent in such work, working safely is paramount. That translates into having and using the proper equipment to ensure one does not get hurt. Today, that means a proper harness, proper clothing and tools, along with some training or instruction. This focus on safety and equipment is critical.

OSHA and Tower Work

OSHA is the federal Occupation Safety and Health Agency (**www.osha.gov**) that sets minimum safety standards for workers. Each state has an agency that is responsible for enforcing the OSHA regulations in that state. In addition, your state agency may have stricter regulations than OSHA; OSHA regulations are just the minimum requirements.

If you are getting paid or paying someone to do tower work, you or they must comply with the federal and state regulations. If you are simply working on your own system, or someone else's without pay, then you don't fall under the OSHA/state laws. But you should still observe them! You should use only OSHA/state approved safety equipment and follow the regulations applicable to your activity. By doing this, you'll be giving yourself a large and acceptable safety margin while working.

26.1.1 FALL-ARREST EQUIPMENT

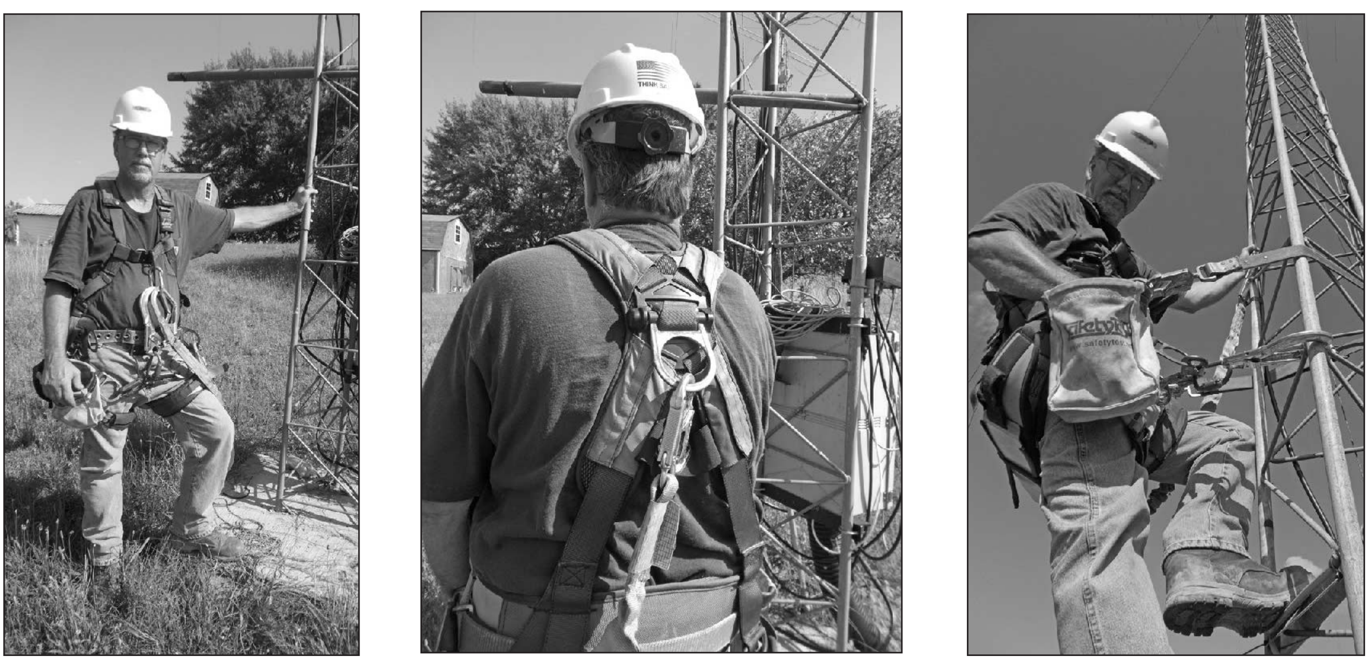
The most important pieces of safety equipment are the *fall-arrest harness* (FAH) and the accompanying lanyards (see **Figure 26.1**). Leather safety equipment was outlawed years ago by OSHA so please don't use any of it. This includes the old-fashioned safety belt that was used for years but offers no fall-arrest capability.

If you drop down while wearing a safety belt, your body weight can cause the safety belt to rise up your waist to your ribcage, where it will immobilize your diaphragm, potentially suffocating you! On the other hand, you can use your safety belt for positioning when it's used in conjunction with your FAH. Just don't depend on it to catch you in case of a fall.

The FAH is the part that you wear and to which the lanyards attach. The FAH has leg loops and suspenders to help spread the fall forces over more of your body. It has the ability to catch you in a natural position — with your arms and legs hanging below your body, so you're able to breathe normally. Plan on spending $300 or more for a new FAH and lanyards.

There are two primary types of lanyards. One is the *positioning lanyard* shown in **Figure 26.2**. That is, it holds you in working position and attaches to the D-rings at your waist. Positioning lanyards can be adjustable or fixed and are made from materials such as nylon rope, steel chain or special synthetic materials. An adjustable positioning lanyard will adjust to fit various tower diameters, while a fixed-length lanyard is often either too long or too short for the job. The rope type is the least expensive version.

The other lanyard is the *fall-arrest lanyard* that attaches to a D-ring between your shoulder blades. The other end attaches to the tower above your work position and catches you in case of a fall. The simplest is a 6-foot rope lanyard that is inexpensive, but doesn't offer any shock absorption. There are also shock absorbing varieties that typically have bar-tacked stitches that pull apart under force and decelerate you (see **Figure 26.3**).



(A) (B) (C)

Figure 26.1 — KI4TZ wearing a Personal Fall Arrest Harness system (A). With shock-absorbing lanyard, positioning lanyard, and a safety hook, he's ready to work aloft. Long pants, hard hat, steel shank boots, and eye protection are included. Shock-absorbing lanyard is attached to the harness's rear D-ring (B). The waist-level pouch (C) allows easy access to required tools.

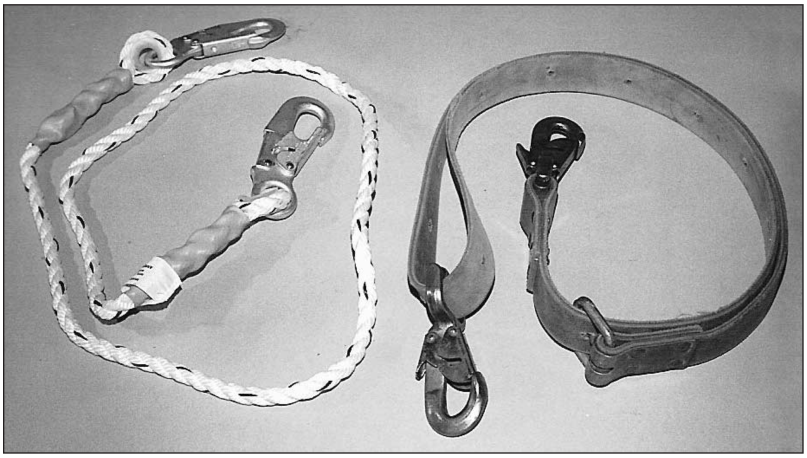


Figure 26.2 — A fixed-length rope positioning lanyard on the left and a versatile Klein adjustable lanyard on the right. They both use double-locking snap-hooks.

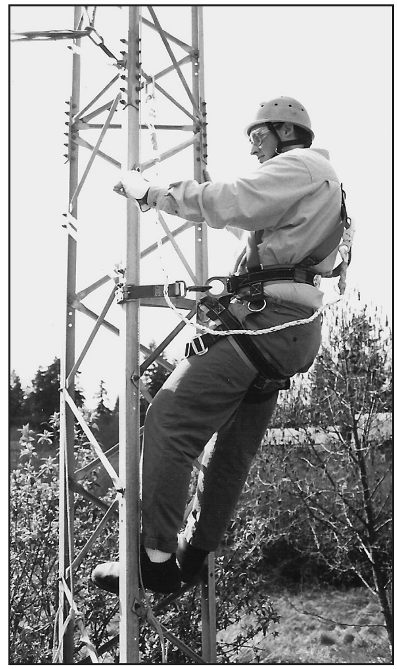


Figure 26.4 — A climber on a tower. Note the fall arrest lanyard attached to the tower above him.

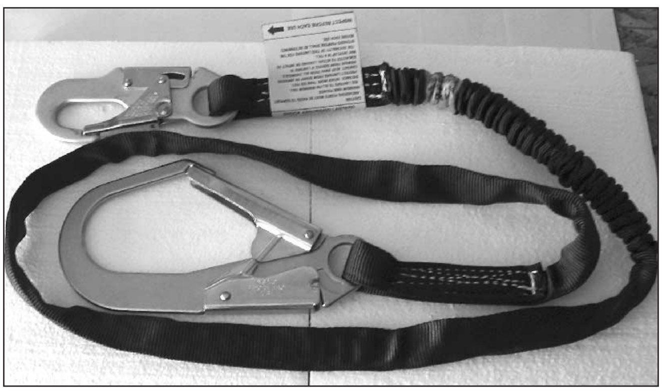


Figure 26.3 — A shock absorbing fall arrest lanyard. Portions of the nylon webbing are sewn together and pull apart under the weight of a climber falling on it, thus decelerating the fall.

26.1.2 SAFELY CLIMBING A TOWER

Common sense, as well as current OSHA rules, say you should be attached to the tower 100% of the time. You can do this several ways. One is to attach the fall-arrest lanyard above you and climb up to it as shown in **Figure 26.4**. Use your positioning lanyard to hold you while you detach the fall-arrest lanyard and move it up again. Repeat while you climb. An alternative is to use two fall-arrest lanyards, alternating them as you climb.

It's not a race! Take your time and climb safely. If you become tired or uncomfortable, stop and rest with your lanyards securely fastened to the tower. If you feel unsafe at any time for any reason — stop and return to a safe position or configuration!

Safety Climb Systems

Most commercial towers have a safety climb system, typically a ⅜-inch steel cable that runs from the top to the bottom of the tower. The climber attaches to a special trolley with a cable from the climber's FAH. The trolley will slide up freely, but clamps the safety cable if weight is put on it, thus preventing you from sliding down the cable and tower. Such installations are rare on amateur towers, but are worth considering.

Mountain Climbing Harnesses — Problems

Some amateurs feel that mountain climbing harnesses offer a less-expensive option for a safety belt. The first problem with using a mountain climbing harness is that most require you to tie the harness directly to a rope or to a carabiner and most hams are not skilled at tying climbing knots properly. You could use a locking carabiner as an attachment point but it is another piece of hardware that could fail or open up at the wrong time.

Second, there are no D-rings for attaching any sort of positioning lanyard; you can only connect one carabiner to the loops in the front. The nylon loop on the front of the climbing harness is only designed to position the leg loops and is intended to be used only with a climbing rope or carabiner, not the metal snaps of your lanyard that are frequently snapped on and off.

Mountain climbing belts are designed to be used only with climbing ropes and hardware, not with tower tools or equipment. They also don't have any provisions for convenient attachment of tool or bolt bags.

The final problems are that a mountain climbing harness may be designed for a force of only 1000 pounds while OSHA-approved fall-arrest gear must be designed for 5000 pounds of strength. Also, the mountain climbing harness has no fall-arrest capability. Although the main advantage of a mountain climbing harness is low cost, its limitations prevent it from being recommended for tower work.

Working on a Crank-up Tower

One of the advantages of a crank-up is the ability to bring the antennas down to rooftop level or close to ground level where it's easier for the station owner to work on it. For this convenience, the price that you pay is the added mechanical complexity and cost of the crank-up apparatus. They can cost two to three times the cost of a guyed tower of the same height.

Another limitation is the fact that a crank-up cannot be climbed safely once it is extended. Do not climb a crank-up tower unless it is totally nested and locked in the lowered position! Again, all of the weight of the system is on the cable and pulley systems and if something breaks or comes loose, your toes and fingers are in the path of the tower sections as they fall! If the tower is jammed and won't come down, don't climb it to fix it. Get a boom truck or crane in to lift you up to work on it. Better yet, get professional help.

It is possible to climb a crank-up if you can lock it into place. One method is to use 3 to 4 foot long pieces of 2×4s or pipes. Another is to place a U-bolt on at least one leg under each section. Insert them at the bottom of each section through the bracing and they'll catch each section before it can move down very far. You can also gently lower the tower until it rests on the safety pieces, thus jamming them into place and eliminating any tower movement at all.

It will still be quite difficult to climb the nested latticework sections. Havng small feet is an advantage here, as silly as that may sound. It may even be difficult to find a suitably rated attachment point for your lanyard. Again, the safest and simplest method of working on a crank-up tower is to utilize a manlift.

Principles of Working Safely

The following safety tenets are adapted to amateur antenna system and tower work from selected items of the Chevron Tenets of Operation. These are 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.

Do not even consider using harnesses not designed for climbing work, such as lightweight tethers or belts for hunting or other recreational uses. Please: use only the tools designed specifically for the job!

26.1.3 WORKING SAFELY

The Mental Game

One of the most important aspects of safety is having the knowledge and awareness that will enable you to perform work safely and efficiently. You must have the mental ability to climb and work at altitude while constantly rethinking all connections, techniques and safety factors. Climbing and working on towers safely is 90% mental. Mental preparedness is something that must be learned. This is an instance when there's simply no substitute for experience.

When it comes to tower climbing, only a small percentage of people are willing to climb and work aloft. The biggest obstacle is making the mental adjustment. Properly installed towers are inherently safe and accidents are relatively rare. The only thing stopping most people is their own mind and attitude.

Would you have any trouble standing on a 24 × 24 inch piece of plywood on the ground? Probably not! But, could you stand on that same four-square-foot platform 100 feet in the air? The only difference is in your mind. It's easier said than done, but you must make the mental adjustment if you are going to do any tower work.

An important lesson learned from mountain climbing that is directly applicable to tower climbing is that when you climb, you have four points of attachment and security — two hands and two feet. When tower climbing, move only one point at a time. That leaves you with three points of contact on the tower 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 to excel at the mental game 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. This way you'll always confirm that you're belted in. Don't rely on the "clicking sound," or assume you're belted in and clipped on. Always look — always!

Check Your Safety Equipment

You should also 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.

Inclement Weather

Tower work is the easiest when the weather is nice and the sun is shining. Unfortunately, that doesn't always coincide with your construction schedule or repair priority. Don't hesitate to call off your project. If you're not sure if the weather is good enough, it probably isn't.

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.

As far as rain goes, unless it's coming in horizontally it's more of a nuisance. For ham towers, you'll always be belted in and you won't be walking across any rain-slicked surfaces, so working in the rain is possible. Just dress with good rain gear and you'll be able to still get some work done. Some ham towers have been painted, and their surfaces become slick when wet, so exercise extreme caution if that's what you're working on. And while the workers aloft may find they can continue working, the ground crew (or the client) suffers more, getting wet while waiting for something to happen. Again, don't be afraid to wait for better conditions.

Electrical Safety

Electrocution due to metal antenna or tower parts touching power lines is the biggest cause of tower related electrical injuries. *Be very careful if you're anywhere near power lines*.

Even without touching a power line, you can still be electrocuted while working on a tower, which is a large, grounded conductor. A major cause of tower injuries and deaths is electrocution. While there usually isn't much 120 V ac circuitry on amateur towers, care should still be taken around ac power. Use battery-powered equipment if possible, both for the convenience and safety. If you do use ac extension cords, make sure they're plugged into a GFCI (ground fault circuit interrupter) for your protection. Power tools operated from ac should be double-insulated. Part of your pre-work safety meeting should be pointing out where the circuit breaker box is in case someone has to turn off the power.

Safety Tips for Tower Work

- Don't climb with anything in your hands; attach it to your harness if you must climb with it or have your ground crew send it up in a bucket after you're in position.
- Don't put any hardware in your mouth; you could swallow it or choke on it.
- Remove any rings and/or neck chains; they can get hooked on things.
- Be on the lookout for bees, wasps and their nests; there aren't too many bigger surprises when you're climbing a tower. If you do get stung, apply a meat tenderizing powder containing the enzyme papain, such as Adolph's Meat Tenderizer, directly on the sting moistened with a little water or saliva. The enzyme neutralizes the venom and reduces the pain within a minute or two. Keep a bottle in your tower tool kit.
- Don't climb when tired; that's when most accidents occur.
- 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 your strength for when you really need it or you'll quickly run out of arm strength.
- If something doesn't work one way, re-rig, and then try again.

26.1.4 SAFETY EQUIPMENT

Boots

Boots should be leather with a steel or fiberglass shank. Diagonal bracing on Rohn 25G tower is only ⁵⁄₁₆-inch rod — spending all day standing on that small step 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 such as Rohn BX that have sharp X-cross braces, plus your feet are always on a slant and that combination can be quite painful and hard on your feet.

Hard Hats

The hard hat is highly recommended. Just make sure hard hats are OSHA-approved and that you and your crew wear them. As you'll be looking up and down a lot while wearing your hard hat, a chin strap is essential to keep it from falling off. Look for the ANSI or OSHA label on the hard hat; that should be the minimum safety compliance for your helmet.

Safety Goggles

Approved safety goggles should be worn to prevent eye injury. Look for ANSI or OSHA approval.

Gloves

If you do a lot of tower work, your hands will take a beating — 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. Leather gloves are the only kind to use; either full leather or leather-palmed are fine.

The softer the gloves the more useful they'll be. Stiff leather construction gloves are fine for the ground crew but the pigskin and other soft leathers allow you to thread a nut or do just about any other delicate job without removing (and possibly dropping) your gloves.

Framers or mechanics gloves (with the fingertips removed) are K4ZA's glove of choice over the past several years. A pair typically lasts for about two to three months of near-daily use.

Safety Equipment Suppliers

Chances are that you've got a safety equipment store in your area, but your best bet is to search the Internet for what you need since tower climbing equipment is not very common. Manufacturers such as Klein, Petzl, DBI-Sala and others all provide OSHA-approved safety equipment. These are more expensive products, but they're preferred by professionals who wear and work in them all day. These companies will have many other useful accessories and rigging supplies, such as rope, canvas buckets, tool pouches and other hardware.

26.1.5 INSURANCE

It is important that you have insurance that covers any potential liabilities (someone getting hurt on the tower, damage caused by tower failure, and so on) as well as the physical equipment itself.

The ARRL also offers the Ham Radio Equipment Insurance Plan (**www.arrlinsurance.com**). Your mobile and home station equipment is covered on an all-risk form which includes fire, lightning, theft, collision, and other accidents and natural hazards. Loss or damage to antennas, towers or rotators is covered. Review the policy's coverage at the insurance plan's website for complete information.

Ray Fallen, ND8L, an agent for State Farm Insurance for over 20 years, wrote an informative article on insurance in the February 2009 issue of *QST*, titled "Homeowners Insurance and Your Antenna System," which is included on this books CD-ROM. Ray also wrote Chapter 12 of *Antenna Towers for Radio Amateurs*, which is focused on insurance.

The National Electrical Code (NEC)

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

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

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

According to the Code, lead-in conductors (except those covered by the exception) must enter a building through a rigid, noncombustible, nonabsorbent insulating tube or bushing, through an opening provided for the purpose allowing a clearance of at least 2 inches or through a drilled window pane. All lead-in conductors to transmitting equipment must be arranged so that accidental contact is difficult.

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

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

26.2 TREES AND MASTS

26.2.1 TREES

Trees were among the first antenna supports and have been used successfully by many amateurs over the years. If you're in an area with suitable trees — congratulations! They're free (compared to towers) and generally unregulated for use as antenna supports. Trees make good temporary antenna supports and with care can support an antenna for many years — even a large one. When attaching an antenna to a tree, it's important to traumatize the tree as little as possible. This will ensure a strong, enduring attachment.

Although it's relatively easy to get a wire up into a tree, it's certainly more difficult to keep it there for the long term. Tree-mounted antennas require more maintenance, but their height and low cost more than make up for the added work. (Although uncommon, even Yagi antennas have been installed in trees using the techniques in the short article "Installing Yagis in Trees" included on the CD-ROM for this book.)

Using a Line Launcher

In this method, you use some sort of line launcher from the ground by which a lightweight line (usually fishing line of a few pounds capacity) with a weight on the end of it is propelled over a branch high up in the tree. Hopefully, the weight drops to the ground and you use the small line to pull up a bigger line with your antenna attached. Such launchers include slingshots, compressed air cannons, fishing rod and reel, bow and arrow, and even tennis ball throwing aids.

Keep people out of the fall zone around the tree since there will be falling weights, plus lines and antennas at some point. Safety glasses and gloves are always a good idea for these kinds of activities.

Attaching an Anchor

A stouter method of securing a rope in a tree is to climb the tree to install an anchor. For light antenna loads, such as the end of a dipole, a threaded eye-screw is the method of choice. (Use welded or forged (closed end) eye-screws and bolts to prevent them from opening up under load.) Just drill a hole into the tree about 1⁄16 inch smaller than the screw diameter, then twist in the screw as shown in **Figure 26.5**. Be certain you use a cadmium-plated eye-screw threaded for use in wood. A screw thread length of two or three inches should secure most antennas. Allow ½ inch of space or more between the trunk and the eye; this allows for outward growth of the tree with time.

For stouter antennas, such as multielement wire beams, a different method for securing wires to trees is recommended (see **Figure 26.6**). This procedure involves using an eyebolt longer than the tree diameter, drilling completely through the tree, and securing the eyebolt on each side of the tree with flat washers and nuts. Drilling a hole through a tree causes much less trauma to the tree than wrapping something around it. Much of the core of a tree is dead tissue, used mainly for physical support.

Although there will be some wounding of the tree at the site of a bolt or screw, such trauma will be far less than that which occurs from wrapping a wire around the trunk. Wrapping a line around a tree's branch or trunk strangles the veins in the sapwood the same way a noose around your neck would strangle you. It's important not to wrap anything around the trunk.

You can find a professional tree climber/arborist in the *Yellow Pages* or perhaps use the services of a talented friend to install a pulley and rope system in your trees of choice. A ⅜ or ½ inch eyebolt screwed into the tree as described above with a pulley attached is the best method. Use a threaded chain link or "cold shut" (a type of chain attachment link) to attach the pulley to the eye.

A non-swiveling pulley is preferred because the lay of the rope can cause the pulley to turn, twisting the rope and possibly jamming the pulley. Use only all-metal pulleys for

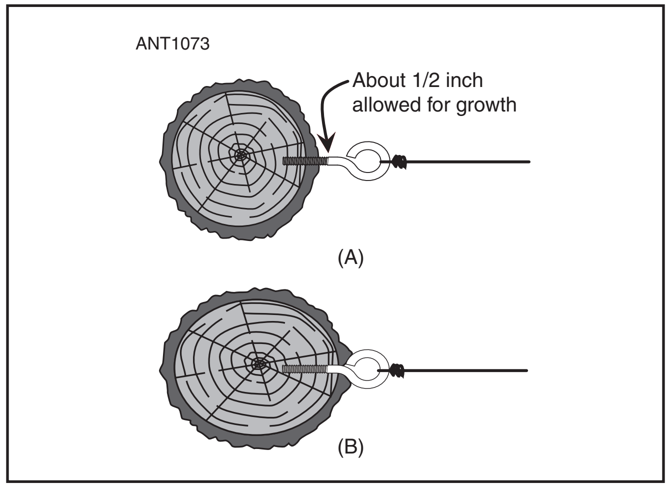


Figure 26.5 — The best way to secure a wire to a tree is with an eye-screw threaded into the wood (A). As the tree grows and expands, however, the eye-screw will become embedded (B) and must be removed and replaced.

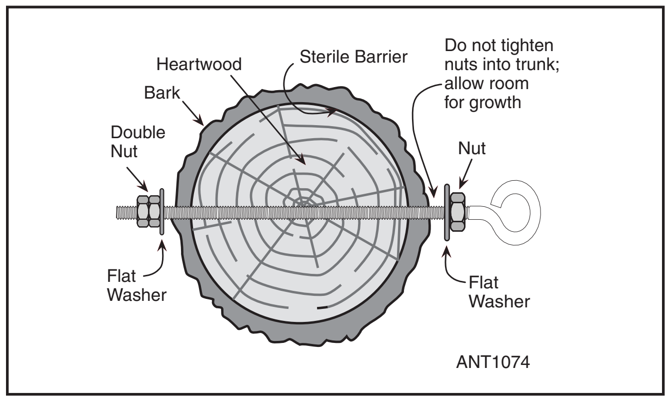


Figure 26.6 — For heavy antenna loads, an eyebolt passed through the trunk or limb will support more weight than an eye-screw. Allow about ½ inch of play between the bolt and trunk or limb. Don't tighten the bolt completely; this allows for tree growth.

permanent installations, preferably ones made from stainless or galvanized materials. Plastic parts will either break or be damaged by UV (ultraviolet) radiation from sunlight. Check your local hardware stores for inexpensive stainless steel pulleys.

Pulleys intended for marine use are excellent candidates for tree-mounted antennas but they are expensive. Years of trouble-free service offset this expense, however. Harken and Schaeffer are two brands offering quality products.

Keep in mind that with pulleys and haul ropes there should be minimal clearance between the sheave (the wheel in the pulley) and the pulley body; the rope or halyard should be larger in diameter than that clearance so it can't get jammed between the sheave and the pulley — a major annoyance. The best type of rope for this purpose is black Dacron UV-resistant line because it doesn't deteriorate when used outdoors. (See the section "Ropes and Rope Care" later in this chapter for more information.)

Have the climber go up the tree to the desired location, screw in the eye-screw, then attach the pulley. It's all but certain that the tree will have to be pruned to clear a decent window through which the line can travel. It's better to over-prune since new growth will invariably grow back in just a few years. Small branches are incredibly strong and resilient and can cause major problems in any tree project or installation.

Having brought the line along, the climber will put the line through the *back* side of the newly installed pulley (closest side to the tree), attach a weight to the end of the line, and throw it out in the direction that your wire antenna will take. The wire antenna must clear all branches to successfully install your antenna. It's very difficult to install an inverted V in a tree from the ground because it's just about impossible to get both sides of the antenna through the branches. A climber can help by throwing each leg of the antenna through the branches separately.

When the end of the line reaches the ground, remove the weight, then tie the ends of the line together, making the rope into a loop (see **Figure 26.7**). This is because in almost all cases it is the antenna that breaks, not the rope. Without the loop, when the antenna breaks the end of the support rope will be at the top of the pulley and you'll have to send someone up to retrieve it. If you have a loop system, all you have to do is pull the line down and reattach the antenna. Tie an overhand knot loop to form the antenna attachment point (this is usually an insulator) where the rope ends are tied together and you're ready to start hoisting.

In a strong wind that will get the trees swaying, you'll want to have a method that allows the trees to move without breaking the antenna. You can attach a weight of some sort (cement block, plastic milk container, a bucket with rocks, etc.) to the rope or place tension on it with an elastic cord or strap.

Tree Climbing

If you're going to climb the tree yourself, you'll need sturdy boots, hard hat, a safety belt with two lanyards and possibly tree climbing spurs. You'll need the two lanyards to leapfrog your belts around branches so that you'll be belted to the tree 100% of the time.

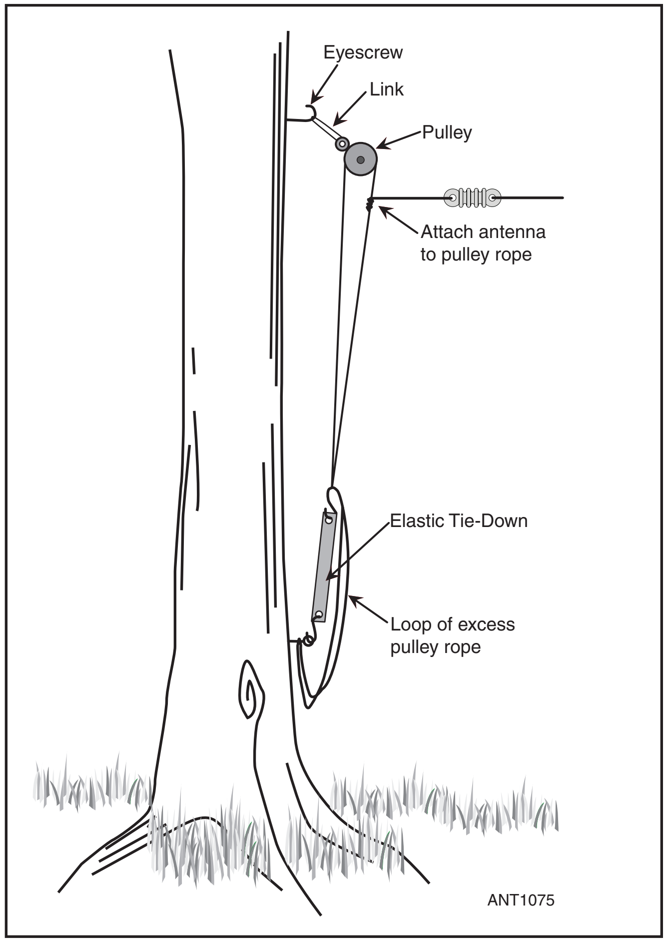


Figure 26.7 — By using a pulley, raising and lowering the antenna for repairs can be done without the need to climb the tree. Elastic cords or straps can be used to apply tension to the antenna. Loop the excess pulley rope to a second eye-screw in case the cord or strap fails.

Newer tree climbing techniques don't use steel climbing spikes as it's deemed harmful to the tree. The latest methods use a line thrown or shot over a branch and then the rope is used to climb the tree using rope ascenders like the ones used by mountain climbers and cavers. You don't even touch the trunk of the tree using this technique. The same techniques used to get a line over a branch for an antenna can be used to position a tree-climbing line.

Tree climbing has even become a recreational activity similar to the way that rock climbing has. There are clubs and resources available and you can find them online. Be sure to check out the equipment and techniques and you can learn to utilize such tools yourself.

26.2.2 GROUND-MOUNTED MASTS AND POLES

TV and Push-up Masts

Stacking TV mast is available in 5- and 10-foot lengths, 1¼ inches diameter, in both steel and aluminum. These sec-

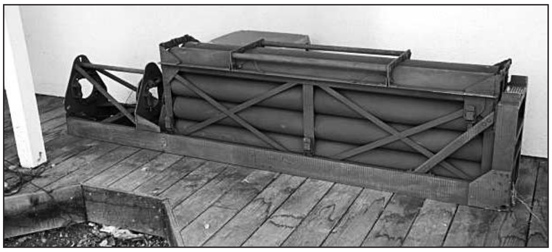


Figure 26.8 — An AB-577 temporary tower system in its transport case. (Photo by Alan Biocca, WB6ZQZ)

Figure 26.9 — Installation of surplus AB-577 tower with tribander at 45 feet at K7NV. (Photo by Kurt Andress, K7NV)

tions are swaged or crimped at one end to permit sections to be joined together. This type of mast is usually mounted on a chimney or some sort of house-mounted bracket and is not intended to be permanently guyed. This mast is suitable for VHF/UHF verticals and small beams and holding up light wire antennas for HF.

Galvanized steel push-up masts such as Rohn H30 or H40 are intended primarily for TV antennas and wireless Internet antennas. The masts may be obtained with three, four or five 10-foot sections and come complete with guying rings and a means of locking the sections in place after they have been extended. These masts are inherently more suitable for guyed mast installations than the non-telescoping type because the diameters of the sections increase toward the bottom of the mast. For instance, the top section of a 50-foot mast is 1¼ inches diameter, and the bottom section is 2½ inches diameter. The mast can be mounted on the ground or on a roof.

While tricky to install (each 10-foot segment must be guyed separately while pushing the mast up section by section), they can provide years of reliable service if not overloaded with anything larger than small VHF/UHF beams and verticals or HF wire antennas. If you are unfamiliar with push-up masts, a local TV antenna installer can perform the actual installation quickly and properly. They cannot be climbed and must be lowered to work on the antennas. Do not attempt to "walk up" these masts when extended.

Push-up masts are available from numerous sources but the shipping cost often exceeds the cost of the mast. These masts can be ordered online (search for antenna, pushup and mast), through hardware stores and from TV antenna installers.

AB-577/GRC Masts

The AB-577 mast is an all-aluminum mast kit available primarily as military surplus. It is designed to be field deployed by one or more people and does not require a prepared surface or foundation of any kind. The complete kit in **Figure 26.8** consists of a "launcher" (the base section), eight tube sections, guy wires and all hardware and tools to assemble the 50-foot mast. The standard AB-577 system, with three sets of guys, will support a modest triband Yagi at 45 feet (see **Figure 26.9**).

A total height of 75 feet is possible with the addition of the MK-806 extension kit. It's useful for any application requiring a temporary or permanent tower such as lighting, surveillance, emergency communications or RF survey work. The quick erection time also makes the mast very useful in neighborhoods where a permanently installed tower is not allowed.

The system consists of several short sections of aluminum tubing, with special end clamp connectors used to join sections. These can be erected from the base fixture, which has a crank-up type winch-driven elevator platform. The tubing sections are installed in the base fixture and connected to the section above it with an over-center locking *Marmon*-style clamp. Then, the elevator platform is raised with the winch and the new tube is locked in place, high on the base fixture. Then the elevator is lowered to accept the next section. While the tower is extended, the supporting guys are adjusted via the unique *snubber* assemblies at the anchor connection. One person can erect this system, even in windy conditions, when special care is given to keeping the guys properly adjusted during each extension.

Fiberglass Poles

Telescoping fiberglass poles have become widely available in recent years. While they are too light to support rotatable antennas, they are popular as supports for wire antennas. Primarily intended for portable use, if you decide to use one in a permanent installation make sure the surface is coated to resist UV from sunlight or paint it. There is more information on these poles in the **Portable Antennas** chapter.

Wooden Poles

A seldom-used but sturdy alternative is to use a wooden utility pole. They vary from new ones to used poles that have been pulled from service by utility companies. Make some inquiries to find out the availability and installed cost in your area. You'll need to add pole steps to climb it and may have to fabricate your own antenna mounting hardware. Pole steps are available from suppliers such as MacLean Power Systems.

The RM-2 Pole Mount from IIX Equipment (**www.w9iix.com**) can be used to attach a rotator and mast to a utility pole. Utility poles are very sturdy, require no guys, and might satisfy your use and budget.

26.2.3 MAST GUYING

Three guy wires in each set are usually adequate for a mast. These should be spaced equally (every 120 degrees) around the mast. The required number of sets of guys depends on the height of the mast, its stiffness, and the required antenna tension if supporting a wire antenna in one end. A 30-foot-high mast usually requires two sets of guys, and a 50-foot mast needs at least three sets. If supporting the end of a wire antenna, one guy of the top set should be anchored to a point directly opposite the antenna. The other two guys of the same set should be spaced 120° with respect to the first, as shown in **Figure 26.10**.

Generally, the top guys should be anchored at distances from the base of the mast at least 60% of the mast height. The separation of the guy anchors from the mast determines the guy loads and the vertical load compressing the mast. At an anchor distance of 60% of the mast height, the load on the guy wire opposite the wire antenna is approximately twice the antenna tension. The compression in the mast will be 1.66 times the antenna tension. For 80% of the mast height, the guy tension will be 1.6 times larger than the antenna load and the mast compression will be 1.25 times larger.

The largest available and practical anchor spacing should be used. Additional compression on the mast caused by closer anchor spacing increases the tendency of the mast to buckle. Buckling occurs when the compression on the unsupported spans between guys become too great for the unsupported length. The section then bows out laterally and will usually fold over, collapsing the mast. Additional sets of guys reduce the tendency for the mast to buckle under the compression by decreasing the unsupported span lengths and stabilizing the mast, keeping it straight where it best withstands compression.

A natural phenomenon, called *vortex shedding*, can occur when the wind passes over the sections of a guyed mast. For every section size, shape, and length, there is a wind speed that can cause the sections to oscillate mechanically. When all the sections of an antenna support mast are close to the same size and length, it is possible for all of the mast sections to vibrate simultaneously between the guys. To reduce the potential for this, you can place the guys at locations along the mast that will result in different span lengths. This creates different mechanical resonant frequencies for each span, eliminating the possibility of all sections oscillating at the same time.

When determining the guy locations along the mast to treat this problem, you also need to consider the mast buckling requirements. Since compression of the mast is greatest in the bottom span and the least in the top span, the guys should be placed to make the bottom span the shortest and the top span the longest. A general guide for determining the different span lengths is to make the unguyed lengths increase by 10 to 20% with increasing height.

Guy Material

When used within their safe load ratings, you may use any of the ropes listed later in the chapter for mast guys. Nonmetallic materials have the advantage that there is no need to break them up into sections to avoid unwanted resonant interactions, also discussed later in the chapter. All of these

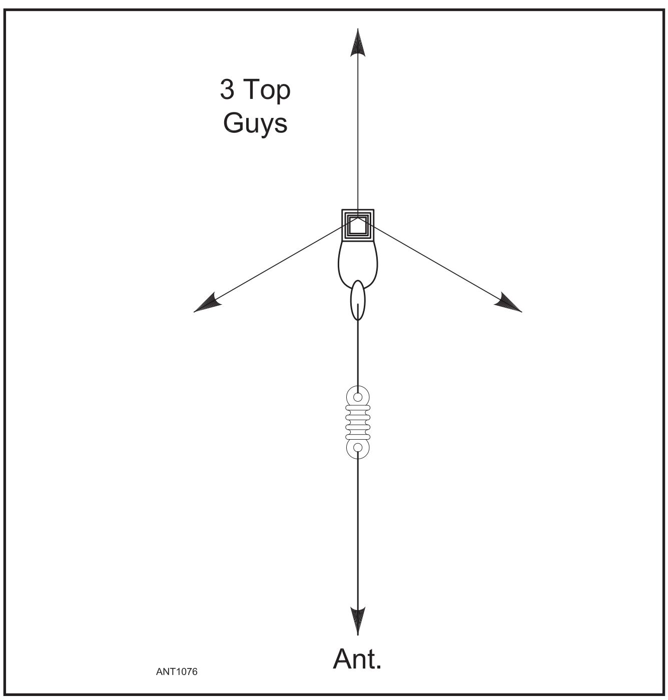


Figure 26.10 — For a mast supporting a wire antenna, the guys should be equally spaced at 120 degrees around the mast with one guy directly in line with the antenna.

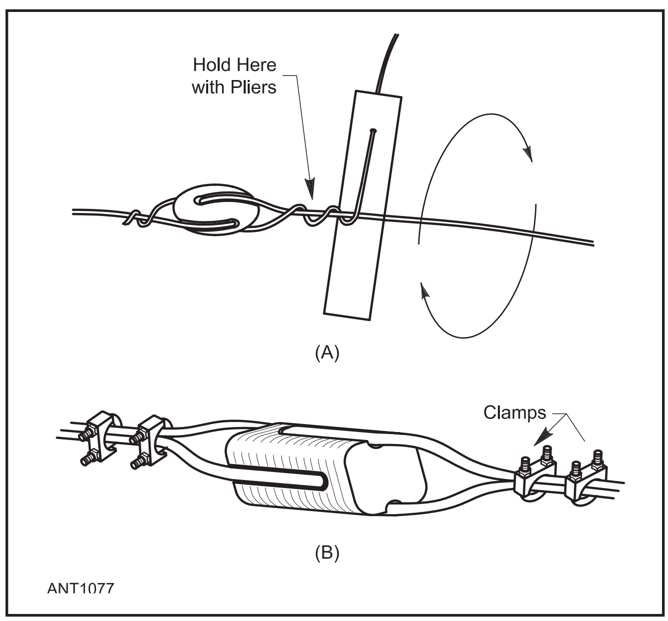


Figure 26.11 — Attaching guy wires to strain insulators. At (A) a simple lever is used to twist solid wire and at (B) standard cable clamps are used for stranded wire.

materials are subject to *stretching*, however, which causes mechanical problems in permanent installations. At rated working loads, dry manila rope stretches about 5%, while nylon rope stretches about 20%. Usually, after a period of wind load and wet/dry cycles, the lines will become fairly stable and require less frequent adjustment.

Solid galvanized steel wire is also widely used for guying. This wire has approximately twice the load ratings of similar sizes of copper-clad wire, but it is more susceptible to corrosion. Stranded galvanized wire sold for guying TV masts is also suitable for light-duty applications, but is also susceptible to corrosion. It is prudent to inspect the guys every six months for signs of deterioration or damage. **Figure 26.11** shows how to attach guy wire to strain insulators.

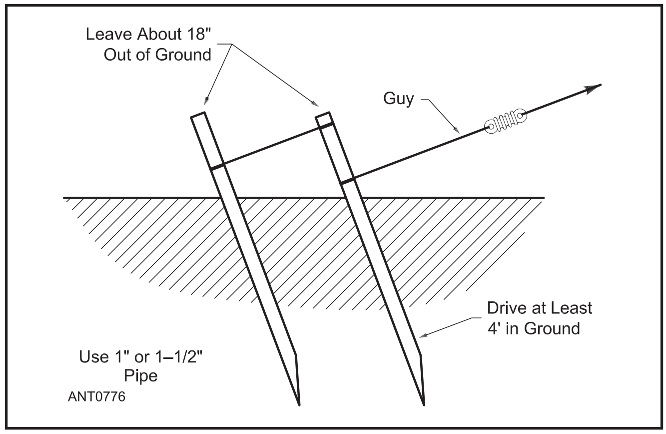


Figure 26.12 — Driven guy anchors. One pipe is usually sufficient for a small mast. For added strength, a second pipe may be added as shown.

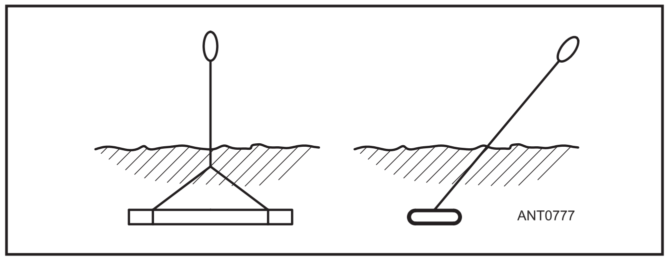


Figure 26.13 — Buried "dead-man" guy anchors (see text).

Guy Anchors

Figures 26.12 and **26.13** show two different kinds of guy anchors. In Figure 26.12 one or more pipes are driven into the ground at right angles to the guy wire. If a single pipe proves to be inadequate, another pipe can be added in tandem, as shown, and connected with a galvanized steel cable. Heavy-gauge galvanized pipe is preferred for corrosion resistance. Steel fence posts may be used in the same manner. Figure 26.13 shows a *dead-man* type of anchor. The buried anchor may consist of one or more pipes 5 or 6 feet long, or scrap automobile parts, such as bumpers or wheels. The anchors should be buried 3 or 4 feet in the ground. The cable connecting the dead-man to the guys should be galvanized wire rope, such as EHS guy cable. You should coat the buried part of the cable with roofing tar to well above the ground and thoroughly dry it prior to burial to enhance resistance to corrosion.

Heavy auger-type anchors that screw into the ground are also used and are commonly used by utilities to anchor power poles. These anchors are usually heavier than required for guying a mast, although they may be more convenient to install. You should conduct annual inspections of the anchors by digging several inches below grade around the anchor to inspect for corrosion.

Trees and buildings may also be used as guy anchors if they are located appropriately. Care should be exercised, however, to make sure that the tree is of adequate size and that any fastening to a building can be made sufficiently secure. See the section above on using trees as antenna supports regarding anchoring to trees.

Guy Tension

Many troubles encountered in mast guying are a result of pulling the guy wires too tight. Guy-wire tension should never be more than necessary to correct for obvious bowing or movement under wind pressure. Approximately 10% to 15% of the working load is sufficient. In most cases, achieving the necessary tension does not require the use of turnbuckles, with the possible exception of the guy opposite a wire antenna. If any great difficulty is experienced in eliminating bowing from the mast, the guy tension should be reduced or additional sets of guys are required. The mast should be checked periodically, especially after strong winds, to ensure the guys and anchors have not stretched or moved, allowing the mast to bend away from the required straight alignment.

In the case of rope guys, use of a "trucker's hitch" (see the section on knots) will provide much more tension than can be obtained by just pulling on the rope since it has a 2:1 mechanical advantage.

26.3 TYPES OF TOWERS

A tower is the best answer to a reliable, permanent antenna support structure and they basically come in two types — self-supporting and guyed. Beginning with the small, roof-mounted “four-footed tripod” models, amateurs use towers up to and beyond 200-foot tall broadcast-size structures. This section is an overview of various common types of towers with some of their key characteristics.

Lattice towers consist of two kinds of *members*: *legs* (often called siderails) and diagonal and horizontal *braces*. Members can either be round, such as used with Rohn G-series (**www.rohnnet.com**), or 90- or 60-degree angled metal. Round-member towers are the most common for amateur towers. The *tower face* is that outward facing area between the legs with the braces between them. Free-standing and guyed lattice towers are built of pre-assembled *sections*, usually 8 to 10 feet long, stacked on top of each other to reach some desired height. Lattice towers are constructed from steel or aluminum, with steel the most common for guyed towers. *Tubular* towers are constructed from telescoping sections of steel tubing. These are referred to as monopoles; some models rotate and can carry significant loads.

26.3.1 ROOF-MOUNTED TOWERS

The self-supporting roof-mounted tower is a modest way to support small to mid-sized antennas. This might be your first foray into a tower and directional antenna and a roof-mounted tower offers an inexpensive way to get started. Glen Martin Engineering (**www.glenmartin.com**) offers several models of four-leg aluminum towers and is a representative source of roof-mounted towers ranging in height from 4.5 to 26 feet. **Figure 26.14** shows a typical installation. Follow the manufacturer’s recommendations for installation and grounding.

A roof-mounted tower is attached to the roof with anchor bolts that extend completely through the roof. Do not use lag

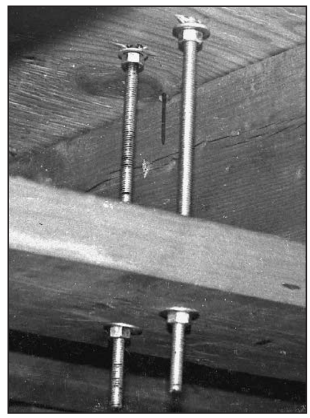


Figure 26.15 — The strengthened anchoring for the roof-mounted tower. Bolts run through the roof and through the anchor plate (2 × 6) between joists. (Photo by Jane Wolfert)

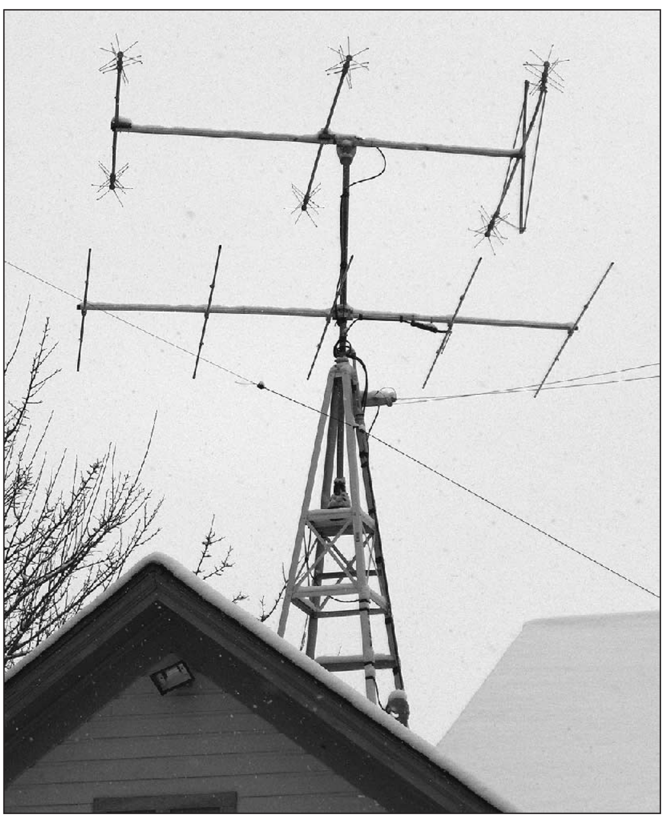


Figure 26.14 — A roof mounted tower will give your antennas a chance to get up in the air with a minimal impact and cost. (Photo by Redd Swindells, AI2N)

Figure 26.16 — Lengths of 2 × 6 on the roof act as footing for the tower legs and are coated by roofing tar to protect against weathering and prevent leaks. (Photo by Jane Wolfert)

bolts into the roof trusses. Use a 2×4 or 2×6 across the trusses inside the attic for a backing plate and attach the anchor bolts to them as in **Figure 26.15**. Another similar board can be placed on top of the roof to further distribute the load. Any wood exposed to the weather should be pressure-treated or coated with roofing tar. Roofing tar is also used to seal around the mounting bolt holes to prevent leaks (see **Figure 26.16**).

Roof-mounted antennas and structures provide practical, easy solutions to getting a directional antenna in the air, but roof mounting can be dangerous work. State and federal safety laws require fall-arrest equipment and it's highly recommended that you use it as well. A fall-arrest harness (FAH) should be attached to an anchor point on the peak of the roof. Most of these small roof-mounted supports cannot be climbed, but require a ladder support against them to provide access to the antenna.

26.3.2 SELF-SUPPORTING TOWERS

Self-supporting towers have a smaller footprint, but are generally more expensive to install. Significantly more concrete is required for the base of a free-standing tower and the amount of steel or aluminum (which ultimately determines the cost of a tower) is higher. The advantage of a self-supporting tower is that no guy wires are required. This appeals to hams without enough room for the necessary guying system and the cleaner "look" sometimes helps with aesthetic concerns.

Because there are no guys to keep them standing, self-supporting towers depend on bending strength and a large concrete base. The base is generally required to have a volume of at least five to six cubic yards, requiring significant digging and preparation. The weight of the base keeps the tower system's center of gravity low or below ground level, minimizing the overturning force from wind. The soil around the base must be solid enough to withstand the pressure from overturning forces on the tower system. If you have any questions about your ability to properly construct the base, consult a professional engineer or hire a concrete contractor.

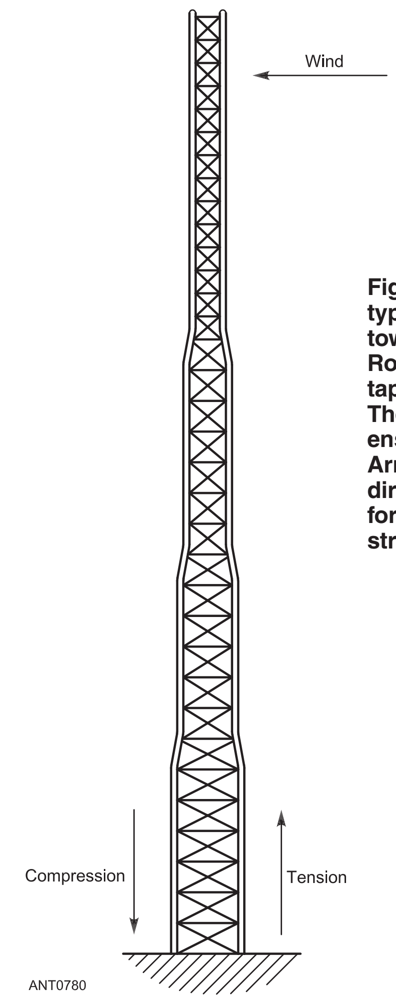


Figure 26.17 — A typical freestanding tower similar to Rohn BX. The tower tapers as it rises. The wide stance ensures stability. Arrows indicate the directions of the forces acting on the structure.

Freestanding Towers

Towers specifically designed and installed for TV antennas are at the low end of suitability for typical HF beams. TV antenna towers have a maximum height of 40 to 60 feet. The most common are the Rohn AX, BX and HDBX series and a tubular-legged type similar to but lighter than Rohn 25G. Universal Manufacturing (**www.universaltowers.com**) offers similar towers made of aluminum.

The common BX-series towers sketched in **Figure 26.17** are made from stamped steel with X-bracing of the legs. The X braces are not connected to each other and the most common failure point is between the braces. Also, the rotator and top plates are made from sheet metal and can crack from wind-induced metal fatigue. For small triband HF beams and VHF arrays they are fine, but be careful of overloading towers using the smaller stacking sections. These towers should be limited to antennas with boom lengths less than 10 feet since they have minimal resistance to torsion (twisting).

For larger antenna arrays, heavier towers are available that are designed for broadcast and commercial applications. These look much the same as the "TV antenna" towers but are made of heavier material and have heavier and stiffer bracing. The most common models of these towers are the Rohn SSV, Trylon (**www.trylon.com**), Universal and AN Wireless (**www.anwireless.com**). While significantly more expensive, they can handle very large loads, including high winds and icing conditions.

Crank-up Towers

Crank-ups are a popular type of self-supporting tower. These towers use either a motorized or manual system of cables and pulleys to extend or retract the tower. They are the most expensive tower for the height due to more materials and hardware, but satisfy many hams with limited space, or those who dislike guy wires. When cranked down, a telescoping tower can maintain a low-profile system, out of sight of the neighbors and family.

Tubular crank-ups are generally limited to a single antenna since the rotator is mounted on a plate at the top of the tower without any additional bracing. This limits the size of the antenna and how far above the rotator it can be mounted.

Lattice crank-ups generally have the same top structure as a guyed tower and can support much larger antenna and mast combinations.

US Tower (**www.ustower.com**) dominates the market for crank-ups, manufacturing good products and offering good customer support. Both lattice- and tubular-type crank-up towers are available as shown in **Figure 26.18**.

Do not use guys with normal crank-up towers (those that have no locking devices between sections)! The increased tower compression will be carried by the hoisting cable, which will eventually cause it to fail.

Tilt-over Towers

Some free-standing towers have another convenience feature — a hinged section that permits the owner to fold over all or a portion of the tower. The primary benefit is in allowing antenna work to be done close to ground level, without the necessity of removing the antenna and lowering it for service. **Figure 26.19** shows a hinged base used with stacked, guyed tower sections. Many crank-up towers come with optional tilt-over base fixtures that are equipped with a winch and cable system for tilting the fully nested tower between horizontal and vertical positions.

The hinged section can also be designed for portions of the tower above the base. These are usually referred to as *guyed tilt-over towers*, where a conventional guyed tower can be tilted over for installing and servicing antennas.

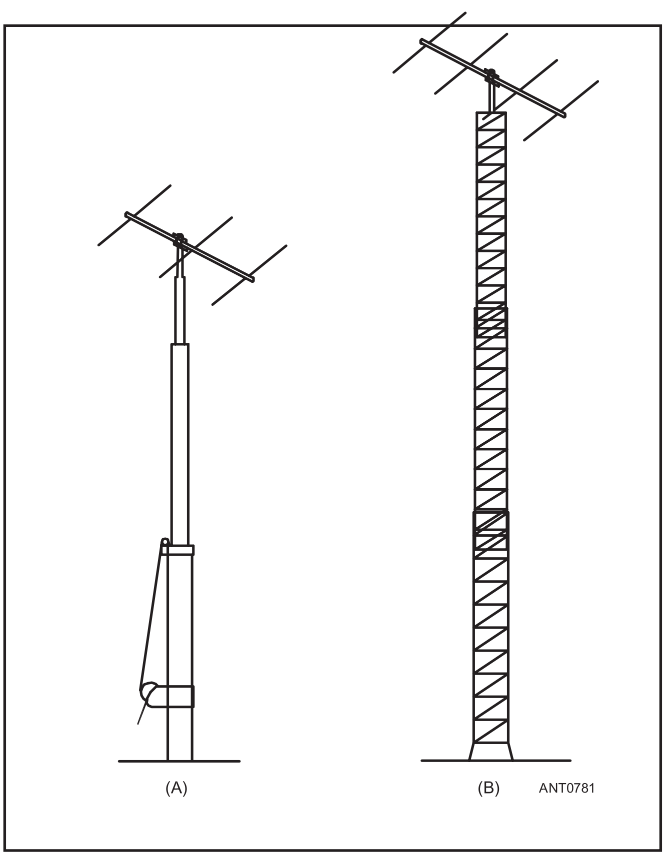


Figure 26.18 — Two examples of crank-up towers. At (A) a tubular style and at (B) a lattice style.

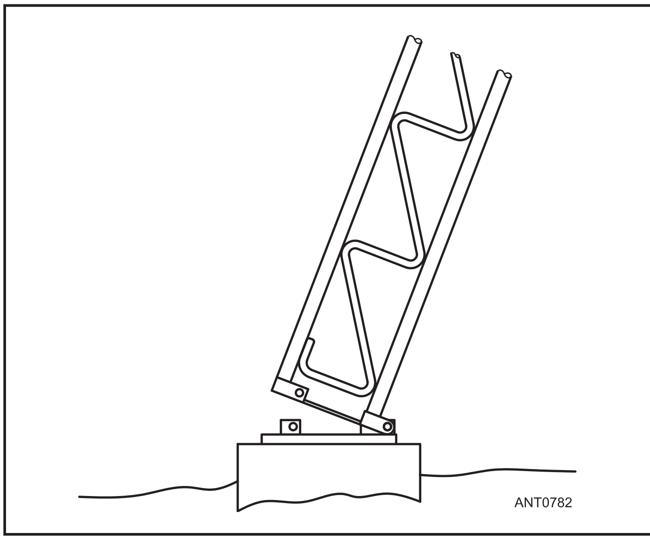


Figure 26.19 — Fold-over or tilting base. There are several different kinds of hinged sections permitting different types of installation. Great care should be exercised when raising or lowering a tilting tower.

Misuse of hinged sections during tower erection is a dangerously common practice among radio amateurs. Unfortunately, these episodes can end in accidents. If you do not have a good grasp of the fundamentals of physics, it might be wise to avoid hinged towers or to consult an expert if there are any questions about safely installing and using such a tower. It is often far easier (and safer) to erect a regular guyed tower or self-supporting tower with gin pole and climbing belt than it is to try to walk up an unwieldy hinged tower.

26.3.3 GUYED TOWERS

Guyed tubular-leg lattice towers are strong, reliable, relatively easy to erect, and have a wide array of accessories designed and intended for ham use. They are usually less expensive to install, but need a big footprint for the guying system. Since the typical recommended guy anchor distance from the tower is 80% of the height, the guys for a 100-foot tower need to be anchored 80 feet away from the tower. A set of three guys spaced 120° around the tower is repeated every 30 to 40 feet up the tower (see **Figure 26.20**).

The most widely used guyed towers for amateur applications are the Rohn 25G and 45G. They are well constructed, are hot-dipped galvanized, and have enough accessory items for any use. These towers have tubular legs and Z-bracing rods welded to the legs. The Rohn product catalog (available for downloading from the company website) provides calculations for rated wind load at various heights and all base and guying requirements.

Rohn 25G has a face width of 12 inches and a 10-foot section weighs 40 pounds. A gin pole and a ground crew is the recommended way to install these towers. A practical height limit of 190 feet at 90 MPH wind speed provides 7.8 square feet of antenna load capacity. A 100-foot tower yields 9.1 square feet of antenna capacity, enough for a small stack of monoband Yagis or a high-performance triband beam. An

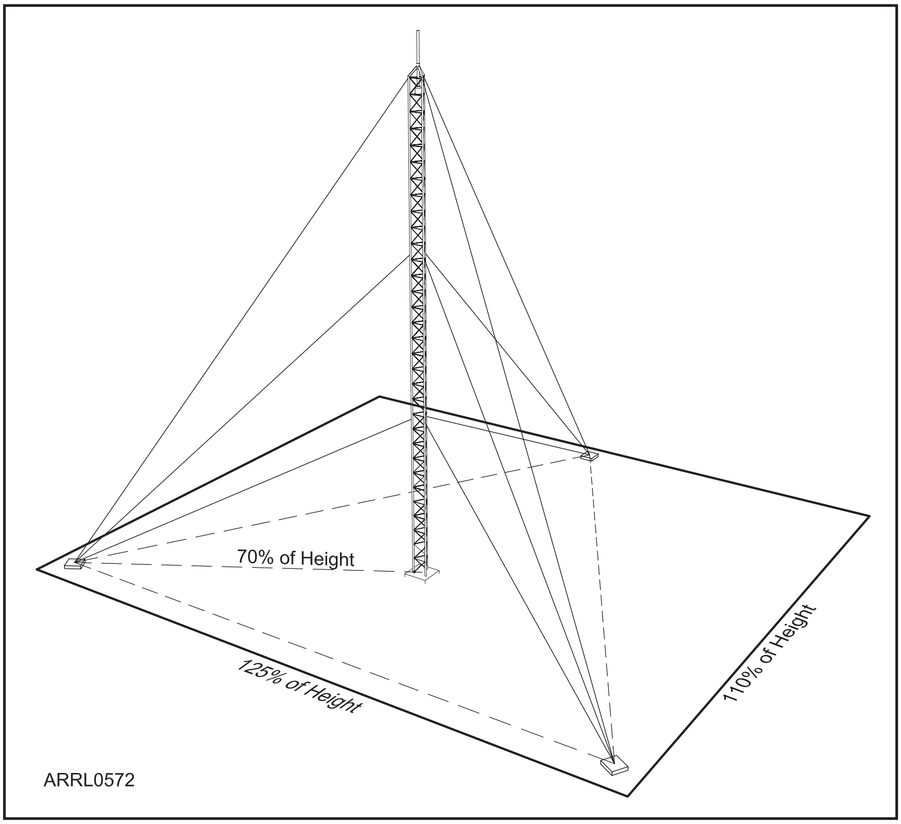


Figure 26.20 — Guyed towers are built from stackable sections that are usually identical except for the base that attaches to the concrete and the top section that supports the rotator and mast. Guy requirements are specified by the manufacturer, but spacing the anchors 70 to 80% of the tower height is typical. As seen in the drawing, the tower and guy wires do take up quite a bit of space.

experienced crew can erect up to a hundred feet a day of this popular tower.

Rohn 45G is 18 inches across the face and a 10-foot section weighs 70 pounds. This robust tower is rated up to 240 feet in 90 MPH winds, with a wind load rating of 16.3 square feet. At a height of 100 feet the wind loading is 21.5 square feet.

Rohn 55G is also 18 inches across the face, weighs 100 pounds per section, and can be installed up to 300 feet with 90 MPH wind ratings. It has a gross capacity of 17.4 square feet in that maximum configuration. The standard Rohn gin pole is not rated for 55G because of its weight.

Tubular-leg towers can also be supported by attaching them to a building with a *house bracket*. The manufacturer will specify how far above a bracket the tower can be extended without guys.

26.4 ENGINEERING THE TOWER PROJECT

Engineering in this sense means to plan, construct, or manage the practical applications of your tower project. The engineering should be done *before* you begin digging, pouring, or constructing!

The process you go through to design your system may begin with site selection ("What is a suitable location for a tower?") or it may start with selecting a tower ("What tower can I put up on this site?"). Everyone's circumstances are different.

It's not unusual to repeat the process of planning and tower selection for several iterations as you work through the various types of towers and associated costs and constraints. The important thing is to work through the various interacting issues until you are satisfied you have addressed all of them.

It is often very helpful to the novice tower installer to visit other local amateurs who have installed towers. Look over their installations and ask questions. Ask about local permitting processes and requirements. If possible, have a few local experienced amateurs look over your design plans — before you commit yourself. They may be able to offer a great deal of help. If someone in your area is planning to install a tower and antenna system, be sure to offer your assistance. There is no substitute for experience when it comes to tower work and your experience there may prove invaluable to you later.

The 10 Most Common Tower Building Mistakes

1. Not following the manufacturer's specifications

Commercially manufactured towers have to comply with current standards for wind loading and structural integrity. Engineers design the towers and make the calculations to make them safe. If you don't follow their specifications at a minimum, the tower will not take the stresses and loads to which it is subjected. In other words, it'll probably fail.

2. Overloading

This is the most common reason for amateur tower failure. You must not exceed the wind load rating. This is even more important for self-supporting and crank-up towers. While you might get away with exceeding the ratings due to built-in design margins, it's never a good idea to overload any part of the tower system. When in doubt, err on the conservative side — you won't regret it.

3. Underestimating wind forces

Wind pressure on a tower and antenna system can be tremendous. Unless you've been on a tower during a windstorm to feel the pressure and the forces, it's difficult to appreciate how significant they are. Increases in wind pressure are not linear; wind loading goes up with the *cube* of wind speed. An increase of 10 MPH in wind speed can increase the wind force by almost 50% in some cases as shown in **Table 26.A**.

4. Not building for the wind speed rating in your county

While many counties and even whole states in the US are only rated for 70 MPH winds (the minimum rating), many other counties have ratings much higher. For example, Dade and Broward counties in Florida have ratings of 140 MPH. Find out what the wind speed rating is for your county or your specific location and use that as the *minimum* wind speed design parameter for your tower and antenna system. Champion Radio Tech Notes provides the wind speed ratings for all 3076 counties (**www.championradio.com/tech.notes.html**).

5. Using the wrong mast for the job

This is an all too common failure. Stacks of medium to large HF beams can put huge stresses on your mast. Pipe may be fine for small installations where you don't have much wind speed or loading or when there is only one antenna at the top of the tower. Structural tubing is carbon alloy steel rated for strength and is the preferred material.

6. Not having the guy wires tensioned properly

Proper guy wire tension is a critical part of a tower's ability to handle wind stresses. Having the wrong tension can be like driving your car with over or under-inflated tires; it is potentially dangerous and is not the proper specification from the manufacturer. Having too little tension can result in wind slamming of the tower and guys as the tower is blown back and forth. Too much tension puts excess preload on the guys and lowers the safety margin significantly.

Around 90% of ham towers use 3/16 inch EHS steel guy wires. Guy wire tension is typically 10% of the breaking strength — in the case of 3/16 inch EHS that would be 400 pounds. The only inexpensive and accurate way to measure this is to use a Loos Tension Gauge, such as the Loos PT-2 for 3/16 and 1/4 inch wire rope sizes.

7. Not having a proper ground system

A good ground system is necessary not only for lightning protection but will also protect your equipment, your home and your life. Proper grounding is discussed elsewhere in this chapter and in *The ARRL Handbook's* chapter on safety.

8. Not doing an annual inspection

Your tower and antennas are undergoing a slow, but constant process of deterioration. The best way to find and fix small problems before they become big problems and potential calamities is by doing an annual inspection.

Look at everything and push and pull on the hardware. You also want to put a wrench on 10% or more of the tower nuts to check for tightness as well as all of the nuts on accessories like antennas, mounts, U-bolts, etc.

9. Not fitting the tower sections on the ground

Tower sections, new or used, may not fit together easily. It's much easier to correct alignment problems on the ground than up on the tower during construction. A handy tool for getting tower sections together (or apart) is the Tower*Jack Combo that combines a leg aligner along with a lever for pulling sections together or pushing them apart.

10. Using the wrong hardware

To slow the process of deterioration, use only hardware that minimizes corrosion. Galvanized or stainless steel materials are the only ones that will survive outdoor use reliably. (See the section on "Corrosion" in this chapter.)

Substituting the wrong hardware can also lead to failure, for example using general hardware store bolts for tower legs when the manufacturer calls for a specific SAE grade. Using hardware totally unsuited for the task is common, i.e. installing the wrong type of 'screw-in' anchor or anchor rods; use of non-closed-eye eyebolts (use only welded or forged ones); use of the wrong guy material (EHS only!); and more.

Table 26.A
Wind Speed and Pressure

Mean Velocity Pressure	*Wind*
50.0 MPH	10.0 PSF
60.0 MPH	14.4 PSF
70.7 MPH	20.0 PSF
86.6 MPH	30.0 PSF
100.0 MPH	40.0 PSF
111.8 MPH	50.0 PSF
122.5 MPH	60.0 PSF

26.4.1 SITE PLANNING AND PERMITTING

Local Ordinances and CC&Rs

Local ordinances, deed restrictions, and any CC&Rs (Covenants, Conditions and Restrictions) should be checked to determine if any legal restrictions affect the proposed installation. While compliance with local building regulations may be pretty straightforward, your CC&Rs may specifically rule out any type of outdoor structure that would make tower or antenna installation impossible.

The FCC's PRB-1 memorandum specifies that local regulations must make "reasonable accommodation" for Amateur Radio antennas and support structures, but does not pre-empt local regulations. For more information on PRB-1, consult the information at **www.arrl.org/prb-1**.

The best book for Amateur Radio tower zoning issues is *Antenna Zoning for the Radio Amateur* by Fred Hopengarten, K1VR, now in its second edition and available from the ARRL or Radioware (**www.radio-ware.com**). Fred is a telecommunications attorney and this book is filled with valuable information on legal issues. Besides covering the legal issues, it also contains many practical insights and examples of real world aspects of working with the local building departments and navigating the permitting process.

Building permits will dictate setbacks from property lines and are likely to place other constraints on where your tower can be located. For example, you may have to stay a certain distance from septic systems or buried utilities.

Safety

You must consider the safety aspects of your installation. For example, a tower should not be installed in a location where it could fall onto a neighbor's property. Imagine what would happen if your tower or antenna fell — where would it be likely to land? What could it hit on the way down? You may not be able to mitigate every possible outcome but thinking about it before construction may lead to a better plan.

The antenna must be located in such a position that it cannot possibly come in contact with power lines, either during normal operation or if the structure should fall. Consider the proximity of power lines to the tower. Safety rules dictate that all parts of a tower and antenna must remain at least 10 feet from power lines when being erected or after being installed. This is the smallest separation you should consider and a greater safety margin is strongly recommended.

Area and Access

For a guyed tower, there must be sufficient space for proper guying. The guy anchors should be between 70% and 80% of the tower height in distance from the base of the tower on level ground — sloping terrain may require larger areas (see Figure 26.20).

Erecting the tower and installing the antennas will require some space. Is there enough room to lay out a tower on a tilt-over base and how should the hinged base be oriented? Think about where antennas will be assembled and how they'll be hoisted to the top of the tower. Where will any necessary equipment need to be positioned and how will it get there?

Another part of choosing a tower site has to do with arranging for access. That is, access for base excavation and access for concrete. If you aren't sure, ask a local contractor to evaluate your site and make suggestions. They may spot something important that you've overlooked.

26.4.2 SELECTING A TOWER

The selection of a tower, its height, and the type of antennas and rotator is probably one of the more complex issues faced by station builders. All aspects of the tower, antenna, and rotator system are interrelated, and you should consider the overall system before making any decisions regarding specific system components.

Selecting a tower must be based on your requirements for what the tower must support, along with considerations such as total budget, permit restrictions, aesthetics, and the specifics of where you intend to install the tower. You should also consider the climate and your ability to maintain a tower. You may already know what general type of tower you want — self-supporting or guyed, lattice or tubular, and so on. Or you may have to select a tower based on the constraints of the available site or other factors.

One of the first things you need to determine in the tower selection process is the type of specification required by the local authorities, if any. Then, you must determine the *Basic Wind Speed* appropriate for the site. The Basic Wind Speed used in most specifications is the average wind speed for one mile of wind passing across the structure. It will be a lower value than the peak readings from an anemometer (wind gauge) installed at the site. For example, a Basic Wind Speed of 70 mph could have a maximum value of 80 mph and a minimum of 60 mph, equally distributed during the passage of the mile of wind. Basic wind speeds can be found in tables or maps contained in the appropriate specifications. Often, the basic wind speed used for the location may be obtained from the local permit authority.

Many building regulations base their specifications for maximum wind speed on TIA-222, "Structural Standard for Antenna Supporting Structures and Antennas." (TIA-222G is the latest revision as of mid-2011.) County wind speeds for all 3076 counties in the US from TIA-222 are also online at **www.championradio.com** under Tech Notes. Remember — these are the minimums and some building departments use a slightly higher figure for issuing building permits.

Add up the total square feet of antenna area (commercial antennas include area in the antenna specifications) you plan on installing. Compare that combination of wind area and your maximum wind speed rating to manufacturer specifications for the specific models of acceptable towers.

Most tower manufacturers provide catalogues or data packages that represent engineered tower configurations. These are provided as a convenience for users to help determine the most suitable tower configurations. The most commonly used design specifications for towers are the previously mentioned TIA-222 and the UBC (Uniform Building Code). These specifications define how the tower, antenna and guy loads are determined and applied to the system, and establish general design criteria for the analysis of the tower. Local authorities often require the review and approval of the installation by a state licensed Professional Engineer (P.E.) to obtain building permits. All local authorities in the United States do not subscribe to the same design standards, so often the manufacturers' general-purpose engineering is not applicable.

Determining Tower Load

Most manufacturers rate their towers in terms of the maximum allowable antenna load that can safely be carried at a specific wind speed. Ensuring that the specific antennas you plan to install meet the tower's design criteria, however, may not always be a straightforward task.

For most towers, the manufacturer assumes that the allowable antenna load is a horizontal force applied at the top of the tower. The allowable load represents a defined amount of exposed antenna area, at a specified wind velocity. Most tower manufacturers rate the load in terms of *Flat Projected Area* (FPA). This is simply the equivalent area of a flat rectangular surface at right angles to the wind. The FPA is not related to the actual shape of the antenna itself, only its rectangular projected area. Some manufacturers provide separate FPAs for antennas made from cylindrical sections and those made from rectangular sections.

In the realm of antenna manufacturers, however, you may encounter another wind load rating called the *Effective Projected Area* (EPA). This attempts to take into account the actual shape of antenna elements. The problem is that there is no agreed-upon standard for the conversion from EPA to load numbers. Different manufacturers may use different conversion factors.

Since most tower manufacturers have provided FPA figures for their towers — allowing us in effect to ignore design-specification details — it would be easiest for us to work only with FPA values for our antennas. This would be fine, if indeed we had good FPA figures for the specific antennas we plan to use! Unfortunately, FPAs are rarely specified for commercially built amateur antennas. Instead, most antenna manufacturers provide effective areas in their specification sheets. You may need to contact the antenna manufacturer directly for the FPA antenna area or for the antenna dimensions so that you can do your own FPA calculations as discussed in **Appendix A** of this chapter.

26.4.3 DESIGNING THE GUYS

The configuration shown in **Figure 26.21A** is taken from an older (1983) Unarco-Rohn catalog. This configuration has the top set of guys placed at the top of the tower with the lower set halfway up the tower. This configuration is best for most amateur installations, which usually have the antennas mounted on a rotatable mast extending out the top of the tower — thereby placing the maximum lateral loads when the wind blows at the top of the tower (and the bottom of the rotating mast). This configuration can limit the ability to easily tram and install antennas on the mast, or at the tower top, but will work fine for one's first tower installation.

The configuration shown in Figure 26.21B is from the current Rohn catalog (Catalog 2). It shows 5 feet of unsupported tower extending above the top guy set. The lower guy set is approximately halfway between the top guys and the base. The newer configurations are tailored for commercial users who populate the top region of the tower with fixed arrays and/or dishes. The installation in Figure 26.21B cannot

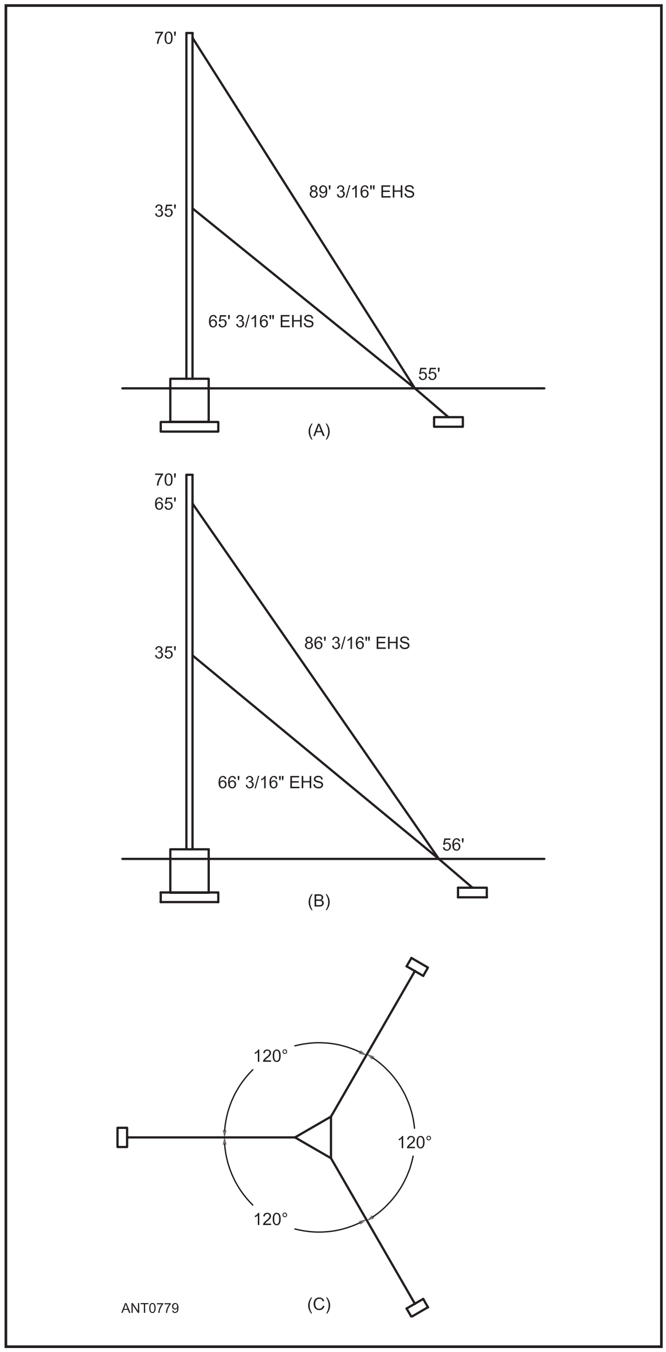


Figure 26.21 — The proper method of installation of a guyed tower. At (A) is the method recommended for most amateur installations. At (B), the method shown in current Rohn catalogs that places considerable stresses on the top section of the tower when large antennas are mounted above the tower (see text). (C) shows the recommended orientation of guy wires, symmetrically spaced around the tower.

safely withstand the same amount of horizontal top load as can the configuration shown in Figure 26.21A, simply because the guys start farther down from the top of the tower.

An overhead view of a guyed tower is given in Figure 26.21C. Common practice is to use equal angular spacings of 120° between guy wires. If you must deviate from this spacing, the engineering staff of the tower manufacturer or a civil engineer should be contacted for advice.

Amateurs should understand that most catalogs show generic examples of tower configurations that work within the cited design specifications. They are by no means the only solution for any specific tower/antenna configuration. You can usually substantially change the load capability of any given tower by varying the size and number of guys. Station builders are encouraged to utilize the services of professional engineers to get the most out of their guyed towers.

26.4.4 DESIGNING THE BASE

Tower manufacturers can provide customers with detailed plans for properly constructing tower bases. **Figure 26.22** is an example of one such plan. This plan calls for a hole that is 3.5 × 3.5 × 6 feet deep. Steel reinforcement bars are tied together to form a cage and placed in the hole.

A strong wooden form is constructed around the top of the hole. The hole and the wooden form are filled with concrete so that the resultant block will be 4 inches above grade. Before it hardens, the anchor bolts are embedded in the concrete, and aligned with the plywood template. The template serves to align the anchor bolts to properly mate with the tower itself. Once the concrete has cured, the tower base is installed on the anchor bolts and the base connection is adjusted to bring the tower into vertical alignment.

For a tower that bolts to a flat base plate mounted to the footing bolts (as shown in Figure 26.22), you can bolt the first tower section on the base plate to ensure that the base is level and properly aligned. Use temporary guys or wooden braces to hold things exactly vertical while the concrete cures. (The use of such temporary guys also works well when you place the first tower section in the base hole and plumb it vertically before pouring in the concrete.) Manufacturers can provide specific, detailed instructions for the proper mounting procedure. **Figure 26.23** shows a slightly different design for a tower base.

The one assumption so far is that *normal* soil is predominant in the area in which the tower is to be installed. Normal soil is a mixture of clay, loam, sand and small rocks. More conservative design parameters for the tower base should be adopted (usually, using more concrete) if the soil is sandy, swampy or extremely rocky. If there are any doubts about the soil, the local agricultural extension office can usually provide specific technical information about the soil in a given area. When this information is in hand, contact the engineering department of the tower manufacturer or a civil engineer for specific recommendations with regard to compensating for any special soil characteristics.

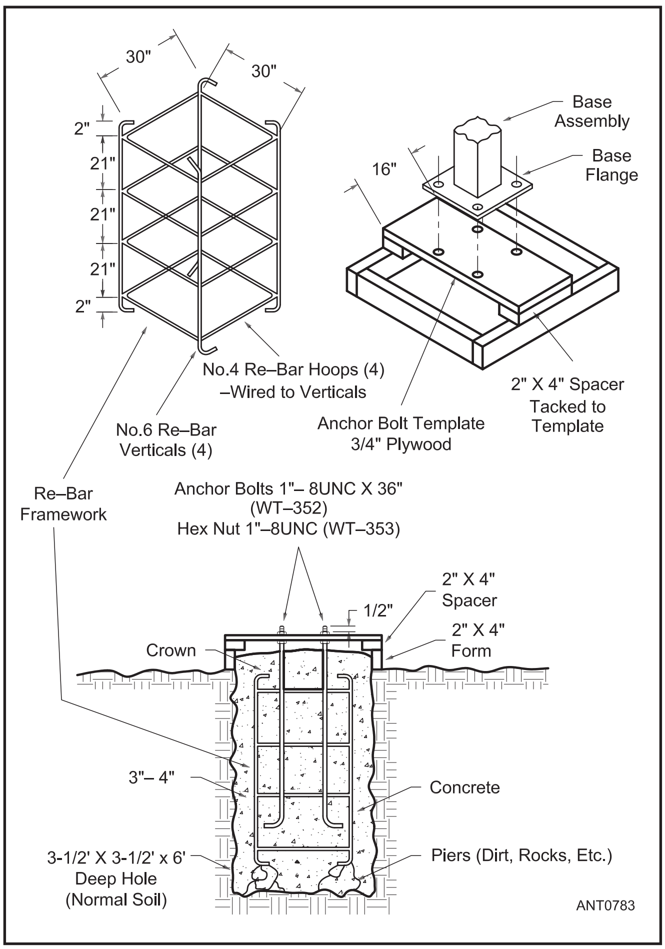


Figure 26.22 — Plans for installing concrete base for a 70-foot tubular crank-up tower. Although the instructions vary from tower to tower, this is representative of the type of concrete base specified by most manufacturers.

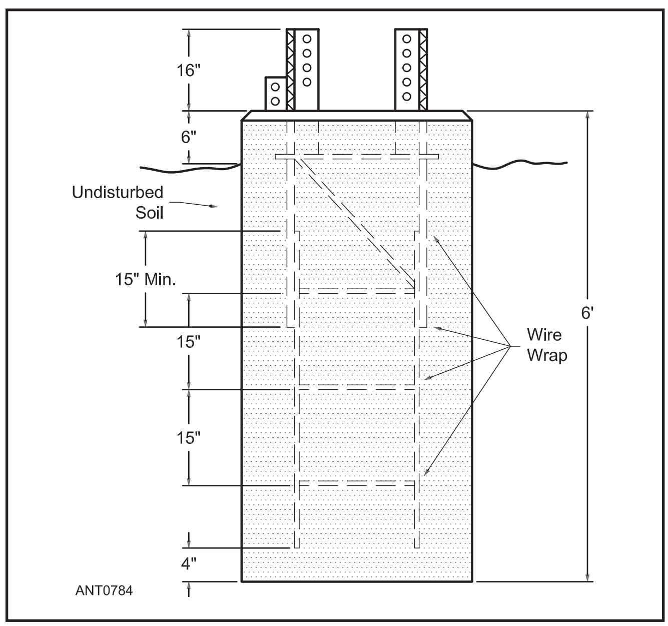


Figure 26.23 — Another example of a concrete base for a 70-foot lattice crank-up tower.

Pier-Pin Bases

An important phenomenon in a guyed tower is stretching of the guy cables. All guys stretch under load and when the wind blows the elongated guys allow the tower to lean over somewhat. If the tower base is buried in the concrete footing — as is commonly done in amateur installations — the bending stress at the tower base can become a significant factor. Towers that have been installed with tapered pier-pin bases much more freely absorb tower leaning, and they are far less sensitive to guy-elongation problems.

The tapered pier-pin tower installation is not without some drawbacks. These installations often require torque-arm guy brackets or six-guy torque-arm assemblies to control tower rotation due to antenna torque. They also require temporary guys when they are being installed to hold the base steady until the permanent guys are mounted. Some climbers also don't like the flexing when they start to climb these types of towers.

On the positive side, pier-pin base towers have all structural members above the concrete footing, eliminating concerns about hidden corrosion that can occur with buried towers. Most decisions regarding the type of base installation are made according to the preference of the tower builder/maintainer. While either type of base configuration can be successfully used, you would be wise to do the stress calculations (or have a professional engineer do them) to ensure safety, particularly when large antenna loads are contemplated and particularly if guys that can easily stretch are used, such as Phillystran guys.

26.4.5 DESIGNING THE ANTENNA MAST

The antenna mast is the pipe or tubing that extends from the top of the rotator through the top of the tower. Wind loading on the mast can be significant for large antenna systems or for antennas mounted well above the top of the tower. This requires careful selection of the mast material and is an important part of completing your tower system design. **Table 26.1** gives yield strengths for various mast materials. For all but the smallest systems, do not depend on unknown materials for this critical component!

Table 26.1
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
4130 cold worked	75,000
4340 1550 °F quench	162,000
1000 °F temper 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)

There are two types of round material used for masts — pipe and structural tubing. Pipe is commonly water pipe or conduit and has extremely limited value. Pipe is designed to carry liquids and is not rated for bending strength. While pipe may have a *yield strength* of 30,000 psi (pounds-per-square-inch), that will only accommodate small loads and wind speeds. Another problem is that the OD (outside diameter) of pipe is 1.9 inches which is smaller than the 2.0 inch ham hardware standard. Conduit should not be used as antenna mast at all except for very small antennas.

Tubing on the other hand does come in 2.0 inch sizes and is rated for strength. There are many different materials and manufacturing processes for tubing that may be used for a mast. Yield strengths range from 25,000 psi to nearly 100,000 psi. Knowing the minimum yield strength of the material used for a mast is an important part of determining if it will be safe.

When evaluating a mast with multiple antennas attached to it, special care should be given to finding the worst-case condition (wind direction) for the system. What may appear to be the worst load case, by virtue of the combined flat projected antenna areas, may not always be the exposure that creates the largest mast bending moment. Masts with multiple stacked antennas should always be examined to find the exposure that produces the largest mast bending moment. The antenna flat projected areas at 0° and 90° azimuths are particularly useful for this evaluation.

A manual procedure for determining the mast bending stress is available in **Appendix B** of this chapter. There are also several online calculators and the *MARC* (Mast, Antenna and Rotator Calculator) program is available from Champion Radio Products for a modest price. If you have any doubts about the strength requirements for your antenna mast, consult a professional installer or engineer.

The often-asked question, "How much mast should be inside the tower?" is certainly important. A good rule-of-thumb is to have ⅓ of the total mast length inside the tower. When selecting the length of the mast, allow for four feet or more of mast extending above the top of the highest antenna on the tower. This extra mast can then be used as a gin pole/pulley attachment point for other antenna or tower work.

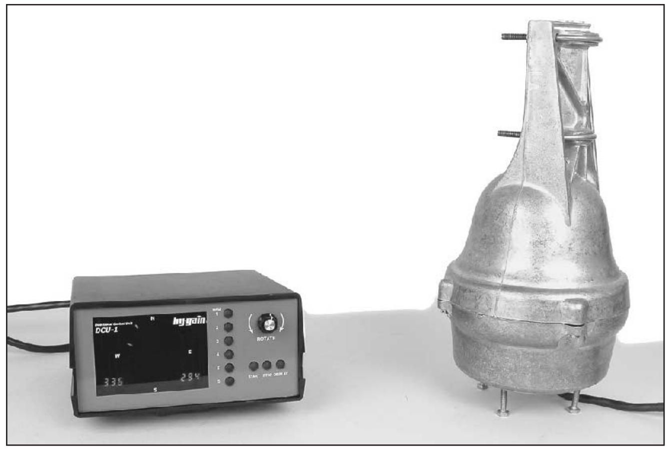


Figure 26.24 — This Ham-V model uses a DCU-1 digital controller.

Figure 26.25 — The accessory shelf in a Rohn 25G top section is pre-drilled with a standard Ham-IV rotator bolt pattern. Note the terminal strip for rotator connections.

26.4.6 ROTATORS

Rotators (not "rotors") are electric motors with sturdy gear trains and bearings in a weatherproof housing. They are used to turn directional antennas attached to a mast sitting directly on the rotator. A control unit in the ham shack allows the operator to turn the antenna. Allow plenty of margin for rated wind load when selecting a rotator — this will improve reliability. A table of rotator specifications is available on this book's CD-ROM.

Light-duty TV antenna rotators can handle loads such as small VHF and UHF antenna systems but only have minimal torque and little or no braking capability.

Medium-duty rotators such as the Hy-Gain Ham-V in **Figure 26.24** have the largest array of choices available. Some use a conventional circular gear train and a solenoid-controlled brake. Several use worm gear drive which has the advantages of fewer gears in the gear train, a significant gear reduction ratio, and do not require a separate brake, all of which improve reliability.

Heavy-duty rotators come in several configurations, from larger amateur rotators to surplus "prop pitch motors" to commercial versions capable of handling extremely large antenna systems. Prop pitch rotators are military surplus motors that varied the pitch of the propellers in propeller driven aircraft. They have tremendous torque and worm gear drive. They require special control boxes and sensors for use as antenna rotators, but are extremely powerful and reliable.

Light and medium-duty rotators can be mounted on top of a mast or tubular crank-up tower with the antenna sitting directly above the rotator but this limits them to turning one mid-sized antenna. Lattice towers designed for ham radio use have shelves or plates for a rotator (see **Figure 26.25**) and a bearing plate or sleeve at the top of the tower for supporting the antenna mast against horizontal loads. This support allows the rotator to turn much larger antenna systems to the limits of its torque specifications.

Antennas can also be mounted along a tower and rotated with an orbital or ring rotator. These rotators hold the antenna in a carriage mounted on a circular track that clamps to the tower. Ring rotators are available from several vendors.

Thrust Bearings

A thrust bearing is mounted at the top of the tower and the antenna mast passes through it to the rotator. The thrust bearing clamps the mast and supports the weight of the antenna system, leaving the rotator to handle the torque load without carrying any weight. Except in unusual circumstances, this is unnecessary since rotator bearings are designed to operate properly at full vertical load. A substitute for an actual thrust bearing is a bushing of heavy plastic or wood that supports a collar clamped to the antenna mast.

Do not use machine shop type pillow-blocks for thrust bearings. They are not intended to be exposed to the weather and will quickly rust solid. Use only outdoor grade (Rohn, galvanized, etc.) thrust bearings.

26.5 TOOLS AND EQUIPMENT

Any job anywhere is easier and safer if you've got the right tools and tower work is no exception. If you are a weekend mechanic or handyman, you've probably already got most of what you need; all you need to do is add a few specialized items and you're good to go. If, on the other hand, all you have is a hammer, pair of pliers and a screwdriver, you'll need to make a trip or two to the tool store before you can really do anything. Once you have them, you'll be all set whenever any of your friends need help on their tower, too. Have the right tools and be prepared; you'll never go wrong.

26.5.1 THE TOWER TOOLBOX

Most amateur tower and antenna work can be done with a minimum of hand tools. Nut sizes of 7⁄16, ½ and 9⁄16 inch are the most common wrench sizes needed. **Table 26.2** lists the tools necessary for building and working on a typical ham tower. Your club may have a gin pole or guy wire tension gauge for members to borrow or you may be able to rent one.

Table 26.2
Essential tools

1	set of combination wrenches: 7⁄16, ½ and 9⁄16 inch
1	set of sockets 3⁄8 inch drive
1 each	deep sockets: 7⁄16, ½, 9⁄16 inch
1 each	screwdrivers (blade and Phillips)
2	adjustable pliers
1	diagonal cutter
1	razor blade utility knife
2	pulleys
1	drift pin or centering punch (for lining up tower sections)
1	hammer (attach some line for hanging on the tower)
3 each	adjustable wrenches — small, medium, and large
1	bubble level
6	carabiners
6	one-inch nylon webbing slings — 2 feet long
250 ft	rope (or more — this is enough for working on a 100 ft tower)
1	canvas bucket (for parts hauling and storage)
1	Loos PT-2 Tension Gauge
1 set	nutdrivers
1 (or more)	come-along or hand cable winch
1 (or more)	cable grips
1	circular saw with aggregate blade or hand grinder (for cutting metal, including guywires)
1	tag line (¼ inch is fine — you chose the size and length)
1	cordless ½ inch drill, with assorted bits and socket driver, 18 V recommended
1	set drill bits including step-drill, e.g. Uni-Bit
1	antenna analyzer
1	gin pole
1	soldering gun and solder

26.5.2 SPECIALIZED TOWER TOOLS

Come-alongs

A come-along or hand cable winch, is very useful for pulling tower sections together, tightening tramlines and tensioning guy wires. You'll probably find more uses for it. Cheap ones cost $15-20 and are fine for occasional use. The best ones for tower work have spring-loaded safety latches over the end of the hooks, and very rugged (not stamped) ratchets and pawls.

Cable Grips

The cable grip in **Figure 26.26** complements the come-along to tighten guy wires. It is a spring-loaded device that slides up the guy wire but clamps down when you put tension on it. Klein is the primary supplier of cable grips and they come in lots of sizes and designs for use with various materials. For amateur use, the Klein 1613-40 is for 3⁄16 and ¼ inch EHS guy material — used on the majority of amateur towers. If you have three come-alongs and cable grips you can put initial tension on a full set of three guy wires at the same time.

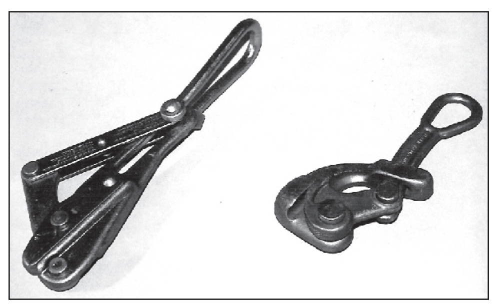


Figure 26.26 — Klein Chicago cable grip on the left and Klein Haven's grip on the right.

Steel Cutter

A portable (6.5-inch) circular saw with a steel-cutting aggregate blade will work to cut EHS guy wire, well, as will a 4-1/2 inch hand grinder with 1/8-inch steel-cutting blades. Always use safety goggles when cutting metal!

Gin Pole

The purpose of a gin pole (see **Figure 26.27**) is to provide a support point high above the top of the tower for lifting and positioning an object. This allows the necessary work to be done on the object without whoever is doing the work having to support its weight at the same time. The Rohn gin pole (Rohn Erection Fixture EF2545) is rated for sections of Rohn 25G and 45G and comes with clamps to secure it to a leg of the assembled sections. Towers made of angled legs require a special gin pole — contact the manufacturer.

Typical gin pole loads are tower sections (10 feet long) and masts (6 to 22 feet long). Pick up these loads just above their balance point so they will hang naturally in the correct upright position for installation. The Rohn gin pole is 12 feet long, just right for lifting a 10-foot tower section. For 20-foot masts, a 12-foot gin pole is marginal because there is barely 10 feet of working length available from the gin pole. A large

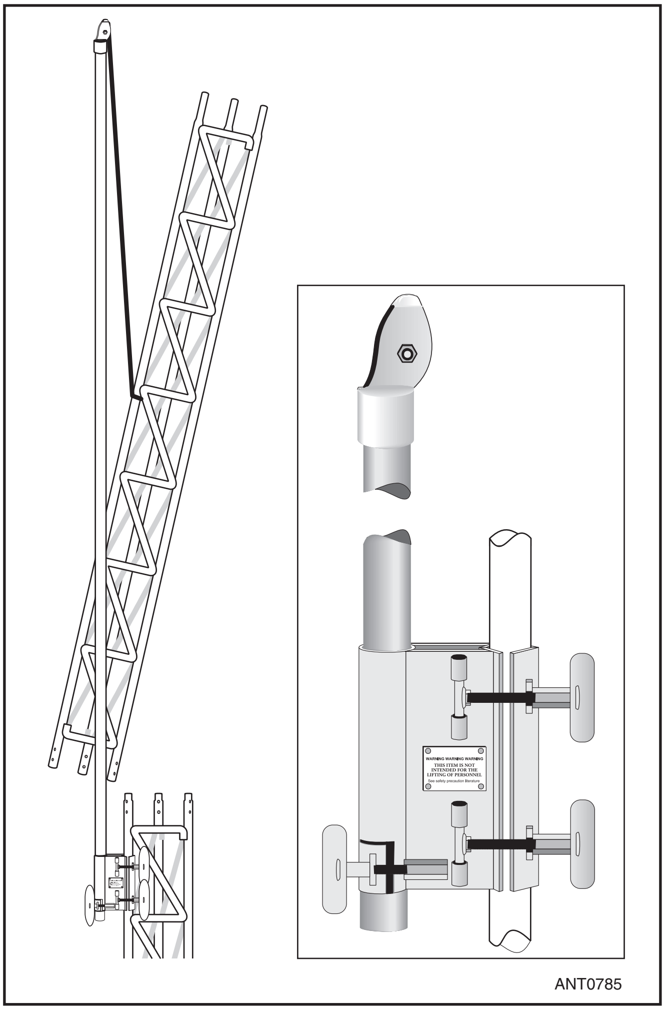


Figure 26.27 — Rohn "Erection Fixture" EF2545 also known commonly as a "gin pole."

mast will probably exceed the rating for the Rohn gin pole (rated for 70 pounds). Large, heavy-duty masts require special handling; consult an experienced tower worker for instructions on installing large masts.

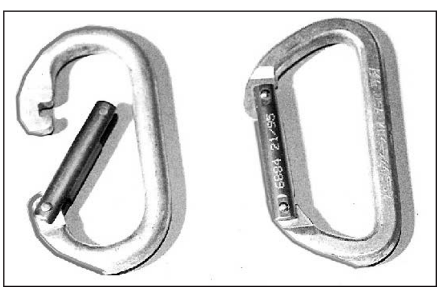
Carabiners

Carabiners are steel or aluminum snap-links with spring loaded gates as seen in **Figure 26.28A** and **26.28B**; they are invaluable for dozens of tower work tasks. A carabiner at the end of your haul rope can be attached to virtually anything that needs to be raised or lowered. A carabiner can be a third hand on the tower; you can clip a carabiner to almost anything with a rung or diagonal brace. You can instantly hang a pulley from a tower rung. Lightweight, they can be clipped on to your climbing harness for easy access. Experienced tower workers may carry twelve to fifteen carabiners on typical jobs. They typically cost $6 to $10 and will last for years with little or no maintenance. If the gate no longer opens and closes smoothly, the carabiner should be discarded.

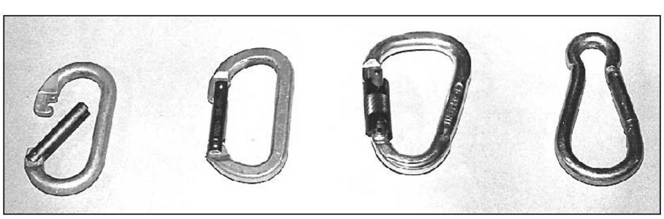
A word of caution: mountain climbing carabiners are considered to be for private use and not OSHA-approved. Current ratings for mountain climbing carabiners are typically in the 6 to 10 kN (1350-2250 pounds of force) range with the gate open and 18-25 kN (4050-5625 pounds) with the gate closed. A typical rating for an OSHA-approved commercial carabiner — called a *safety hook* — is 40kN (9000 pounds). If you don't feel that mountain-climbing carabiners are adequately rated, safety hooks are available from safety equipment vendors.

Larger carabiners are available with locking gates; these will give you an added degree of safety, particularly if you are using them for your own protection or if you just want to be doubly safe. They're only a couple of dollars more than the standard, non-locking types.

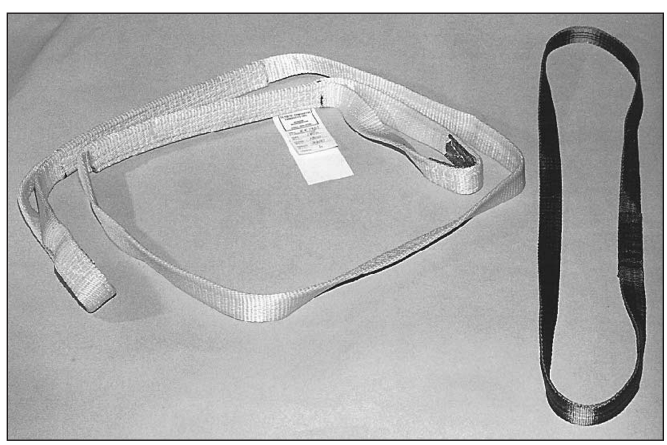
Big carabiners are used for rescue work and other applications where a wider gate opening is needed. These are sometimes called *gorilla hooks* or *rebar hooks* and are used



(A)



(B)



(C)

Figure 26.28 — (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 snap link. (C) A heavy duty nylon sling of the left for big jobs and a lighter-duty loop sling on the right for everything else.

for larger tower rungs (Rohn BX, for example) and larger loads. OSHA-compliant devices are offered by safety equipment vendors.

Using Carabiners

Here are some common ways that carabiners are used on tower projects:

1) Attach a sling to a guy anchor rod as an attachment point for the come-along when pulling guy wires.

2) Clip a carabiner onto a rung at the bottom of the tower then attach the haul rope snatch block pulley to it. This will change the direction of the haul rope from vertical to horizontal, making it much easier to pull. It also allows the ground crew workers to watch the load as it goes up or down the tower (without having to strain to look upward) and it removes them from the fall danger zone at the bottom of the tower.

3) Dedicate a sling and carabiner to the gin pole for easy lifting as the tower is assembled.

4) Put a loop through a frequently used tool, then clip it to your belt with a carabiner.

5) Always have a carabiner clipped into the bowline at the end of your haul rope and tag line for quick load attachment.

6) Clip a carabiner into the U-bolt on your rotator to haul it up.

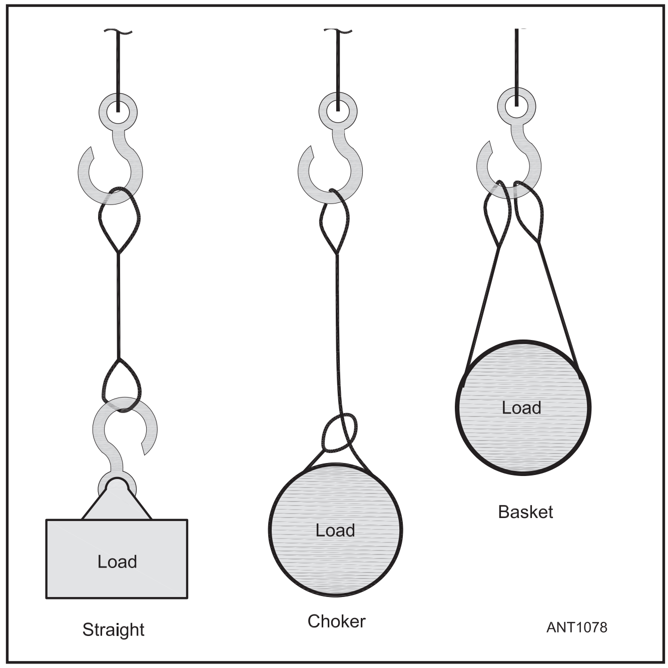


Figure 26.29 — Three basic lifting hitches used with slings and ropes.

Slings

A loop sling is made from one-inch nylon tubular webbing as seen in Figure 26.28C. Mountain-climbing slings are a continuous loop of webbing. A configuration with a sewn loop at each end is also useful. Slings can be wrapped around large or irregularly shaped objects and attached to a rope or tower member with a carabiner. Slings have around the same breaking strength as carabiners (approximately 4000 pounds, or 18.1 kN force) and are very handy for amateur applications and loads. Wrapping one around a tower rung or leg provides a convenient place to hang tools, parts or a pulley. Like carabiners, slings are not OSHA-approved but they're used for mountain climbing protection. OSHA-approved slings are available from a safety equipment vendor.

Lifting Loads with Slings

Slings are typically used in one of three rigging configurations shown in **Figure 26.29**:

1) *Straight pull* — A simple direct vertical attachment such as for a tower section. Run the sling around a tower member and clip both ends in a carabiner for lifting.

2) *Choker* — Wrap the sling around the load one or more times, insuring that you pull the loop through itself on each wrap, cinch it tight, clip it into a carabiner and pull it up. The more tension you put on the sling, the tighter it gets. Chokers are the best way to lift a mast.

A choker will work in many other cases where you have an irregular load to haul, not just masts. Using a sling as a choker reduces the lifting capacity of the sling by as much as 30% though. A U-clamp can be installed above the sling when raising a mast for redundant protection if desired.

3) *Basket* — Basket hitches distribute a load equally between the two legs of a sling. The greater the angle between the two legs, the smaller the capacity of the sling.

26.5.3 USING A GIN POLE

This section was condensed from the ARRL book *Simple and Fun Antennas for Hams*. We're going to assume in the following discussion that you are using a Rohn EF2545 to install sections of Rohn 45G, which weigh about 70 pounds.

The main working part of the gin pole is the pulley mounted at the top of the 12-foot long heavy-wall aluminum tubing. This pulley has a haul rope going down to the ground crew through the center of the aluminum tube.

An adjustable, sliding clamp toward the bottom of the aluminum tubing is clamped to the tower using a swinging L-bracket-type clamp with two clamping bolts. These have T-bar handles that can be tightened by hand. In fact, this gin pole can be moved and deployed without any tools. The clamp is positioned just below the top braces of the tower section onto which the next tower section is to be installed. Once clamped to the top of the tower, you would loosen the T-bar handle that tightens the clamp against the sliding aluminum tube and slide the tubing up to its maximum extent.

In practice, the following steps are taken as each 10-foot section of tower is installed, one-by-one. We're assuming here that the gin pole starts out on the ground, with at least one person harnessed safely at the top of the tower. We're also assuming that the haul rope has been threaded through the aluminum tube and the top pulley, with a carabiner to prevent it from falling back down the tube.

Here's a rope tip — If the wind is blowing it may be difficult to lower the end of the rope to the ground. Attach a weight to the end of the rope; a wrench works well. If added weight isn't enough, use a carabiner to clip the free end of the haul rope around the other side of the rope. The carabiner will guide the free end back down the haul rope without blowing around.

1) The clamp holding the aluminum tubing is loosened so that the pulley on the tube can be lowered to where it is just above the bottom clamp. Then the T-bar handle for the tube clamp is tightened.

2) The climber lowers a work rope for the ground crew to tie to the gin-pole pull rope. (This work rope has been looped through a temporary pulley clipped to the top of the tower. It is also used to pull up tools and other materials.) The ground crew then pulls the gin pole up to the climber, using the work rope. Once the gin-pole head reaches the top of the tower, the climber clamps the gin pole clamp securely to the top of the tower. The tag line is then removed from the gin pole.

3) The T-bar handle for the tube clamp is loosened, and the aluminum tube is extended to its maximum height, as shown in Figure 26.27. Make sure the free end of the haul rope cannot slip through the top pulley, or else you'll have to lower the gin pole and go through this step again. In other words, the climber keeps the "business end" of the gin pole rope while raising the pole.

4) The free end of the haul rope is then dropped to the ground, often using a weight to keep the rope from waving about. (See the rope tip above.)

5) The ground crew then attaches the free end of the rope *above* the balance point of the tower section. For Rohn 25G or 45G there are eight horizontal cross braces per section. The crew should attach the rope to the fifth horizontal brace from the bottom. Please remember that the tower section should hang with its bottom down so that it is properly oriented when it reaches the top of the tower.

6) Once the bottom of the tower section has been lifted to just above the top of the legs of the bottom tower section, the tower crew can guide the section down onto the top of the three legs, while calling out to the ground crew instructions about *slowly lowering* the new section down onto the legs. See **Figure 26.30**, which illustrates guiding the new section of tower onto the previous section's legs.

Figure 26.30 — Tower worker lowering a new section onto the top of the assembled stack of sections. The gin pole attached to the left leg is bearing the weight as the tower worker gives verbal instructions to the ground crew pulling on the haul rope. (Mike Hammer, N2VR, photo)

7) Once the new tower section has been guided down onto the male ends, the pinning bolts are inserted and tightened with nuts. Note that Rohn uses two different sized bolts on 25G and 45G sections, with the larger diameter bolt on the bottom.

8) Finally, reposition the gin pole for the next section of tower. The T-bar at the clamp is loosened, the tube is dropped down to the level of the clamp, and the climber walks the gin pole up to the top of the section just installed and clamps it there, ready to pull up the next tower section.

26.5.4 ROPES AND ROPE CARE

If you are going to do tower and antenna work, you'll be using ropes. The most common uses are for haul rope, tag lines or work rope and temporary guys. A *halyard* is a rope used for hoisting.

Manila

Manila is the best known natural fiber rope. Manila must be handled and stored with care as any dampness will cause it to rot and damage its effectiveness and safety.

Polypropylene

Polypropylene makes lightweight, strong ropes that float on water, are rot-proof and are unaffected by water, oil, gasoline and most chemicals. Polypropylene rope is relatively stiff and doesn't take a knot well.

Nylon

Nylon is the strongest fiber rope commercially available. Due to its elasticity, nylon ropes can absorb sudden shock loads that would break ropes of other fibers. Nylon is particularly recommended for antennas using trees as supports. A disadvantage of new nylon rope is that it stretches by a significant percentage.

Nylon has very good resistance to abrasion and will last four to five times longer than natural fiber ropes. Nylon ropes are rot-proof and are not damaged by oils, gasoline, grease, marine growth or most chemicals.

Dacron

Dacron rope comes in three sizes ($\frac{3}{32}$, $\frac{3}{16}$ and $\frac{5}{16}$ inch) and is UV resistant. This is an excellent candidate for any rope used permanently outside such as for wire antenna halyards.

Rope Lay

All rope is twisted, or laid; and nearly all laid rope is *three-strand* construction, typically what you'll find at your local hardware store. Another type of rope is known as *braid-on-braid*, or *kernmantle*. This rope has a laid core covered with a braided jacket to produce a strong, easy-handling rope. In most instances, braid-on-braid rope is stronger than twisted rope of the same material and diameter. It is available in various synthetic fibers. Marine supply stores and mountain climbing stores carry a large variety of braid-on-braid types as well as a variety of types and sizes.

Which Rope to Use

The best rope for holding up wire antennas with spans up to 150 or 200 feet is ¼-inch nylon rope. Nylon is somewhat more expensive than ordinary rope of the same size, but it weathers much better. UV-resistant Dacron rope is also popular. After an installation with any new rope, it will be necessary to repeatedly take up the slack created by stretching. This process will continue over a period of several weeks, at which time most of the stretching will have taken place. Even a year after installation, however, some slack may still arise from stretching.

For ropes to be used on tower work, first decide which size will suit your needs based on working load. Most amateur loads are less than 100 pounds and very rarely do they exceed 250 pounds. A haul rope having a working load between 100 and 250 pounds will handle just about anything. **Table 26.3** summarizes the sizes and working loads for different types of rope.

Second, choose the type and material of your rope. Polypropylene rope is stiffer and more difficult to knot than nylon. Nylon and braid-on-braid ropes are softer and will take a knot very easily. The softer ropes also coil more easily and are more resistant to kinking.

Finally, choose the length that will be most useful for you. If you double the height of your tower and add 25%, you'll have plenty. A 100-foot tower requires $(100 \times 2) + (100 \times 2 \times 0.25) = 200 + 50 = 250$ feet.

Price varies from less than $20 for 600 feet of ¼ inch polypropylene rope to more than $100 for 165 feet of high quality kernmantle climbing rope. K4ZA recommends having a variety of ropes. All are doubled-braided construction. Lengths vary from 100 feet to 600 feet. Each rope is carried and stored in simple plastic tubs, which are labeled appropriately, including dates of purchase. If you simply feed the rope loosely into its container, it will pull back out without kinking or knotting.

Make certain that the rope ends will not unravel. Most supply stores will cut the length with a hot knife; that will do the best job of sealing the ends. You can do it at home by simply melting the ends with a lighter. An alternative is to tightly wrap a few layers of electrical tape or heatshrink tubing around the ends. Be sure to tape the ends of all your ropes to protect them.

Rope Care

Inspect your rope periodically and replace it if there is any visible serious abrasion or damage. Here are some additional tips for using ropes:

1) Be certain your rope size is adequate for the job; don't use a rope that is too small.

2) Dry your rope before storing it. Natural fiber (Manila) ropes will mildew and rot if stored wet. You can put nylon ropes in the clothes dryer on low heat if they are really soaked.

3) Don't store ropes in direct sunlight; UV deterioration will significantly weaken them.

4) Cut out and discard any badly worn or abraded portions of a rope; better to have two shorter ropes you can trust than one long one that is suspect.

5) Keep your rope clean. Don't drag it through the mud, or over a rough or gritty surface. Try not to even step on your ropes, especially on wet or muddy soils.

6) Watch for kinks; they can cause permanent damage and weakening.

7) Protect ropes from all chemicals such as acids, oils, gasoline, paints, solvents, etc.

8) Avoid sudden strains; shock loading or jerking may cause failure.

9) Avoid overloading. A safe working load for a rope is 10-20% of its breaking strength.

10) Avoid abrasion. If the rope must run over a tower leg or any surface with a sharp edge, protect it with a layer or two of canvas or other such material.

11) Avoid bending a rope around corners or at sharp angles.

Table 26.3
Rope Sizes and Safe Working Load Ratings in Pounds

3-strand twisted line

Diameter	*Manila*	*Nylon*	*Dacron*	*Polypropylene*
¼	120	180	180	210
⅜	215	405	405	455
½	420	700	700	710
⅝	700	1140	1100	1050

Double braided line

Diameter	*Nylon*	*Dacron*
¼	420	350
⅜	960	750
½	1630	1400
⅝	2800	2400

26.5.5 KNOTS

You can do about 98% of your tower and antenna work with only three knots — and you already know one of them. Remember that any knot will decrease the breaking strength of the rope — usually 40% or more. Choose and use the correct rope and knots for the job, and you should have no problems. Knots not listed here and additional knot-tying know-how can be found online at Animated Knots (**www.animatedknots.com**) and Real Knots (**www.realknots.com/knots**). **Figure 26.31** shows several common knots.

Overhand Knot

Start with an overhand loop, then passing the end under and up through the loop and then tightening. To form an overhand loop in the middle of a rope, double the rope for about two feet and tie an overhand knot with the doubled rope.

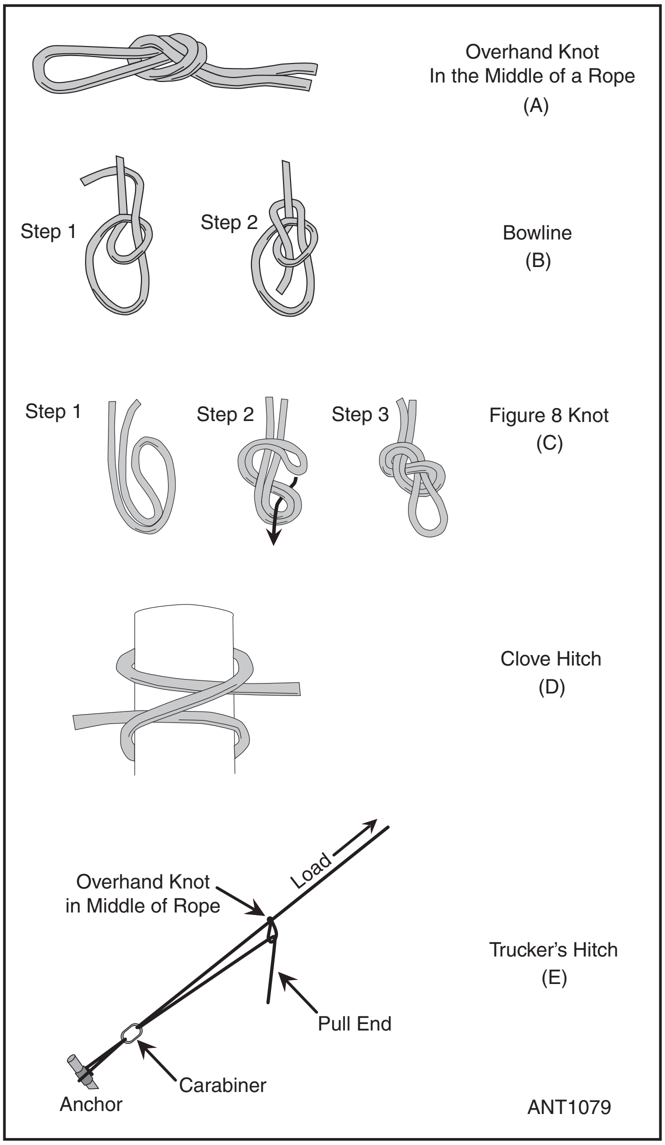


Figure 26.31 — Common knots used in tower and antenna work.

Bowline

The bowline forms a loop that will not slip or jam, yet unties easily. It is used for hoisting, joining two ropes and fastening a rope to a ring or carabiner. To tie it, form a small loop in the rope. Run the end up through the loop, behind the standing part, then back down through the loop. Pull tight. Practice this one until you can make it almost automatically.

Figure-eight

Simpler than the bowline, a figure-eight knot may be used in most situations in place of a bowline. It is tied like a doubled overhand except that the rope is twisted an additional half-turn before the knot is pulled through the loop. It is one of the few knots that can be easily untied after holding a severe impact load, such as a falling tower section. Its only disadvantage for tower work is that it is a physically larger knot, and it takes a bit more rope than a bowline.

Clove Hitch

The clove hitch can be invaluable when you're working with round objects, and it can be put on or around almost any object very quickly.

Truckers' Hitch

The trucker's hitch allows you to tighten the rope as much as you can without a come-along. Tie an overhand loop (see above) toward the load end, run the end of the rope through a carabiner or shackle at a convenient anchor point, pass the end through the loop and then pull to tighten the rope. This technique gives twice the mechanical advantage of pulling on the single rope.

Plastic Line

For types of plastic line that are too slick to hold common knots well, **Figure 26.32** shows a more suitable knot. Needless to say, these lines should probably not be used for lifting loads or holding climbers.

26.5.6 PULLEYS

Pulleys are used constantly in tower and antenna projects. One should always be placed at the top of the tower for a haul rope to bring up materials. Steel pulleys costing $25-35 are found in many hardware stores or rigging shops but are heavy. Both K4ZA and K7LXC recommend lightweight nylon pulleys used by utility company line crews for tower work. Wood-sheathed pulleys used in "block and tackle" devices and for sail hoisting should work well for very heavy loads. K4ZA prefers lightweight (aluminum) pulleys designed for "rescue" work. These can be placed on the line at any point, and have load ratings comparable to carabiners as well.

Two important things to consider when shopping for pulleys are sheave size and sheave clearance. A sheave is the pulley wheel with a groove in it. A two-inch diameter sheave is the minimum size to use and larger sizes are better. Use a

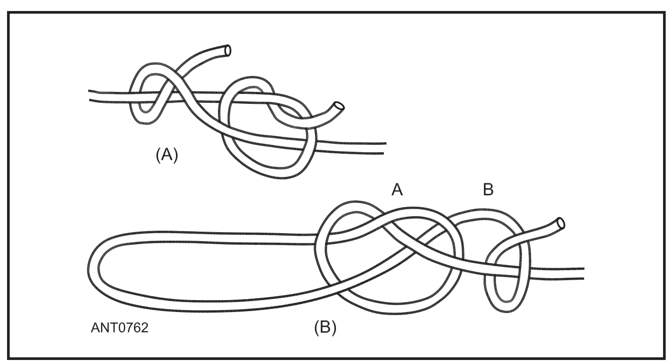


Figure 26.32 — This is one type of knot that will hold with slick types of line. Avoid these types of lines for lifting or safety uses. Shown at A, the knot for splicing two ends. B shows the use of a similar knot in forming a loop, as might be needed for attaching an insulator to a halyard. Knot A is first formed loosely 10 or 12 in. from the end of the rope; then the end is passed through the eye of the insulator and knot A. Knot B is then formed and both knots pulled tight. (courtesy Richard Carruthers, K7HDB)

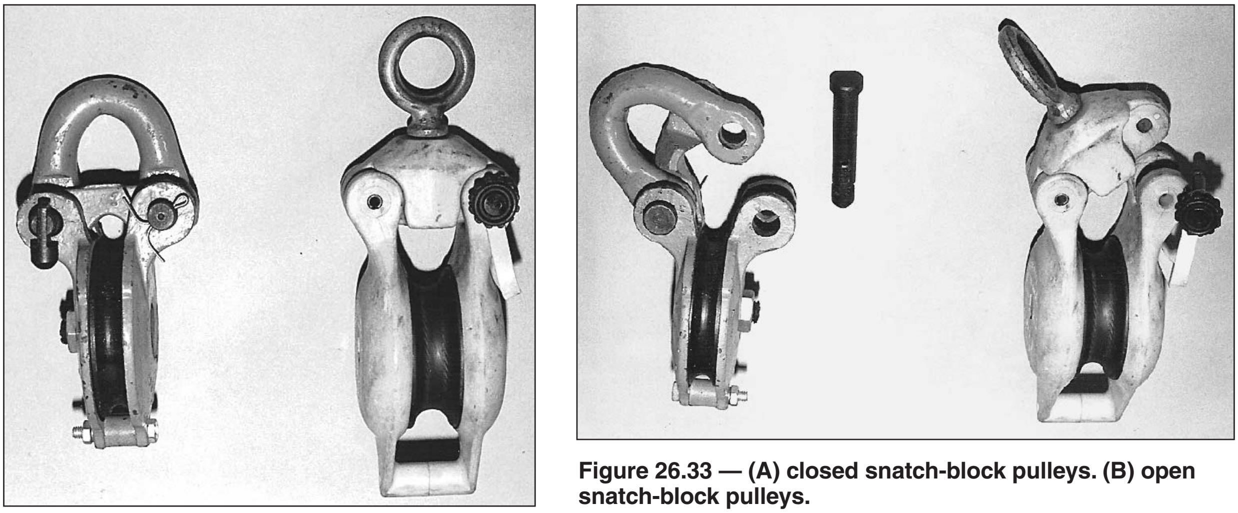


Figure 26.33 — (A) closed snatch-block pulleys. (B) open snatch-block pulleys.

jam-proof pulley with minimal clearance between the sheave and the pulley body. If there is any way for your haul rope or cable to jump the pulley and get jammed, it almost certainly will.

A *snatch-block* is a pulley with a body that opens up so that it can be placed directly anywhere on a rope without needing one end of the rope to be free. This is useful when the rope is under tension (see **Figure 26.33**).

For supporting wire antennas, avoid small galvanized pulleys designed for awnings and clothesline pulleys. Use heavier and stronger pulleys intended for outdoor and marine installations with good-quality bearings.

An important consideration for pulleys to be constantly exposed to the weather is corrosion resistance. Use a good-quality pulley made entirely of alloys and materials that do not corrode readily. Galvanized pulleys will quickly rust. Marine pulleys have good weather-resisting qualities since they are usually made of bronze but they are comparatively expensive and the smaller pulleys are not designed to carry heavy loads.

26.6 TOWER CONSTRUCTION

Now that you have done all the planning and purchased the materials, it's time to start "growing" your tower. We'll start at the bottom!

26.6.1 THE LXC PRIME DIRECTIVE

After working on more than 225 Amateur Radio tower and antenna systems over the last 20 years, Steve Morris, K7LXC, has seen many problems and failures that could have, and should have, been avoided. By avoiding these mistakes, your tower and antenna system will be safer and more reliable. You'll sleep better when that big storm blows through, too.

When it comes to tower construction, you are strongly advised to always observe the 'LXC Prime Directive; that is, to "DO what the manufacturer says." Similarly, "DON'T do what the manufacturer doesn't say to do." Follow the specifications for materials, concrete and wind load and you'll minimize the chances for failure, small or large. Follow the directions for assembling equipment and using tools and supplies. Professional engineers have designed every aspect of these systems for safe, long-term and reliable use and it's in your best interests to follow their specifications and directions. Pretty straightforward and simple to follow advice. K4ZA observes that there are many situations where nothing matches or is covered by the directions. In cases like these, either carefully devise a plan or seek professional advice.

26.6.2 BASE EXCAVATION AND REBAR

To avoid underground utility lines, please don't dig without calling one of the utility locator services. There are several websites such as **www.call811.com** that can help or you can call your local utility for assistance. Avoid expensive and embarrassing surprises. It may even be illegal in your area to begin digging without determining the location of buried utilities!

Hand-digging the hole for a large self-supporting tower base entails a lot of work! Excavating the necessary hole can be done quickly and effectively by a professional contractor. You can also rent excavating equipment and do the job yourself. No matter how you dig the hole, extreme caution should be used when someone is in the hole due to the risk of wall collapse. Many building regulations make it illegal to be in a hole or trench more than 4 feet deep without shoring up the sides of the hole. If you're doing the work yourself, never work alone in a hole that is deeper than your waist.

Building a Rebar Cage

Once the hole is dug you'll be installing the reinforcing bar, or rebar. The tower manufacturer will provide a recommended design for the rebar "cage" in the concrete base. **Figure 26.34** shows a typical completed cage.

Rebar is sized in eighths of an inch. For example, #4 rebar is 4⁄8 of an inch, or ½ inch, and #6 rebar is 6⁄8, or ¾ inch. Rebar vendors will cut and bend the rebar to your order which is a lot easier than buying long lengths of it at your local hardware store and trying to cut it yourself.

You can either build the rebar cage on the ground or in the hole. You'll need a backhoe or other piece of equipment to lift the completed cage up and lower it into the hole. Building the cage in the hole is harder since room to work is really restricted. Remember to shore up the hole and don't work by yourself.

To tie the rebar together to form the cage use bailing/tie wire at each joint. Take about 2 feet of bailing wire and bend it in half. Wrap the tie wire through one of the Xs of the joint twice. Next wrap it twice through the other axis of the joint, bring the ends together and wrap them together several times. Use a large pair of pliers, or a wire tie tool, to twist it until snug. To stiffen the cage, add an X cross brace, using two pieces of rebar across each face.

Guy anchors are easy to deal with since they're smaller, take less concrete and you don't have to move as much soil. The easiest way to locate the anchors is to temporarily put up a tower section at the desired location and then sight through each face across the opposite leg — that'll give you the angle. Then run your measuring tape out the appropriate distance to the anchor location. A more accurate way of measuring is to use a transit, which will ensure each guy anchor is spaced exactly 120 degrees apart. Suitable transits can be rented quite reasonably.

Once the rebar cage has been placed in the hole, a wooden form surrounding the top of the base hole provides for a neater appearance and also raises the top of the base above ground a few inches. This allows water to run off the base and not pool around the legs or bolts of the tower.

Figure 26.34 — The rebar cage for KX8D's tower base. (Duane Durflinger, KX8D, photo)

Installing the Base Section

If you're installing a guyed tower such as Rohn 25G or 45G with tubular legs, be sure to put 4 inches or so of crushed stone at the bottom for drainage and set the legs of the base in the gravel. Water will condense in the legs, and if there's no place for the water to drain out, it will build up and split the leg when it freezes.

Place the base section, if used, in the hole without touching the rebar cage and use wooden braces to hold it precisely vertical. Alternately, you can join one of the tower sections to the base section and use temporary guys to hold it up. For bigger tower bases, it's sometimes convenient to attach the leg(s) to the rebar cage with tie wire. A properly constructed rebar cage will be strong enough to support it and you can stand on it if needed.

If anchor bolts are being used, a piece of plywood with the proper hole pattern can be used to hold the bolts in position while the concrete is being poured.

26.6.3 CONCRETE FOR BASES

The tower manufacturer will specify the type of concrete required for the base and your building permit may also impose some requirements. The strength specification is generally 2500 to 4000 PSI for tower bases and a slump (a measure of the concrete's workability) of 4. Consult an engineer if you are unfamiliar with ordering or working with concrete. The Wikipedia entry for concrete (**en.wikipedia.org/wiki/Concrete**) provides a great deal of good information.

You can mix the concrete yourself by using bags of premixed concrete and a powered mixer. It takes about 45 80-pound bags of concrete mix to make one cubic yard of concrete so for large bases ordering ready-mix concrete is more practical. The delivery truck will need to be relatively close to the hole (within 10 to 15 feet) to be able to position the delivery chute properly. If the truck cannot get close enough to the hole, you'll have to move the concrete yourself.

To avoid moving tons of concrete (a yard of concrete weighs about 4000 pounds!) in long runs to the hole with a wheelbarrow, use a concrete line pumper — a truck-mounted pump that uses 3-4-inch hoses laid on the ground for concrete distribution. They're not that expensive and can pump up to 400 feet. There are big hydraulic boom pumpers that can work over obstacles such as buildings and fences, and much greater distances, but they are more expensive to hire. In either case, using professional equipment makes the job of moving tons of concrete much easier.

Concrete takes a long time to cure to its rated strength — at least three weeks until it reaches 90% of its rated strength. The concrete supplier can give you complete instructions on how long to wait and whether the concrete needs to be kept damp during the curing period or any other special treatment. It's hard to sit and wait a month before beginning work on the tower but be safe and don't put any load on the base until it is ready to support it. Your building permit may require inspection of the base before tower work can begin.

26.6.4 WORKING WITH GUY WIRES

Guy wires are the heart of a reliable guyed tower system. Almost any tall amateur tower is going to be guyed. Rohn 25G, 45G and 55G are the most common towers used by amateurs and they all need to be guyed. Before you begin building the tower, familiarize yourself with guy wires and the associated equipment, hardware and techniques. Practice until you are confident of being able to handle guy wires correctly.

Guy Wire Grades

Steel guy wire comes in several different grades. Rohn specifications call for EHS (Extra High Strength) cable exclusively. As you can see from **Table 26.4**, this is the strongest steel cable available.

Guy Wire Terminations

The three most common methods of terminating guy wires are to use cable clamps, swaged or crimped pressed fittings, or preformed guy grips. With the advent of the Preformed Guy Grips, cable clamp and swage fitting use has declined dramatically.

Cable Clamps

The least expensive and most common cable fittings are cable clamps consisting of two parts; the U-bolt and the saddle. The guy wire is put through a thimble or insulator and doubled back for clamping (this is called a *turnback*) as shown in **Figure 26.35**. A thimble is used to prevent the wire from breaking because of a sharp bend at the point of intersection. Conventional wisdom strongly recommends the use of thimbles that are at least two wire sizes larger than the cable to provide a more gentle wire bend radius.

Wrapping the wire around the thimble results in two parallel guy wires. The wire that bears the tension of the guy wire forces is called the "live" end and the short piece that is turned back is called the "dead" end. It's "dead" because it is not load bearing.

Table 26.4
Guy Wire Specifications

Typical 3⁄16 inch steel guy wire breaking strengths

Common Grade	1540 pounds
Utility Grade	2400 pounds
Siemens-Martin Grade	2550 pounds
High Strength Grade	2850 pounds
Stainless Steel Aircraft	3700 pounds
Extra High Strength Grade	3990 pounds
Phillystran HPTG4000	4000 pounds

EHS guy wire sizes and breaking strengths

3⁄16 inch	3990 pounds
1⁄4 inch	6650 pounds
5⁄16 inch	11,200 pounds
3⁄8 inch	15,400 pounds

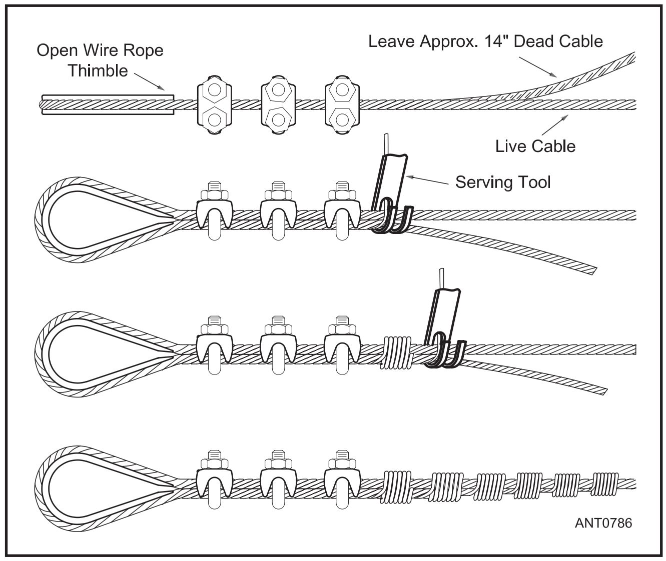


Figure 26.35 — Traditional method for securing the end of a guy wire. This technique is becoming increasingly uncommon as Preforms replace cable clamps.

Always use three cable clamps per joint and make certain that the saddle is on the live (load-bearing) side of the guy wire. The saddle portion provides the majority of the holding capacity of the clamp and goes on the "live" side of the cable. To remember the correct method, use the saying "Don't saddle a dead horse." In other words, don't put the saddle on the dead side of the turnback. A clamp mounted backwards loses 40% of the holding capacity of a properly installed clamp.

At one time, the guy wire end strands were unwoven and wrapped around the guy wire itself. This process was known as "serving," and was best done using a special tool. Not only is this procedure quite difficult with EHS, the wrapped bundle will trap water running down the cable, which will accelerate the rusting process. With the near-universal adoption of Big Grips, this practice is no longer used very much.

Swaged Fittings

Swaged fittings produce a strong, clean connection. If you don't like the look of lots of cable clamps, swaging may be for you. The most common swages are *Nicopress* fittings shown in **Figure 26.36**. While the fittings themselves are relatively inexpensive, you have to buy or rent a Nicopress tool to crimp them onto the guy wire. Once they're crimped on they can't be removed.

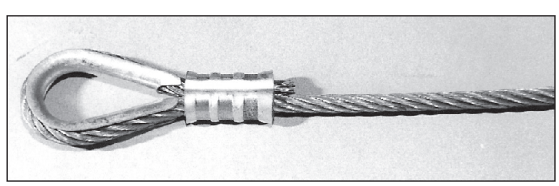


Figure 26.36 — Swaged guy wire end using Nicopress fitting.

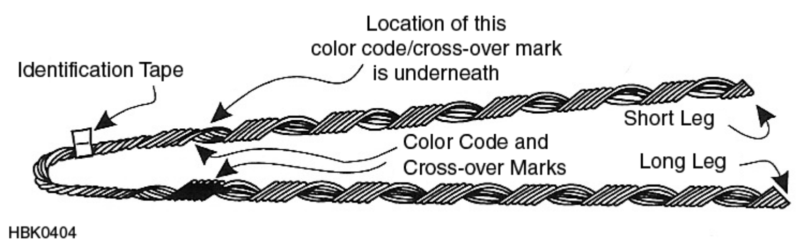


Figure 26.37 — Preformed guy wire "dead end" grip. The grip is wound around the guy wire and holds the load through friction.

Preformed Guy Grips

Preformed guy grips (or *Big-Grip Dead-Ends* from Preformed Line Products — **www.preformed.com**) are the easiest to use and the most expensive (see **Figure 26.37**). You simply curl them onto the end of the guy wire to produce a permanent termination. Preformed cable grips have virtually replaced cable clamps for power, telephone, and communications companies. Factory specs say that you can remove and reapply the grips twice. If removal is necessary after a guy grip has been installed for a period greater than three months, it must be replaced. If you can't find them locally, they are available from several *QST* advertisers.

Preforms are color-coded for guy wire sizes, as follows:

⅛ inch — blue
³⁄₁₆ inch — red
¼ inch — yellow
⁹⁄₃₂ inch — blue
⁵⁄₁₆ inch — black
⅜ inch — orange

Use only the correct size Preforms for the guy wire you are using. Guy wire and related hardware, including cable clamps and Preforms, are designed for a certain number of strands in the wire rope, and for a specific lay for each cable size. Do not mix different hardware. Note that Preformed grips have two sets of crossover marks. The set closest to the loop is for normal guy wire attachment. The set farthest from the loop is for when the guy wire goes through an insulator.

Installing Preforms

Preformed guy grips are precision devices, designed to be installed by hand; do not use any tools to install them. They should be installed only in conjunction with heavy-duty wire rope thimbles.

1) Insert a heavy-duty thimble into the eye of the Preform, then through the attaching hardware (shackle, etc.).

2) Wrap the first leg (either one) around the guy wire with two complete wraps. Simply wrap them around the guy wire. Line up the crossover marks, then wrap the second leg with two complete wraps, ending opposite the first leg.

3) Complete the installation by either simultaneously wrapping both legs (keeping the legs opposite each other) or alternating between the legs a couple of wraps at a time. Bending the EHS guy wire as you wrap the Preform leg around it will make it easier to attach.

4) Finish the short leg first, then the long leg.

5) Seat the ends of the legs by hand or use a flat blade screwdriver under the end of the strands. For Phillystran guy wire you may need to separate the strands to finish the ends of the Preform.

6) Attach a black tie-wrap or end sleeve around the grip at the end to secure it.

Cutting Guy Cable

Many different methods have been used over the years to cut guy cable. These days, EHS (extra high strength) guy wire is the standard and special cutters are needed to cut this hard wire. Always wear safety goggles when working with guy wires. There can be lots of metal chips floating around when you cut them or the guy wire can easily whip around and hit you in the face or other body parts.

Table 26.5
Guy Cable Comparisons

Cable	*Nominal Dia. (inches)*	*Breaking Strength (lbs)*	*Weight (lbs/100 ft)*	*Elongation (inches/100 ft)*	*Elongation (%)*
³⁄₁₆ inch 1×7 EHS	0.188	3990	7.3	6.77	0.56%
¼ inch 1×7 EHS	0.250	6700	12.1	3.81	0.32%
HPTG6700	0.220	6700	3.1	13.20	1.10%
HPTG8000	0.290	8000	3.5	8.90	0.74%
⁵⁄₁₆ inch 1×7 EHS	0.313	11200	20.5	2.44	0.20%
HPTG11200	0.320	11200	5.5	5.45	0.45%
⅜ inch fiberglassrod	0.375	13000	9.7	5.43	0.45%

EHS steel cable information is taken from ASTM A 475-89, the industry standard specification for steel wire rope.
The HPTG listings are for Phillystran aramid cables, and are based on the manufacturers' data sheets. The elongation (stretch) values are for 100 feet of cable with a 3000-pound load.

Resonance in Guy Wires

If steel guy wires are resonant at or near the operating frequency, they can receive and reradiate RF energy. By behaving as parasitic elements, the guy wires may alter and thereby distort the radiation pattern of a nearby antenna. For low frequencies, where a dipole or other simple antenna is used, this is generally of little or no consequence. But at higher frequencies, where a unidirectional antenna is installed, it is desirable to avoid pattern distortion if at all possible. The symptoms of re-radiating guy wires are usually a lower front-to-back ratio and a lower front-to-side ratio than the antenna is capable of producing. The gain of the antenna and the feed point impedance will usually not be significantly affected, although sometimes changes in SWR can be noted as the antenna is rotated. (Of course other conductors in the vicinity of the antenna can also produce these same symptoms.)

The amount of re-radiation from a guy wire depends on two factors — its resonant frequency, and the degree of coupling to the antenna. Resonant guy wires near the antenna will have a greater effect on performance than those that are farther away. Therefore, the upper portion of the top level of guy wires should warrant the most attention with horizontally polarized arrays. The lower guy wires are usually closer to horizontal than the top level, but by virtue of their increased distance from the antenna, are not coupled as tightly to the antenna.

To avoid resonance, the guys should be broken up by means of egg or strain insulators.

Figure 26.A shows wire lengths that fall within 10% of ½-λ resonance (or a multiple of ½ λ) over all the HF amateur bands.

Unfortunately, no single length greater than about 14 feet avoids resonance in all bands. If you operate just a few bands, you can locate greater lengths from the chart that will avoid resonance. For example, if you operate only the 14, 21 and 24 MHz bands, guy wire lengths of 27 feet or 51 feet would be suitable, along with any length less than 16 feet.

Of course, you could neutralize the whole problem by using Phillystran at some expense. One way to minimize the cost is to use Phillystran on only the top or top two sets of guys. Further, it's not necessary to use Phillystran all the way down to the anchor. Even using Phillystran for the top 50% will reap benefits.

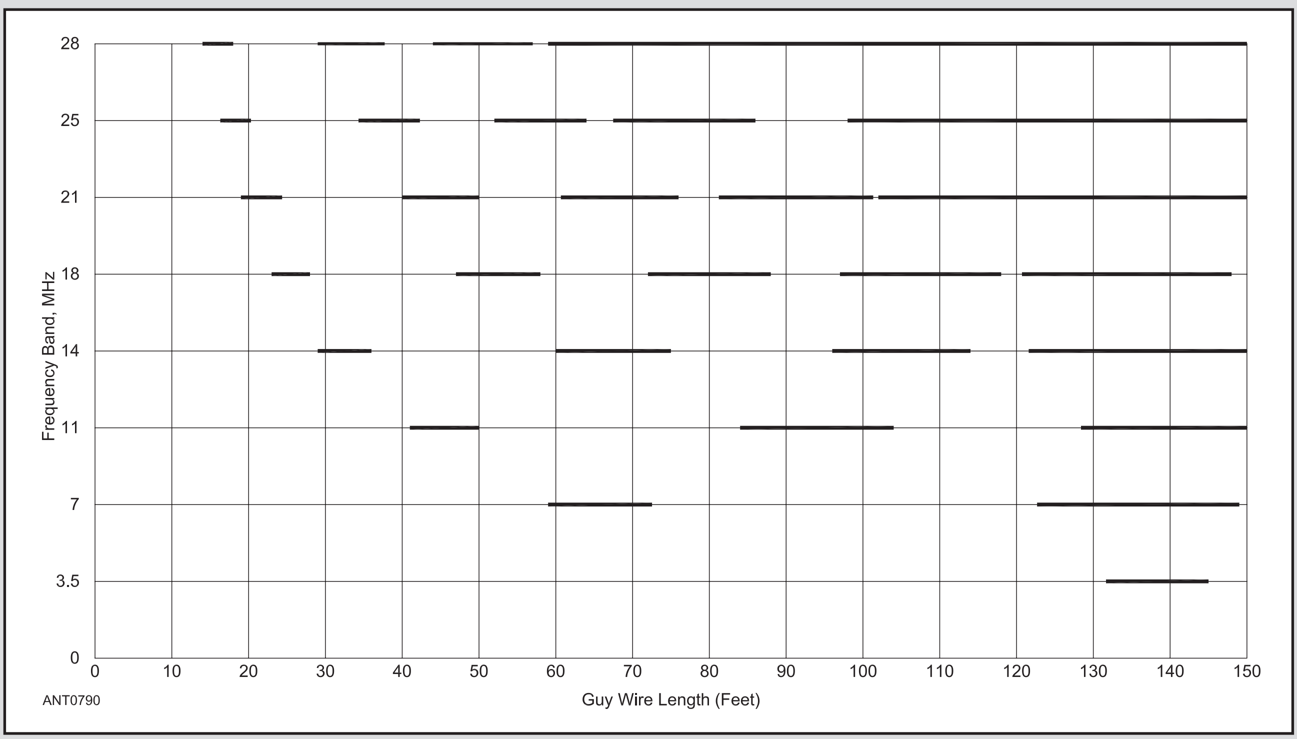


Figure 26.A — The black bars indicate ungrounded guy wire lengths to avoid for the eight HF amateur bands. This chart is based on resonance within 10% of any frequency in the band. Grounded wires will exhibit resonance at odd multiples of a quarter wavelength. (chart by Jerry Hall, K1TD)

To cut the guy wire, rent or borrow a bolt cutter. Be certain it will cut EHS, not just soft metal. Another method is to use a circular saw or hand grinder with a metal cutting aggregate blade. These blades are less than $4 at your neighborhood hardware store and will cut pipe mast material as well. Use electrical tape not only to mark where you want to cut, but also to prevent the guy wire from unraveling after it's cut.

Phillystran

Introduced in 1973, Phillystran offers the strength of EHS guy wire with the added advantage that it is nonconducting and electrically transparent to RF. It consists of a polyurethane resin-impregnated aramid fiber rope with a thick extruded jacket of specially formulated polyurethane. Its non-conductivity makes it ideal for tower systems where some antennas will be under or close to guy wires. Guy wire interaction with stacks and wire antennas will be eliminated by using Phillystran. **Table 26.5** compares EHS, Phillystran and fiberglass rod guying material.

Recommended Phillystran installation calls for at least 10 to 25 feet of steel cable from the end of the Phillystran to the anchor. This prevents damage from vandalism, accidents and ground fires that can weaken Phillystran and cause a tower failure.

Phillystran Cable Grips

Preformed Line Products now manufactures Phillystran-compatible Preformed guy grips. These are different from those used with ¼ or ⅜ inch EHS with a different lay (twist) to match the characteristics of Phillystran. The grips for Phillystran cannot be interchanged with the grips for EHS.

The guy grips are installed generally the same way, except that you must keep some tension on the *Phillystran* while installing them, and you may have to split the strands on the end of the Preform in order to finish wrapping them on. This is because the *Phillystran* is very flexible, particularly when compared to EHS. Other than that, they're installed just like the Preforms for steel guys.

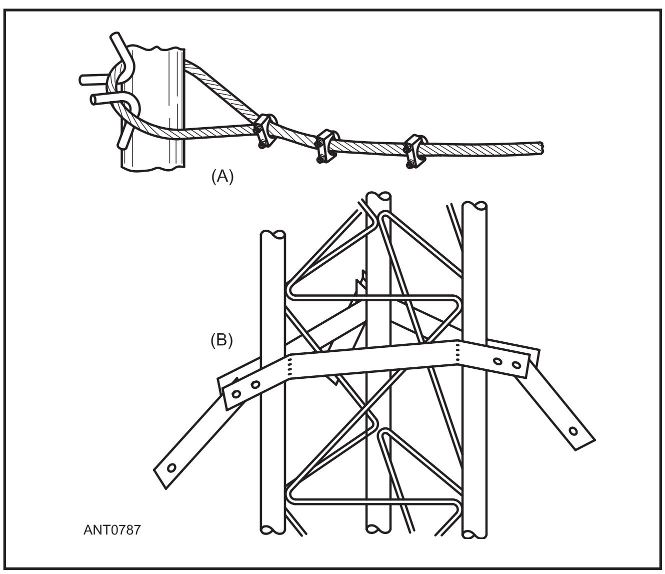
Attaching Guy Wires to the Tower

Figure 26.38 shows two different methods for attaching guy wires to towers. At Figure 26.38A, the guy wire is simply looped around the tower leg and terminated in the usual manner. At Figure 26.38B, a *guy bracket*, with *torque arms* has been added. Even if the torque arms are not required, it is preferred to use the guy bracket to distribute the load from the tower/guy connection to all three tower legs, instead of just one. The torque bracket is more effective at resisting torsion on the tower than simply wrapping the Big Grip or EHS around the tower leg. Rohn offers another guy attachment bracket, called a *Torque Arm Assembly* (sometimes called a "star guy" bracket), which allows six guys to be connected between the bracket and anchors. This is by far the best method of stabilizing a tower against high torque loads, and is recommended for installations with large antennas.

Attaching Guys to Anchors

Turnbuckles and associated hardware are used to attach guy wires to anchors and to provide a convenient method for adjusting tension. **Figure 26.39A** shows a turnbuckle with a single guy wire attached to the eye of the anchor. Turnbuckles are usually fitted with either two eyes, or one eye and one jaw. The eyes are the oval ends, while the jaws are U-shaped with a bolt through each tip. Figure 26.39B shows two turnbuckles attached to the eye of an anchor. The procedure for installation is to remove the bolt from the jaw, pass the jaw over the eye of the anchor and reinstall the bolt through the jaw, through the eye of the anchor and through the other side of the jaw.

If two or more guy wires are attached to one anchor,



8Figure 26.38 — Two methods of attaching guy wires to tower. See text for discussion.

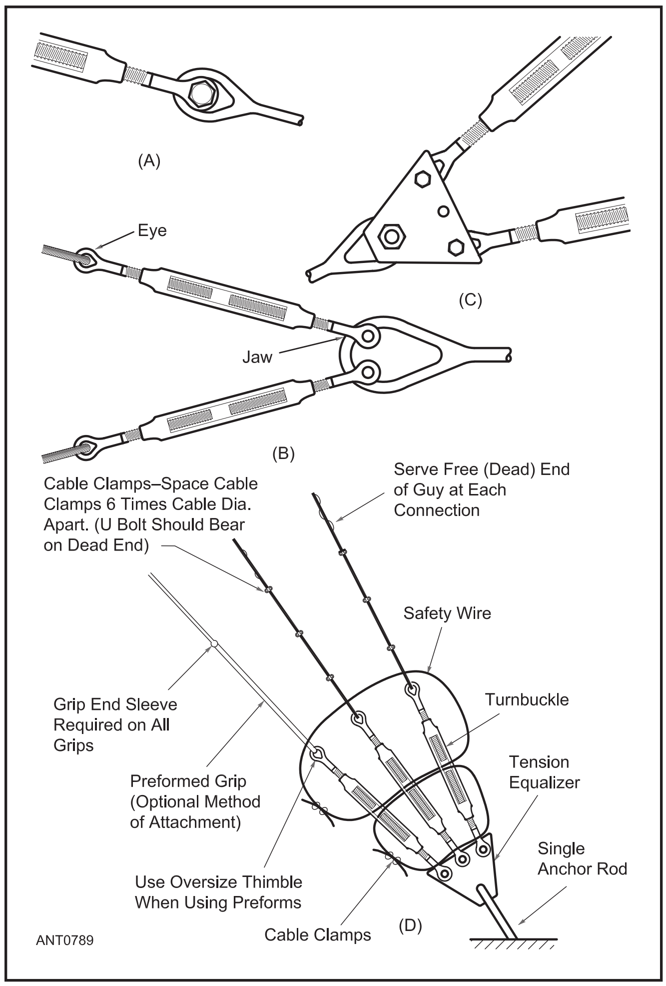


Figure 26.39 — Variety of means available for attaching guy wires and turnbuckles to anchors.

equalizer plates should be installed (Figure 26.39C). In addition to providing a convenient point to attach the turnbuckles, the plates pivot slightly to equalize the various guy loads and produce a single load applied to the anchor. Once the installation is complete, a safety wire should be passed through the turnbuckles in a figure-eight fashion to prevent the turnbuckles from turning and getting out of adjustment (Figure 26.39D).

Pulling and Tensioning Guy Wires

Once the guys are cut to their appropriate lengths and are attached to the tower, you need to pull them so you can attach them to the turnbuckle at the guy anchor. One method is to pull them by hand with a moderate amount of force (100-200 pounds of pre-tension will stabilize the tower under construction) and then secure them to the anchor. This will deflect the tower slightly but will put some initial tension on them. Another method shown in **Figure 26.40** is to use a come-along and cable grip. Place a nylon sling around the guy anchor for attachment of the other end of the come-along.

Most manufacturers require the final tension of the guy wire to be 10% of its breaking strength. That amount of tension is necessary to eliminate looseness in the cable caused by the spiral wire construction and to eliminate excessive dynamic guy and tower motion under wind loading. For 3/16-inch EHS that amount of tension would be approximately 400 pounds.

How do you know when you've got the right amount of tension? A calibrated dynamometer can be used, but such tools are quite expensive. The Loos Tension Gauge in **Figure 26.41** is an accurate, inexpensive device for measuring guy tension. While originally designed for accurate, repeatable tuning of a sailboat's standing rigging (which typically uses 7X19 SS cable), the accuracy of measurement is quite good

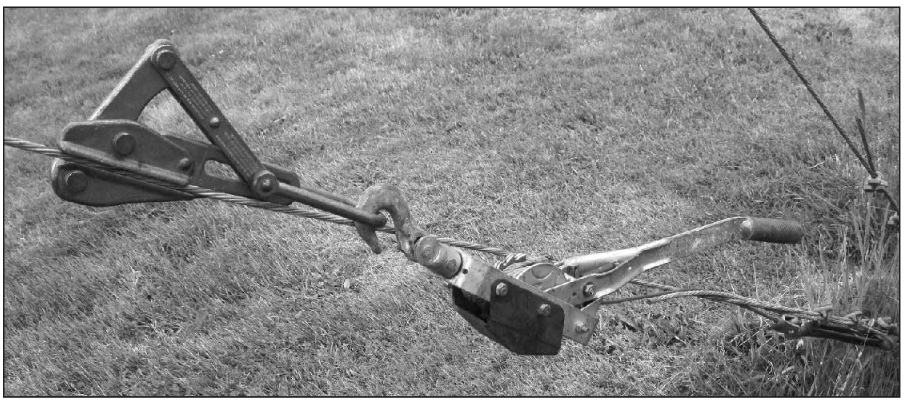


Figure 26.40 — To tighten guy wires a nylon sling (see at the lower right of the photo) is attached to the guy anchor and a come-along. The come-along is then hooked to a Klein cable grip on the guy wire. The come-along is then tightened until the required guy tension is achieved as measured with a Loos tension gauge or dynamometer. The guy wire can then be attached to the guy anchor and the Klein grip released. (courtesy of Dale Boggs, K7MJ)

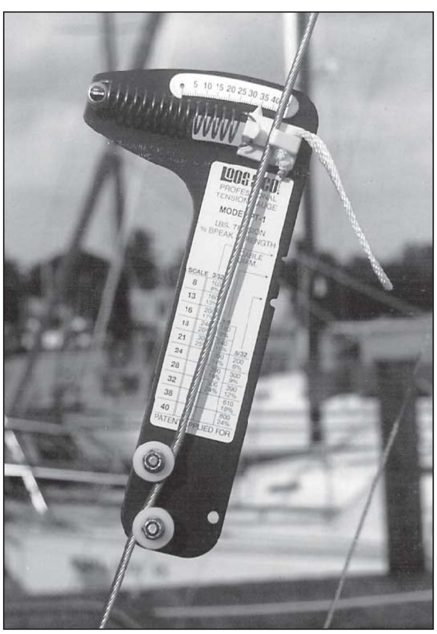


Figure 26.41 — Loos PT-2 guy wire tension gauge.

Figure 26.42 — A length of guy cable is used to assure that the turnbuckles do not loosen after they are tightened. This procedure is an absolute requirement in guyed tower systems, as shown by Jodi Morin, KA1JPA (left) and Helen Dalton, KB1HLF.

enough for ham radio towers, using EHS. It works by measuring the deflection of the guy wire and does not need to be inserted into the guy wire. (If you are using Phillystran, measure tension in the recommended section of steel EHS between the Phillystran and the ground anchor.)

The guy is gripped with a cable grip, which is connected to the anchor below the eye (or equalizer plate) with a block and tackle arrangement (see Figure 26.40) or a come-along. Then the turnbuckle is adjusted to take up the load, the cable grip is released and the final guy tension is adjusted and checked.

Regardless of how you measure guy tension, the important thing is to tighten all the guys so tension is approximately the same within each set of guys. Having all tensions equal avoids pulling the tower out of alignment. When you adjust the guys at each level, you should check the tower for vertical alignment and straightness. This is often done with a transit from two ground points located 90° from each other. After plumbing the tower up to the first set of guys, another method is to look up the face of the tower from the bottom. It will be obvious if the sections above the guys are out of plumb.

Safety Wiring Turnbuckles

The final step in installing guy wires is to safety wire them as shown in **Figure 26.42**. This keeps turnbuckles from loosening from normal vibration and discourages vandalism. Use some pieces of leftover guy cable and loop it through the anchor shackle and the turnbuckles, securing the ends with a cable clamp.

26.6.5 BEFORE WORKING ON A TOWER

The Work Crew

For small antenna jobs, two people (one on the tower and one on the ground) are usually enough. Even erecting 25G tower (40 pounds per section) can be accomplished with two people but a third person to handle the tag line is very handy. For 45G, it takes two people on the haul rope as these sections weigh 70 pounds each and a section with guy brackets is close to 100 pounds.

Commercial riggers commonly use some type of winch or windlass to haul up heavy loads. For working with large antennas, such as 40 meter beams, two people on the tower along with one or two tag line handlers, plus two to four on the haul rope, makes for a large crew.

Regardless of size, take care of your crew! Roll out the red carpet for them. They're giving up their time to help you and they deserve it. Make an effort to provide lots of water or iced tea and by all means feed everybody a nice lunch. *No alcohol* until after the work is done!

Pre-Work Meeting

On project day, the first thing you should do is have a session with the entire crew and go over what is going to be accomplished and the order and manner in which it is going to be done. Cover all safety issues, commands and equipment related to the job. Identify any hazards in the work area, such as power lines. Explain any specialized equipment or tools, including carabiners and slings, come-alongs, hoisting grips and so on. If a come-along or other special tool is going to be used, be sure that someone on the tower and ground crews knows how to use it properly.

One of the most important jobs for the ground crew is to act as a spotter and take care of the safety of the tower crew and the whole team. Point out where a phone is and any phone numbers that may be needed in an emergency. Also discuss and understand what to do in an emergency situation. For minor emergencies, knowing where the closest medical facility is will be valuable. Since just about everyone will have a mobile phone, calling 911 won't present any problems for bigger emergencies. Not many emergency services professionals have been trained for high-angle rescue such as lowering someone off of a tower, so you're probably going to be on your own at least initially. Search and rescue crews are used to working with ropes and other hardware for extrications, so hopefully your 911 operator will be able to put you in touch with them. Physical trauma can set in quickly even with a fall-arrest harness so fast action is vital.

Let your ground crew know not to be standing around the bottom of the tower unless they must specifically be there. This is the danger zone for dropped tools and hardware which reaches high speeds and can bounce a long way from the tower.

Rule #1. The tower crew is in charge. The ground crew should do what the tower crew tells them and not do what the tower crew doesn't tell them. Being on the ground crew is usually pretty boring, but they should not do anything that would have any impact up on the tower. With very few exceptions, the ground crew shouldn't do anything unless directed to. If they are not sure about something, ask the tower crew.

Rule #2. When the ground crew is talking to the tower crew, look up and talk in a loud, concise voice. Although it may be still and quiet on the ground, the ambient noise level on the tower is always significantly higher 50 feet or more in the air and you have major communication obstacles. VHF/UHF handhelds, FRS handhelds, or VOX-operated 47 MHz headsets all work. Make sure that all have fully charged batteries before work begins.

Rule #3. Really communicate. Insist that the ground crew keeps the tower crew really informed. If something is lowered to the ground, the ground crew should tell the tower crew that it's "on the ground." If the tower crew is waiting for the ground crew to do something, they should keep the tower crew informed about status. This prevents the "everybody waiting on everybody" problem.

Commands

Make certain that everyone understands each of the commands — whether they are the ones given here as examples or your own preferred set — and that they all use the same ones. All of the following commands refer to the "load" (antenna, tower section, etc.) and are applied to the "haul rope" (the line to which the load is attached). There are also several common hand signals to use. Simple ones for up, down and stop can be useful, particularly in high-noise situations. Make certain everyone knows what they are. For example:

- "Tension" tells the ground crew to put tension on the line, to take up any slack. Once you have some tension, move the load with "Up" or "Down" commands. Add "Slow" for slower lifting and lowering.
- "Slack" means giving the load some slack.
- "All slack" means the ground crew may gradually and gently release their grip on the load.
- "Stop" is obvious and "Stand by" indicates that they should maintain their assignment while awaiting the next command. Again, the tower crew is in charge; don't do anything without their instruction.

If something drops or falls, alert the ground crew immediately. Yell "Look out below!" or "Headache!" so that they can get out of the way of the wayward bolt, nut or tool. Their hardhats only provide minimal protection against this occurrence. Dropped items are not only dangerous, but it also means sloppy work. Take your time and concentrate on not dropping anything.

The Tower Crew

If you're on the tower crew, you should know what you're doing or be working with someone who does. If you are working on a standing tower, before climbing walk around it and make a thorough visual inspection. Look at the base for cracked or rusted legs or missing hardware. Go out to the anchors to check the turnbuckles, clamps and other hardware. Look for bee or wasp nests. Never assume that any tower is safe to climb — always inspect it thoroughly before you take that first step.

Before beginning any maneuver, discuss how you're going to do it and the sequence that will be used. This way, everyone will understand the process and will hopefully do the right thing at the right time. This is particularly important if you're up there with someone you've never worked with before. Sometimes you both assume that the other person is going to do something obvious that needs doing and then neither of you does it — this can be dangerous. Go over everything. This trains an inexperienced person and makes it easier the next time you work together.

Keep your tools either in your bucket or tool bags on your belt or tied to the tower. Try to avoid putting anything on a flat surface such as the rotator plate or thrust bearing plate; they can roll off.

Avoid using ac-powered tools on the tower. Battery powered tools are safer; you can buy, borrow or rent them. If you must use ac-powered tools, make certain they are insulated and that the extension cords are suitable. Zip cord extensions are dangerous. Make certain the ground crew knows where to disconnect the extension cords and where the breaker box is located.

Managing the Work to be Done

Break everything down into bite-sized pieces and only do one step at a time. Trying to combine two or more steps in the same task is asking for trouble. For example, don't try to bring up the guy wires already attached to the tower section; bring them up after the section and guy brackets are installed. Trying to combine too many steps often results in doing things twice, along with undoing what you've already done. You'll be more efficient and safe by doing things one step at a time.

Prepping the Materials

Many tasks are a lot easier to do on the ground than up on the tower. Take the time to prepare all of the materials before hoisting them so that the tower crew's job is as simple as possible.

For a tubular-legged lattice tower, there are several things you can do to make the job easier while the tower sections are still on the ground. First, there will be excess galvanizing from the hot-dip process in many of the leg bolt holes on new tower sections. This will prevent a bolt from going through the hole. Except as a last resort, do not drill out the holes as it exposes the steel. Use a drift pin or taper punch and a hammer to enlarge the hole only enough for a bolt to clear the hole. Next, check the inside of each lower leg for that same excess galvanizing and remove it carefully with a round file. These steps are much easier to do on the ground than in the air.

Check that the sections fit together. It's not uncommon that one leg won't line up, particularly with new sections. Using a piece of pipe or another tower section as a lever, gently bend the out-of-line leg until it slips on properly. This also is easier to do on the ground. Lay out the sections in order of fit and mark one pair of the mating legs with tape or a felt marker to ensure they can be assembled the same way they were on the ground. Be sure to send the sections up the tower in the same order they were checked for fit.

Put some grease around the *inside* of each *lower* leg of a tubular-legged tower section. Not only will they slide on more easily during installation, but the grease will help minimize corrosion and oxidation between the sections and make later removal easier. Skipping this step at assembly makes disassembly harder to the point where a jack may be required to get the sections apart! If the tower is to be conductive, for example if it's to be used as a vertical antenna, then use a conductive antioxidant compound instead.

Inspect all of the remaining metal pieces and parts for blocked holes, damaged threads, bent braces or arms — anything that will make it hard to assemble on the tower. These are much easier to repair on the ground. Use a file to round the sharp edges of all plates, steps, brackets or arms to keep them from damaging you.

If more than one antenna is to be installed on the mast, measure and mark where each antenna will be mounted and where the thrust bearing, if any, will be.

Hook the rotator up to its control box and test its operation. Turn the rotator until it indicates North or another known direction, then get it ready for hoisting. It doesn't really matter which way the rotator is physically installed in the tower as the antennas can be oriented when mounting them on the mast. By knowing the rotator's indicated direction the antennas can be aligned properly without stopping work.

If you are assembling an antenna for the project, let it sit overnight then retighten all of the nuts and bolts the next day. The hardware will have temperature cycled from warm to cold and warm again and some of the hardware will have loosened up during that temperature-induced expansion and contraction. This is the time to be sure it's all tight!

Antenna element hose clamps invariably catch on anything — wire antennas, guy wires, cables, and so on. To minimize this annoying characteristic, wrap the hose clamp with a layer or two of electrical tape while it's still on the ground. This is another good reason to use rivets instead of hose clamps for beam assembly.

If your rotator doesn't have a connector for the control cable, you can add one using vehicle trailer connectors — they come in a flat 4-wire polarized configuration. Get two sets and install a pigtail to the rotator terminated in one male and one female connector. Do the opposite at the end of your control cable to the shack. This will ensure that the cable is always connected correctly. Another system is to use a European Molex connector to connect a short jumper from the rotator to the longer control cable run to the shack. Weatherproof the connector by inserting it into a short piece of 2-inch capped PVC tubing taped to a tower leg. Being able to access the rotator wiring at the rotator, without having to look underneath or open up a connector, can be extremely time-saving during troubleshooting.)

When putting something together "temporarily," always install it as though you won't be coming back; "temporary" sometimes means it will be up and used for years!

Hardware Prep

Make sure all hardware is stainless or galvanized hardware. Avoid plated hardware.

Never place a load on eyebolts with eyes that can open. Only eyebolts that are forged or welded closed should be use on tower or antenna projects if they will be carrying a load.

Always take extra hardware, nuts and bolts up the tower in case you run short or drop something. If you don't have them, you'll invariably need them.

26.6.6 ASSEMBLING THE TOWER

Route the haul rope through a snatch block at the bottom of the tower to transfer the hoisting effort from pulling down to pulling horizontally. Pulling vertically is all arm strength plus the ground crew is exposed to falling objects. Pull horizontally by putting the rope around your hips and walking backward to hoist the load. This uses larger muscle groups and hoisting will be much easier. In addition, those hoisting can watch the load while staying out of the danger zone. Of course, working with ropes under load near the tower means wearing leather gloves, and a hard hat.

To hold onto a haul rope, put it around your hips then bring the tail or dead end in front of you. *Do not* tie the rope around your waist — this is potentially dangerous. Aiming the tail end in the same direction as the load rope, grasp both ropes with one or both hands. This is the best way to hold or brake a rope load. Don't depend on just using your hands; it's not as reliable and your hands and arms will quickly tire. With the rope secured around you, it can be held comfortably for quite some time.

Section Stacking

After rigging the gin pole as in Figure 26.27 (the haul rope goes up the middle of the pipe, across the pulley, then down to the load), attach the leg bracket to the top of the top section, *below* the top brace. Make certain that it's secure before you push the gin pole mast up to the extended position where it'll be ready for the lift. (This is a good procedure to rehearse on the first section above the base with the ground crew watching.) K4ZA recommends placing a suitably sized piece of plywood or OSB right at the tower base, on which to "stage" or set the sections. This prevents the legs from getting dirt stuck in them. (If you're installing used sections, make sure each siderail is clear of any debris before hauling them aloft.)

The tower section should be rigged so that it hangs more or less vertically; the heavier the section, the more important this becomes. Here are a couple of rigging options: Put a sling around a leg at about ¾ of the way up the section (double-check for proper top and bottom orientation) to establish the pick-point. Attach the haul rope just above the section mid-point and, on the command of the tower crew, start to pull on the haul rope. Or, a carabiner can be clipped to the third horizontal brace down from the section top, and a second carabiner (simply clipped on to the haul rope) can be attached to the topmost horizontal brace.

As soon as it clears the top of the tower, the tower crew should yell "stop," then "down slow" when ready to have the section lowered onto the top of the tower.

If leg alignment problems are discovered (see item 9 in the sidebar on tower building mistakes), use a come-along around the bottom of the whole section and tighten it up to pull the legs together. (This is common practice when putting up angle-legged self-supporting towers.) If you don't have a come-along, a ratchet-operated truck strap may suffice. One person on a tower doesn't have a whole lot of leverage and if the sections line up but won't slide down, use a come-along or TowerJack and pull the section down into place.

Stack an appropriate number of sections (typically up to the next guy point), then bring up the first set of guys and attach them. Your ground crew can use their cable grips and come-alongs to put the initial tension on them, then attach them to the anchors. You'll be able to tell them which ones to tighten and which ones to loosen by using a level on the leg to plumb the tower. Once that's done, repeat the same steps until all the sections are in place and guyed.

It's important to plumb the first set of sections including the first set of guys. Once that segment is plumb, you can look up the face of the tower to see if everything above it lines up — it'll be pretty obvious. If it doesn't, just adjust the come-alongs or turnbuckles to get it straight.

Installing the Mast

For small and medium masts, use the gin pole to bring it up using a sling as a choker. The choker should be above the balance point so that the mast goes up vertically. Lower the mast into the tower from the top.

Large and heavy masts more than 20 feet long are bigger

Tower Climbing Shield

A tower can be legally classified as an "attractive nuisance" that could cause injuries and/or lawsuits. You should take some precautions to ensure that "unauthorized climbers" can't get hurt on your tower.

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

An article describing such a tower shield by Baker Springfield, W4HYY and Richard Ely, WA4VHM was published in September 1976 *QST*. It has been added to this book's CD-ROM, including construction diagrams. Installing it should eliminate the worry.

than the usual gin pole can control properly. When building the tower, put the mast inside the bottom sections. Remove any rotator shelves or other obstructions so the gin pole can lift the mast up through the tower. Once the mast is captured at the top of the tower, it can be raised gradually. The books referenced at the beginning of this chapter provide more details.

Once the mast extends slightly above the top of the tower and is captured by the thrust bearing or a clamp acting as a collar, install the top antenna on the mast if more than one is to be installed. Once the first antenna is installed, pull the mast up with a come-along to where the next antenna is to be installed. Repeat the sequence until all the antennas are installed.

One "trick" to making this vertical lift easier is to replace one of the thrust bearing mounting bolts with a forged eye or eyebolt. This provides an attachment point for your come-along, making it as close to vertical as possible. This helps ensure the mast comes up as plumb as possible. The eye can, of course, be left in place.

Installing the Rotator

Clip a carabiner and haul rope onto a U-bolt on the rotator clamp or lift it with a bucket. Bring up the rotator, install it under the mast, and lower the mast into the rotator clamp. To haul up the control cable, tie an overhand knot in the cable and snap that into the haul rope carabiner.

To minimize the possibility of binding in the rotator/mast/thrust bearing system, work down when doing the final tightening. Do the thrust bearing first, the rotator mast clamps next, the rotator shelf bolts, and the rotator base bolts last.

When connecting the multiconductor control cable, one way to keep wire colors straight and consistent is to use the resistor color code: black, brown, red, orange, yellow, green, blue, violet, grey and white.

Rotation Loops

The rotation loop should be made with the rotator oriented North (typically its midpoint here in North America), ensuring the loop itself is centered. There are two ways to make a rotation loop for your cables. One way is to tape all the cables coming down the mast into a bundle, leaving an extra 4-5 feet of slack before securing the bundle to a tower leg. The bundle will have some rigidity that will help keep it out of harm's way. Make sure that it doesn't snag on anything as the system rotates and you'll be good to go. If you have a flat-topped tower, wind the cable around the mast 2-3 times in a diameter smaller than the top plate so that the coil lays on the flat surface.

26.7 RAISING AND LOWERING ANTENNAS

While small antennas can simply be pulled up directly on a haul rope, working with HF beams requires some technique. If done properly, the actual work of getting the antenna into position can be executed quite easily with only one person at the top of the tower. The ground crew does all the lifting by using a large pulley attached to the antenna mast or a gin pole with its pulley a foot or two above the point at which the antenna is to be mounted. Because raising an antenna often requires the load to be pulled away from the tower — either to avoid guy wires or as part of a tram or V-track system — this places significant bending forces on a mast or gin pole and may bend them if the pulley is too far above where they are attached to the tower.

The advice and suggestions in this section also apply to removing antennas by following the procedures in reverse. An antenna should probably be removed the same way it was installed. If installing it required a crane, it will most likely have to be removed by a crane.

26.7.1 AVOIDING GUY WIRES

Guy wires often obstruct the antenna's path to the top of the tower. One method of avoiding them is to tie a tag line to the middle of the boom and to a middle element for leverage (but within reach of the tower crew). The ground crews then pull the antenna out away from the guys as the antenna is raised. With this method, some crew members are pulling up the antenna to raise it while others are pulling down and out to keep the beam clear of the guys. Obviously, the opposing crews must act in coordination to avoid damaging the antenna.

A second method is to tie the haul rope to the center of the antenna. A crew member, wearing a climbing harness, walks the antenna up the tower as the ground crew raises it. Because the haul rope is tied at the balance point, the tower climber can rotate the elements around the guys. A tag line can be tied to the bottom end of the boom so that a ground crew member can help move the antenna around the guys. The tag line must be removed while the antenna is still vertical.

The third method is characterized as the "wig-wag" system by Tom Schiller, N6BT in his book *Array of Light*. It is particularly useful when other antennas are already installed on the antenna mast. The new antenna is lifted until it is immediately below the lowest antenna on the mast and rotated so that its elements are parallel to the boom of the installed antenna. The new antenna's elements are then tipped up to clear the elements of the installed antenna so that the new antenna is rotated around the installed antenna until its boom is above that of the installed antenna. Once above the installed antenna, the new antenna can be lifted so that its elements can be rotated to clear those of the installed antenna and then returned to horizontal and lowered for installation. This can be difficult if more than one antenna is already installed on the antenna mast.

26.7.2 USING A TROLLEY OR TRAM SYSTEM

Sometimes one of the top guys can provide a track to support the antenna as it is pulled upward. Insulators in the guys, however, may obstruct the movement of the antenna. A better track made with rope is an alternative. One end of the rope is secured outside the guy anchors. The other end is passed over the top of the tower and back down to an anchor near the first anchor. So arranged, the rope forms a narrow V-track strung outside the guy wires. Once the V-track is secured, the antenna may simply be pulled up, resting on the track. This is known as the trolley or V-track system. It is not an easy method to use. It requires two trolley cables spread apart some distance with the same tension on each line or the beam will tip. Plus there is a lot of added friction to the system from the weight of the antenna on the lines.

A much easier system is the tram line in which one line runs from the top of the tower to an anchor on the ground and the antenna is slung below the tramline. The system is illustrated in **Figure 26.43**.

Install one long (6-foot) sling on each side of the center mounting point of the antenna with two or three wraps around the boom; then bring them together to form a truss with the pick point directly above where the boom plate will attach to the mast.

This assures that the antenna is balanced and will arrive in the correct mounting position. Using two slings on the boom enables you to hoist the beam while it remains horizontal. Even if the antenna is mechanically off balance, you can adjust the slings so that it will remain basically horizontal.

You'll need three pulleys, a haul rope, a length of wire rope for the tram line, an anchor on the ground and miscellaneous slings and carabiners. K7LXC's preference is to use a wire rope tram line with the antenna suspended below the tram wire. Small diameter aircraft cable or wire rope such as ⅛ inch or $^3/_{16}$ inch ($^3/_{16}$-inch EHS works well) is sufficient to take the static load of just about any amateur antenna.

To set up the tram line, first secure a sling choker on the antenna mast about three feet above the place where the antenna will be mounted. Use two or three wraps and bring the choker through itself as described earlier.

Clip a carabiner or shackle to the tail of the sling. Then clip a large pulley into the carabiner. Bring up one end of the tram line and clip it into the same carabiner. Obviously, it's easiest if the tram line can "bisect" the guys, which provides the most clearance for the antenna coming up. This may require using some sort of temporary anchor point. A good rule of thumb for tramming is to try and have 1.5 times the tower height of working room; having a shallow angle makes tram work easier.

Secure the other end of the tram line to an anchor. You can use a tree, a fence post, a car, a stake driven into the ground or any other convenient strong point. Use a come-along and cable grip to tighten the cable until most of the slack is taken up. Do not over-tighten; you could damage your mast. If the sling on the mast is now high enough to create a significant bending force on your mast (more than four or five feet), back guy it in the opposite direction with another wire line or rope that is anchored to a convenient spot.

Run the haul rope through the back of the antenna mast pulley and out the front in the direction of the ground anchor. Lower the end of the haul rope directly to the ground or tie it to a carabiner clipped onto the tram line and let it slide down the wire. Figure 26.43A shows how the system should look at the top of the tower.

You may have to drop one or two of the top guy wires or any wire antennas closest to the antenna tram path if the antenna is going to be installed close to the top of the tower. Guys should be detached at ground level.

On the ground, attach the tram pulley (**Figure 26.44**) to the tramline. Turn the pulley upside-down (the antenna will be suspended under the tramline) then clip in the load end of the haul rope. Lift the two slings forming the antenna truss to the tram pulley and clip it in. The boom should be at a right angle to the tram line (elements parallel to the line) with the boom-to-mast bracket pointed toward the mast ready to accept U-bolts.

At this point, the haul rope should be attached to the tramline pulley. It goes up through the pulley on the mast, then down the tower to the ground. The third pulley is used at the bottom of the tower to change the direction of the haul rope from vertical to horizontal. At this point the system should look like Figure 26.43.

With antennas that have the elements mounted above the boom the antenna will attempt to flip over or "turn turtle." Minimize that tendency by tying the slings with opposite wraps (one around the boom in one direction, the other wrapped in the other direction).

Another method that helps counteract this unwanted tendency is to use a "tiller" as shown in **Figure 26.45**. It's a 4-foot long or so piece of angle iron or aluminum that is U-bolted to the boom on one end and has a small U-bolt on the front that captures the tramline and acts as a guide. Alternately, the

Figure 26.43 — A schematic drawing of the tram line system. 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.

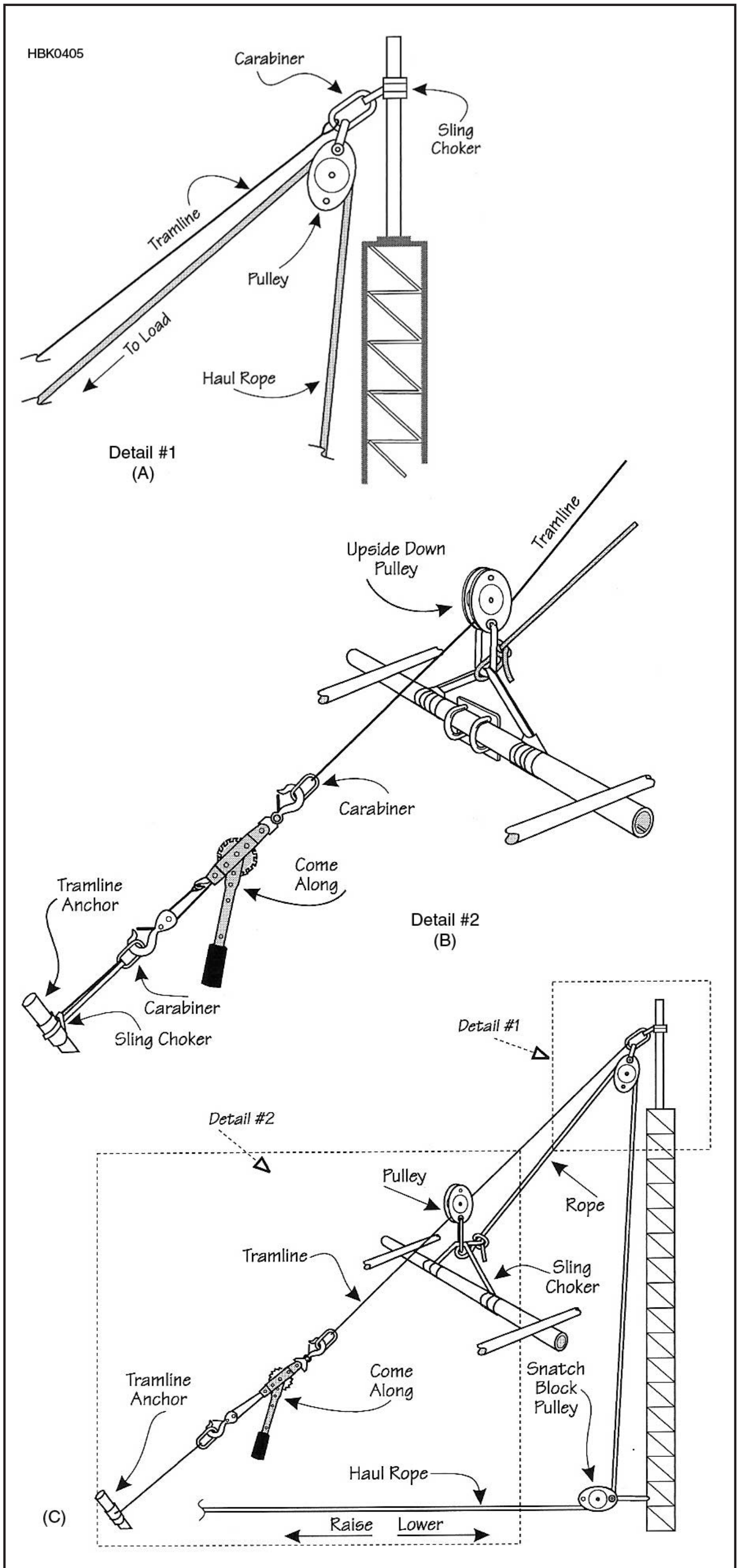


Figure 26.44 — A sturdy all-metal pulley suitable for tramming. (Don Daso, K4ZA, photo)

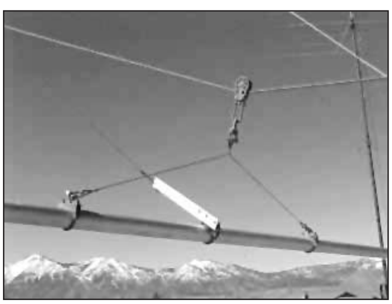


Figure 26.45 — Photo of the tram suspension system used by K7NV. Note that the tiller is attached to the haul rope in this system. The boom of the antenna can be rotated in the U-bolt holding it to the tiller to adjust the tilt of the elements to clear guy wires. (Kurt Andress, K7NV, photo)

front of the tiller can be attached to the haul rope. The tiller holds the antenna boom in a relatively fixed position, thus preventing it from turning over. Once the antenna has been lifted off the ground, the boom can be rotated in the tiller's U-bolt so that the element halves facing the tower are raised to clear the guy wires.

Next, attach any tag lines. Use a small line such as ¼ inch polypropylene because it's light and stiff enough to resist hanging up on any clamps or hardware sticking out on the elements. Tie one end to the boom at a convenient spot that the tower crew can reach to untie it. Wrap the tag line around an adjacent element two or three times. You can add one or two wraps of electrical tape to hold it in place on the element to keep the fulcrum out on the element and away from the boom. The tag line will pull easily through the tape when you're done. If the tag line does hang up on a guy wire, lower the antenna to free it then tram it back up again.

When it's time to launch the antenna, have the ground crew pull the haul rope while another person helps the antenna off the ground. Once the antenna is launched, crew members holding the tag lines can guide it as it goes up. (For big beams, such as 40 meter antennas, more than one person may be required to maneuver it up and on to the tram line and get the lift started.)

Use the tag lines to pull the element halves pointing away from the tower down so that they'll clear the guys. You'll be pulling against the haul rope so don't pull too hard on the tag line. The tag lines can also be used to move the boom so that the antenna will be in the proper mast-mounting orientation.

The tower crew can guide the antenna when it gets close to the tower. Once the antenna has cleared all obstacles and if everything was rigged correctly, the antenna should come right up to the mast. (If using the tiller, once the beam arrives at the mast, you'll find it's now in the way. Having a come-along or a second haul rope you can transfer the load to will allow you to move it out of the way. A second pair of hands can help greatly at this point, too.)

Another advantage is that while on the tram line you can run any on-the-air tests you'd like. Just attach a run of coax before you lift the antenna. To make any adjustments, lower the antenna, make the changes and pull it up again. Make measurements with the boom 90° to the tram line if possible (elements parallel to the tramline).

To take antennas down, rig everything the same way, then lower the antenna down the tram line. Be certain as it comes up from the ground, the haul rope goes behind the boom before it goes through the mast pulley.

26.7.3 BUILDING ANTENNAS ON THE TOWER

A fourth method is to build the antenna on the tower and then swing it into position. Building the Yagi on the tower works particularly well for Yagis mounted partway up the tower, as you might do in a stacked array. The technique works best when the vertical spacing between the guys is greater than the length of the Yagi boom.

Figure 26.46 illustrates the steps involved. A haul rope through a gin-pole or tower-mounted pulley is secured to the boom at the final balance point and the ground crew raises the boom in a vertical position up the tower. A tie rope is used to temporarily secure the upper end of the boom to keep it stable while the boom is being raised. The tower person removes the tie-rope once the boom is raised to the right level and has been temporarily secured to the tower.

The elements are then brought up one at a time and mounted to the boom. It helps if you have a 2- or 3-foot long spotting mast temporarily attached to the boom to form a 90° frame of reference. This allows the ground crew to spot from below so that the elements are all lined up in the same plane. After all the elements are mounted and aligned properly, the temporary rope securing the boom to the tower is released, suspending the antenna on the haul rope. The tower person then rotates the boom 90° so that the elements are vertical. Next, the elements are rotated 90° into the tower so that they are parallel to the ground. The ground crew then moves the completed antenna up or down using the haul rope to the final point where it is mounted to the tower.

A modification of this technique also works for building a medium-sized Yagi on the top of the tower. This technique will work if the length of the gin pole at maximum safe extension is long enough (see **Figure 26.47**). (This method is much easier if the top guy set is not exactly at the tower top, as previously mentioned. The extra working space helps immeasurably!)

As usual, the gin pole haul rope is attached to the balance point of the boom and the boom is pulled up the tower in the vertical position, using a rope to temporarily tie the haul rope to the top end of the boom for stability. The boom is temporarily secured to the tower with slings or a short length of rope in the vertical position so that the top end is just higher than the top of the tower. In order to clear the gin pole when the elements are mounted and the boom is raised higher to mount the next element, you must tilt the boom slightly so that the element mounted to the top end of the boom will be behind the mast. This is very important!

The elements are first mounted to the bottom side of the boom to provide weight down below for stability. Then the top-most element is mounted to the boom. The tower person removes the temporary rope securing the boom to the tower and the ground crew uses the haul rope to move the mast vertically upwards to the point where the next element from the top can be mounted. Once all the elements are mounted and aligned in the same plane (the center element closest to the mast-to-boom bracket can be left off until the boom is in place), the temporary securing rope is removed. The boom is now swung so that the elements can be maneuvered to clear the top guy wires. Once the elements are horizontal the boom is secured to the mast and the center element is mounted if necessary.

A special boom-to-mast mounting plate that supports both building and working on antennas at the top of the tower was designed by members of the Potomac Valley Radio Club. It is described in a short article ("The PVRC Mount") on the CD-ROM for this book.

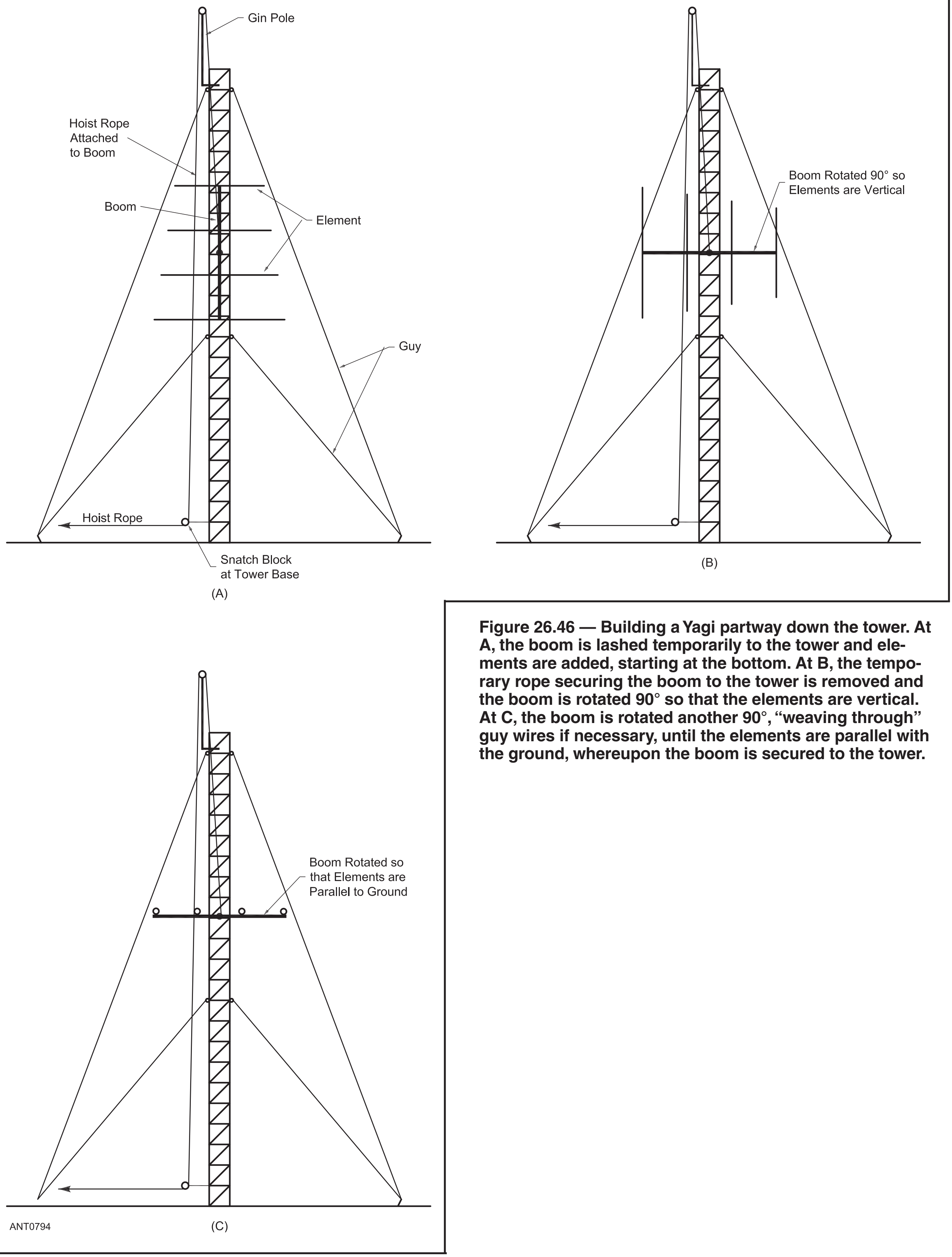


Figure 26.46 — Building a Yagi partway down the tower. At A, the boom is lashed temporarily to the tower and elements are added, starting at the bottom. At B, the temporary rope securing the boom to the tower is removed and the boom is rotated 90° so that the elements are vertical. At C, the boom is rotated another 90°, "weaving through" guy wires if necessary, until the elements are parallel with the ground, whereupon the boom is secured to the tower.

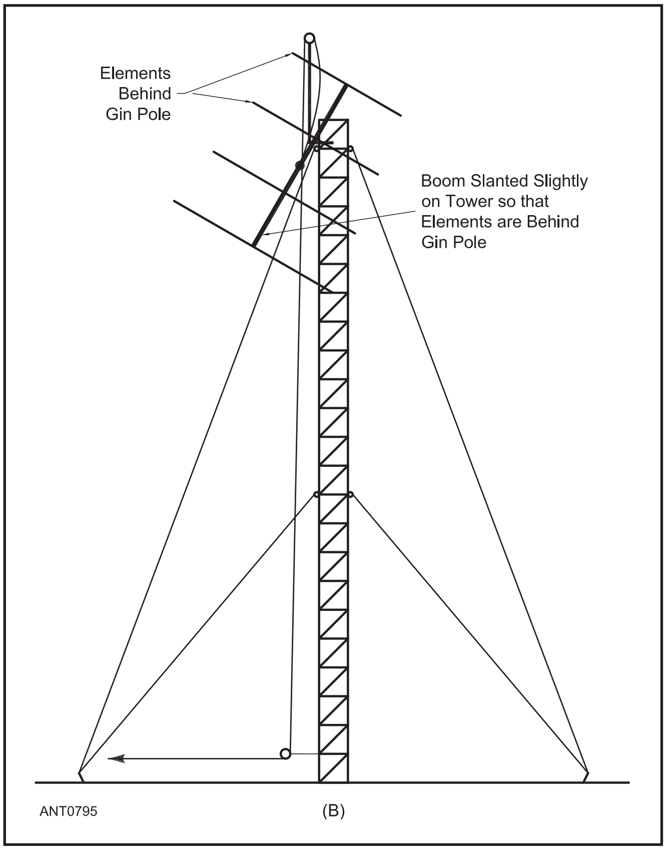


Figure 26.47 — Building a Yagi at the top of the tower. The length of the gin pole must be longer than 1/2 the boom so that the boom can be hoisted upwards to the place where it is mounted to the mast. Usually the boom is initially lashed to the tower slanted slightly from vertical so that the top element ends up behind the gin pole. The elements are mounted at the bottom end of the boom first to provide stability. Then the element at the top of the boom is mounted and the boom is moved upwards using the gin-pole hoist rope so that the next-to-top element may be mounted, again behind the gin pole. This process is repeated until all elements are mounted (save possibly the middle element if it can be reached easily from the tower once the beam has been mounted to the mast). Then the boom is tilted to the final position, weaving the elements to clear guy wires if necessary.

26.8 NOTES ON CABLES AND CONNECTORS

The following sections contain information that applies to the construction of antenna and tower systems. For more information on the characteristics of coaxial cable and RF connectors, including cable selection, see the **Transmission Lines** chapter.

A general tip for handling cable and wire — when removing it from a reel or spool, unroll it so that it lies straight and flat along the ground. Pulling it straight up and off the coil twists the cable, leading to strength-reducing kinks in the braid and endless aggravation as you attempt to get it untwisted and untangled.

26.8.1 COAXIAL CABLE

Bending Radius

Bending coax is acceptable as long as the radius of the bend is larger than the specified minimum bending radius. For example, a common minimum bending radius specification for RG-8 is 4 inches (8 times the cable diameter). Coax with more rigid shield materials will have a larger bending radius. Bending the coax tighter than the minimum bending radius can cause impedance "bumps" in the line by distorting the geometry of the conductors. It can also cause the center conductor to migrate through the plastic insulation and eventually short to the outer shield.

Burying Coax

There are several reasons why you might choose to go to all the work of burying your coax. One is that direct burial cable is virtually free from storm and UV damage, and usually has lower maintenance cost than cable that is out in the open. Another reason might be aesthetics; a buried cable will be acceptable in almost all communities. Also, being underground reduces common-mode feed line current on the outside of the shield, helping to reduce interstation interference and RFI.

Although any cable can be buried, a cable that is specifically designed for direct burial will have a longer life. The best cable to use is one that has a high-density polyethylene jacket because it is both nonporous and will take a relatively high amount of compressive loads. "Flooded" direct burial cables contain an additional moisture barrier of non-conductive grease under the jacket; this allows the material to leak out, thus "healing" small jacket penetrations. (These can be messy to work with when installing connectors.)

Here are some direct burial tips:

1) Because the outer jacket is the cable's first line of defense, any steps that can be taken to protect it will go a long way toward maintaining the internal quality of the cable.

2) Bury the cable in sand or finely pulverized dirt, without sharp stones, cinders or rubble. If the soil in the trench does not meet these requirements, tamp four to six inches of sand into the trench, lay the cable and tamp another six to eleven inches of sand above it. A pressure-treated board placed in the trench above the sand prior to backfilling will provide some protection against subsequent damage that could be caused by digging or driving stakes.

3) Lay the cable in the trench with some slack. A tightly stretched cable is more likely to be damaged as the fill material is tamped.

4) Examine the cable as it is being installed to be sure the jacket has not been damaged during storage or by being dragged across sharp edges.

5) You may want to consider burying it in plastic pipe or conduit. Be careful to drill holes in the bottom of the pipe at all low spots so that any moisture can drain out. While PVC pipe provides a mechanical barrier, water incursion is practically guaranteed — you can't keep it out. It will leak in directly or condense from moisture in the air. Use the perforated type so that any water will just drain out harmlessly.

6) It is important that direct burial is below the frost line to avoid damage by the expansion and contraction of the earth during freezing and thawing of the soil and any water surrounding the buried cables.

Coax Jumpers

With many beam antennas, the feed point is out of reach from the tower and should be connected to a jumper just long enough to reach from the feed point to the antenna mast. That way, the feed line connection and waterproofing can be done at the most convenient location. If you ever have to remove the antenna in the future you can just disconnect the jumper and lower the antenna.

Coax "Pigtails"

Most manufacturers use some type of feed point system that accepts a PL-259 or N connector. Some antennas require you to split the coax and attach the shield and center conductor to machine screws on the driven element. The exposed end of the coax is very difficult to seal; indeed, it's nearly impossible. Water will wick down the outer shield and into your shack unless you take great pains to weatherproof it. Coating the entire pigtail and attachment terminals with Liquid Electrical Tape or some other conformal sealant is a good approach, although UV will degrade such coatings over time. Another approach for HF beams is to use a "Budwig HQ-1" style insulator with the integral SO-239 and wires for connecting to the terminals (See the **Antenna Materials and Construction** chapter.) As always, follow the manufacturer's directions.

26.8.2 CONTROL CABLES

In addition to coaxial cables, most towers will have some sort of control cable for rotators, antenna switches or other accessories. The manufacturer should provide the size that is necessary and again, you should follow their specifications.

In the case of rotator cables, some rotators are sensitive to voltage drop so bigger sizes should be used. For really long runs, some amateurs use THHN house wire or UF-Romex, (with the motor start capacitor installed at the rotator) from the local hardware store to get reasonably-priced bigger wire. Only the motor and solenoid (if used) conductors typically require the larger wire.

26.8.3 WEATHERPROOFING RF CONNECTORS

The primary purpose of weatherproofing is to keep moisture and contaminants out of your coaxial cable connections. Whether it is rain or condensation, water in a connector can put you off the air.

Properly sealed connector joints will be very effective and reliable in maintaining electrical and mechanical integrity. Here's how to do it as illustrated in **Figure 26.48**:

1) Install the connector correctly on the end of the coax.

2) Use pliers when attaching a PL-259 to a SO-239 or PL-258 barrel connector. Hand-tightened connections are not tight enough! Do not crimp or deform the connector.

3) Apply two wraps of premium electrical tape such as Scotch 33+ or 88.

4) Apply a layer of vapor-wrap material. Vapor-wrap is a butyl rubber material that comes in rolls or sheets and does an excellent job of isolating the joint from the elements. A commercial vapor-wrap, such as from Andrew Solutions or Decibel Products won't stick to connectors and comes off easily. By putting one or two wraps of tape over the joint first, your connector will be protected from the vapor-wrap and it will look as good as new if you ever have to take it apart. To remove, simply take your razor knife, slice down the joint and peel off the weatherproofing.

Putty-type "coax seals" are *not* recommended as the surface can crack and dry out with age. If applied directly to a connector, the connector will become unusable as the inner putty forms a sticky mess. If you want to use putty-type sealants, wrap the connector with a layer of tape first.

5) Apply two or three layers of tape over the vapor wrap.

6) When your coax joint will be vertical, always apply the final layer of tape in an upward direction. This way the tape will overlap in such a way that water will not be conducted into the tape layers (like the shingles on your house). Tape wrapped downward will form little pockets that will trap the rain and conduct it right into your joint.

7) Do not stretch the tape when applying the final few inches. If you put it on under tension, it will eventually "flag," meaning it will come loose and blow around in the wind.

8) Paint the whole joint with a UV-resistant protective layer such as clear acrylic spray paint. That joint should never fail.

9) K4ZA recommends installing a UV-rated tie wrap above the weather-proofed connector, pulling it tight and cutting off the end. Capillary action will wick any water running down the coax off and away from the connector.

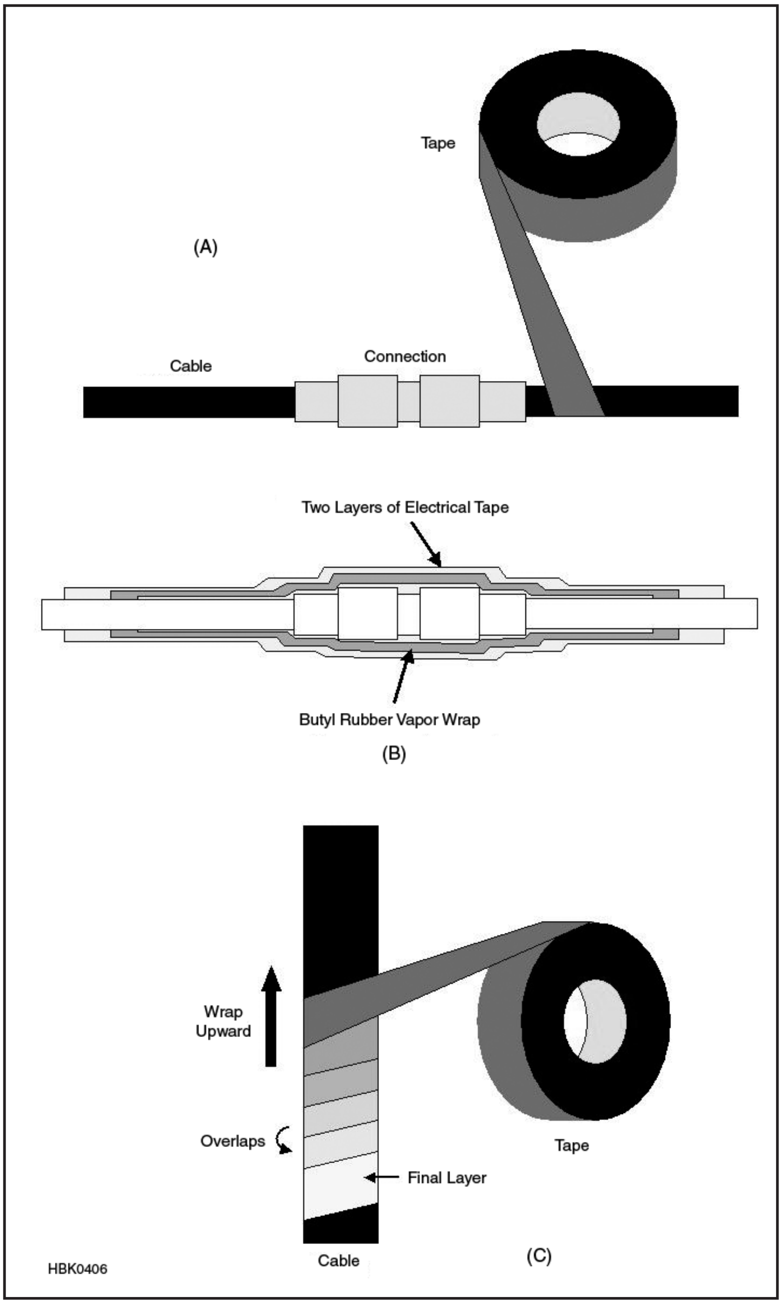


Figure 26.48 — Waterproofing a connector in three steps. At A, cover the connectors with a layer of good-quality electrical tape. B shows a layer of butyl rubber vapor wrap between the two layers of electrical tape. C shows how to wrap tape of a vertical cable so that the tape sheds water away from the connection. (Drawing (C) reprinted courtesy of *Circuitbuilding for Dummies*, Wiley Press)

Shrink-Fit Tubing

A recent product for coax joints is shrink-fit tubing impregnated with hot-melt glue along the inside. As you apply heat to the shrink-fit tubing, it shrinks while the glue melts and oozes inside between the fitting and the tubing. It not only keeps the tubing from slipping, but it also fills in the voids in the joint and provides an additional seal. It's an expensive alternative (approximately $1 per inch) but is very simple to use and remove if necessary.

Silicone Sealants

Do not use silicone sealant that gives off acetic acid (a vinegary smell) and absorbs water when curing. Acid and water will migrate into the connection causing problems later. Use only aquarium-type sealants or Dow-Corning 3145 for reliable connections. Be aware that once cured, silicone sealants are very hard to remove from connectors — practically impossible.

Giving off that vinegar-like odor means the silicone is "out-gassing," and K4ZA has found that once the curing period has passed, the silicone does not corrode or otherwise damage materials. Extensive tests have shown this to be the case.

26.8.4 TAPE AND TIES

Every amateur installation has many feet of electrical tape used outdoors in a variety of applications. The "3 rolls for $1.00" bargain specials are not recommended for demanding outdoor use, particularly for weatherproofing. Scotch Super 88 is the recommended standard for waterproofing connectors. Besides being conformable to 0 °F (–18 °C), it will perform continuously in ambient temperatures of up to 220 °F (105 °C) and it is UV-resistant. The data sheet says it provides "moisture-tight electrical protection" and it retails in the $4 to $5 range per roll. Another Scotch tape, Super 33+, is another "premium grade, all-weather vinyl insulating tape" with many of the same properties and specs as the Super 88. The only difference is that Super 88 is slightly thicker than Super 33+ (10 mils for 88 vs 7 mils for 33+). Both tapes are easily applied at low temperatures, and will even stick to a wet aluminum antenna boom.

Another specialized tape is the Scotch 130C Linerless Rubber Splicing Tape. This is a fairly thick (30 mils vs 7 mils for Super 33+) tape intended for high-voltage splices and is moisture-sealing. 3M makes many products for demanding electrical use — these are just several of them. You may have your own favorite.

Cable ties or tie-wraps are locking plastic fasteners intended to bundle cables and secure them to brackets and other supports, such as tower legs. They come in a variety of lengths, strengths, and materials at the local hardware store. For outside work, do not use white or translucent tie-wraps; they'll deteriorate quickly from UV exposure, often in less than a year. Black, UV-resistant tie-wraps are better, but they still eventually break down. A wrap of electrical tape will protect the tie.

A tie-wrap also makes a simple drip loop for coax and control cables. Attach a medium-size tie to the cable just before it enters the building with the tie's free end pointing down.

26.9 GROUNDING AND LIGHTNING PROTECTION

The subject of grounding and lightning protection is very broad, covering everything from low-frequency ac safety through RF electromagnetics. As such, a thorough treatment is well beyond the scope of this section although certain important points and concepts can be introduced and discussed. This section covers the requirements for safety grounding of the antenna system components and discusses ground or earth connections used for lightning protection.

Providing "cookbook" solutions for grounding and lightning protection is unrealistic because every station and antenna system is different. Local codes, soils, and lightning environment all vary from location to location. Thus, the goal is to provide general guidance, define common terms, and identify authoritative sources of information so that the underlying principles can be applied to a specific station's needs.

It is recommended that station builders study the references and articles cited in this section, including those provided on this book's CD-ROM, when designing and constructing their own station. The Bibliography lists several well-known and respected industry standards for lightning protection of military and commercial communications and broadcast facilities. While a professional-quality installation may be out of reach for amateurs, the references provide guidance for how best to make use the limited resources available.

This section also includes material from the **Safety** chapter of *The ARRL Handbook* and other ARRL publications. The ARRL's Technical Information Service web page on Safety (**www.arrl.org/safety**) also contains lists of useful references and guidelines for installing protective systems in your shack.

26.9.1 STATION GROUNDING

Permitting

Most locations impose some kind of permit process on significant outdoor building projects, such as towers. Along with mechanical and civil engineering concerns for whether the structure is sound and appropriately sited, electrical requirements for grounding and lightning protection are also included.

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 directory or online for professional engineers, electricians, and contractors. Accommodating local code requirements at the beginning of your project is usually a lot less expensive than trying to bring a non-compliant system up to code later on.

Electrical safety equipment and materials can be found in the list of vendors and dealers provided on this book's CD-ROM. Your local electrical supply houses and distributors are also good sources for both references to contractors, and materials.

AC Safety Grounding

The National Electrical Code (NEC) specifies standard methods for dealing with electrical shock and fire hazards. Article 250 deals with grounding and bonding. Article 810 deals with radio and television equipment. Your local code may refer to these sections or may impose different or more stringent requirements. In either case, the local code has authority over your installation. The NEC is published by the National Fire Protection Agency (NFPA) and can be read online at **www.nfpa.org/aboutthecodes/aboutthecodes.asp?docnum=70**.

Reducing the detailed language of the NEC to simple terms, you must connect all exposed metal from ac-powered equipment to a central, common ground. All equipment electrically connected to an ac-powered device should have a permanent safety connection, even if the equipment is unpowered, such as an antenna tuner or audio switch. This includes masts and towers, along with any other outdoor equipment.

This connection is usually referred to as the *ac safety ground* and the connection is made through the "third wire" of your ac power wiring; the bare or "green" wire. If a short circuit develops between the ac wiring and the enclosure of a piece of equipment, the resulting fault current in the ground connection trips a circuit breaker in the hot conductor. Leakage current is mostly due to capacitance between the phase (hot) ac conductor and the equipment chassis or enclosure. This includes capacitors used for ac line filtering and stray capacitances such as between a power transformer's windings and its metallic frame, which is usually bonded to the equipment enclosure and thus to the equipment's ground connection.

Ground-Fault Circuit Interrupter (GFCI) breakers go one step further and monitor the balance of current on the hot and neutral lines of an ac circuit. If an imbalance is detected, it is assumed that the missing current is flowing on the equipment chassis or enclosure, where it can present a shock hazard and the GFCI trips to remove power.

Since the ac safety ground is concerned with currents at the power line frequency and its first few harmonics, the length of the connection is relatively unimportant. Similarly, resistance in the ac safety ground path or imbalances of a few ohms between circuits doesn't matter much from the perspective of safety. (Imbalances might be significant for signal-level connections.) The important thing is that hazardous current takes a path that doesn't go through a human being.

Bonding

Bonding refers to connecting equipment enclosures and earth connections (ground rods) together so they are at the same electrical potential, even if there is a short-circuit in the ac power connection or a lightning strike. The goal of bonding is to minimize the voltage between exposed metal surfaces to reduce shock hazards. In the amateur station, bonding also minimizes RF current flow between pieces of equipment that can cause improper or degraded operation.

Equipment can be bonded together regardless of whether there is an earth connection. Bonding connections should be made with conductors that are heavy enough to be mechanically secure and that have minimal resistance.

The minimum recommended grounding conductor for bonding earth connections together is #6 AWG stranded wire. Copper strap (or flashing) should be a minimum of 1.5 inches wide and 0.051 inch thick. In the station, bonding equipment enclosures together can be done with #12 or #14 AWG wire or flat-woven braided strap. Use grounding fittings and blocks for connecting the bonding wires and strap together.

Do not use braided strap outdoors or where exposed to moisture because the individual strands oxidize over time, greatly reducing the effectiveness of braid at RF. Use bare copper for buried ground wires. (There are some exceptions; seek an expert's advice if your soil is corrosive.) Braid removed from coaxial cable should not be used as an RF bonding conductor. Without the protection and compression of the jacket, the weave of round braid loosens and the individual wires will oxidize.

Exposed runs above ground that are subject to physical damage may require additional protection (such as a conduit) to meet code requirements. Wire size depends on the application but never use anything smaller than #6 AWG for bonding conductors. Local lightning-protection experts, electricians, or building inspectors can recommend sizes for each application.

Static Dissipation

Wind and precipitation can develop a large static charge on any ungrounded antenna or tower, up to thousands of volts. If not discharged to ground, the charge will eventually build up and arc to a convenient grounded point. This can obviously lead to equipment damage. There are several methods of dissipating static charge without affecting the antenna system. The first two suggestions are primarily useful at HF.

- High-value, non-inductive resistors of 10 kΩ or more connected from ungrounded feed line conductors to ground allow small currents from static electricity to be discharged safely. The resistors should be rated for at least 1 kV to avoid arcing from high RF power levels and induced voltage surges from nearby lightning strikes. Metal-oxide resistors of ½-W or higher power rating can withstand short pulse overloads and are inexpensive.
- RF chokes below their self-resonant frequency provide a dc path to ground for static while having sufficiently high reactance to have a minimal effect on impedance. Note that wire-wound chokes use fine wire that can act as a fuse and become an open circuit from a lightning-induced transient.
- DC-grounded antenna designs use shunt inductors to ground at the feed point or have driven elements connected to a supporting structure, such as a gamma-matched Yagi. These antennas dissipate static charges continually.
- Quarter-wave shorted stubs (see the **Transmission Line System Techniques** chapter) act as an open-circuit at the design frequency while providing a direct path to ground for static electricity. This technique only works on a single band and can't be used on multiband antennas.

26.9.2 LIGHTNING PROTECTION

Effective lightning protection system design is a complex topic. There are a variety of system tradeoffs that must be made and that determine the type and amount of protection needed. 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. The basic techniques are thoroughly explored in the three-part 2002 series of *QST* articles "Lightning Protection for the Amateur Station" by Ron Block, KB2UYT, that are available on this book's CD-ROM and online at **www.arrl.org/lightning-protection**. Another useful document on lightning protection is available from the IEEE, "How to Protect Your House and Its Contents from Lightning" (see the Bibliography).

You may also wish to use the services of a local lightning protection expert to advise you on specific techniques appropriate for your area. Companies that sell lightning-protection products may offer considerable help to apply their products to specific installations. One such source is PolyPhaser Corporation (now owned by Smith Power (**www.smithspower.com/brands/polyphaser**). The Bibliography of this chapter contains a partial list of PolyPhaser's publications.

Tower and Feed Line Grounding

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 26.49**). Connect a continuous bonding conductor between the tower ring ground and the station's cable entrance panel.

Make all connections with fittings approved for grounding applications. Do not use lead-tin solder for these connections — it will be destroyed in the heat of a lightning strike. If the fitting is to be buried, use welded connections such as CADWELD or clamps that are specifically rated for direct burial.

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.

To provide an alternate path for strike energy to entering your home or shack via the feed line, ground the feed line outside the home. Ground the coax shield to the tower at the

Welding Earth Connections

The best way to ensure that a buried ground rod connection remains effective is to weld it. Conventional welding may be used but a far easier method is to use exothermic welding in which a fast-burning fuel melts the rod and connecting wire together, resulting in a mechanically and electrically secure connection. The best known products in this line are the CADWELD products by Erico (**www.erico.com/cadweldcatalog/cadweld**) which include reusable and "one-shot" products.

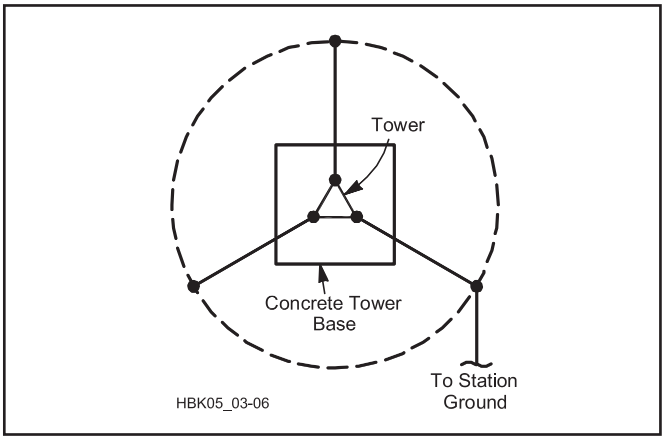


Figure 26.49 — Schematic of a properly grounded tower. A bonding conductor connects each tower leg to a ground rod and a buried (1 foot deep) bare, tinned copper ring (dashed line), which is also connected to the station ground and then to the ac safety ground. Locate ground rods on the ring, as close as possible to their respective tower legs. 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.

antenna and the base to keep the tower and line at the same potential. Several companies offer grounding blocks that make this job easy to do properly.

Bonding Earth Connections

Significant voltages can be created between separated earth connections, especially during lightning surges. The solution is to bond all external earth connections together. The ground rods and buried bonding conductor provide a low impedance path for the lightning's charge outside the building and help keep equipment at close to the same voltage at low frequencies. Both are important — keep as much of the lightning energy as possible outside while minimizing large voltage differences and current surges that damage equipment inside.

The *service entrance ground* connection from the ac power distribution panel to a ground rod establishes a local earth connection for lightning protection of ac-powered equipment and appliances. All other earth connections should be bonded to the service entrance ground.

All earth connection bonding requires at least #6 AWG copper wire. 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 service entrance ground as required by the NEC and local codes.

Ufer Ground

If you live in a dry or rocky area where ground rods are difficult to install or ineffective, a Ufer ground or "concrete-encased electrode" is often used. The Ufer ground relies on the conductivity of concrete to make contact with the soil over the large area of a foundation slab or tower footing. Reinforcing bar (rebar) inside the concrete is bonded to building steel or a tower with a heavy bonding conductor.

More information on Ufer grounds is available in NEC section 250.52, the PolyPhaser book *Lightning Protection and Grounding,* and in *Lightning Protection & Grounding Solutions for Communication Sites* (see Bibliography).

Lightning Arrestors and Surge Suppressors

Feed line lightning arrestors (known as *antenna discharge units* in the NEC) are available for both coaxial cable and parallel-conductor or balanced line. Most of the balanced line arrestors use a simple spark gap arrangement, but a balanced line impulse suppressor is available from several vendors.

DC blocking arrestors for coaxial cable have a fixed frequency range. They present a high-impedance to lightning energy below 1 MHz while offering a low impedance to higher-frequency RF.

DC-continuous 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. **Figure 26.51** shows examples of typical arrestors for coaxial cable.

Cable Entrance Panel

The basic concept for lightning protection is to make sure that all the radio and other equipment is bonded so that it "moves together" in the presence of a transient voltage. It's not so important that the shack 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 shack is "far" from Earth potential.

The easiest way to ensure that everything is at the same potential is to tie all the signals 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 like a ham station is to have a common connection point for all the cables. Often referred to as an *entrance panel* or *single-point ground panel* (SPGP), the object is to provide a common potential reference for shields and signal connections.

The easiest way to create an entrance panel is to install a large metal enclosure or a metal panel as a bulkhead and grounding block in the exterior wall. The panel should be bonded to the lightning dissipation ground with a short wide conductor, and, like all grounds, bonded to the electrical system's ac service entry ground. This is illustrated in **Figure 26.50** which shows the various grounding systems at a typical home station. (W8JI's website at **www.w8ji.com/station_ground.htm** shows examples of an entrance panel

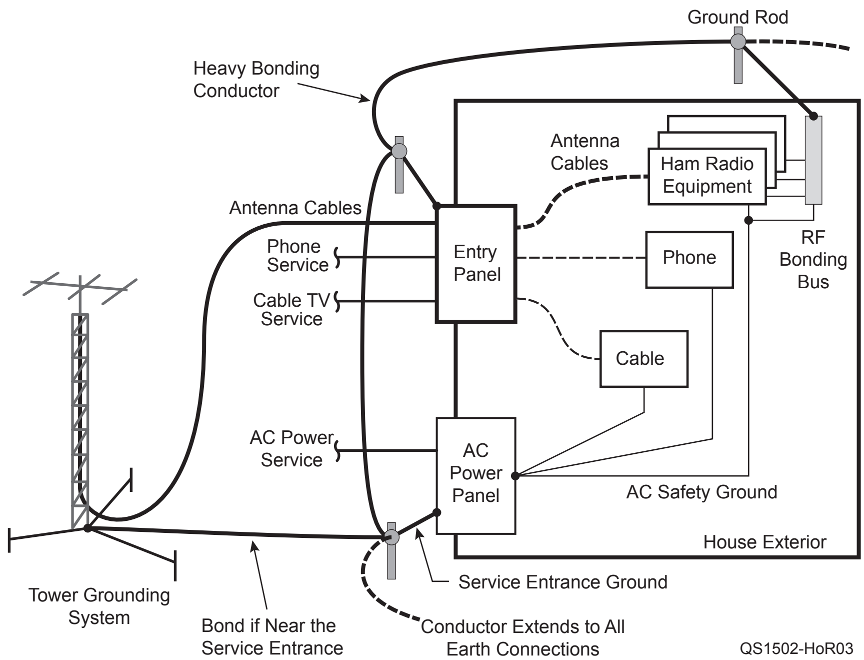


Figure 26.50 — A lightning protection system attempts to dissipate charge outside the home or station. All earth connections are bonded together to provide a low-impedance path for lightning, and to minimize voltage differences and current flow between equipment and circuits.

system and wiring practices.)

If multiple entry panels or lightning arrestors are used for different services, such as telephone or cable TV, connect those panels or lightning arrestors to the outside bonding conductor that connects all of the ground rods together.

Every conductor that enters the structure, including antenna system control lines, should have its own surge suppressor on an entrance panel. Suppressors are available from a number of amateur equipment vendors, as well as the usual electrical equipment suppliers such as Square-D, Graybar, and so forth. (See Parts 1 and 2 of the *QST* articles by Block for illustrations.)

Mount all lightning arrestors, protective devices, switches and relay disconnects on the outside facing wall of the bulkhead. 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. To avoid creating another path to ground around the panel, route the feed lines, rotator control cables, and so on at least six feet away from other nearby grounded metal objects.

Upper Floor Stations

A common situation is for an amateur station to be on the floor of a building well above ground level. For these stations, a grounded entrance panel as described above can still be constructed outside the building at ground level as in **Figure 26.51A**. Antenna feed lines and other cables are run to the entrance panel where they are connected to arrestors and suppressors. Cables to the station are then run outside the building from the entrance panel to an entry point on the higher floor.

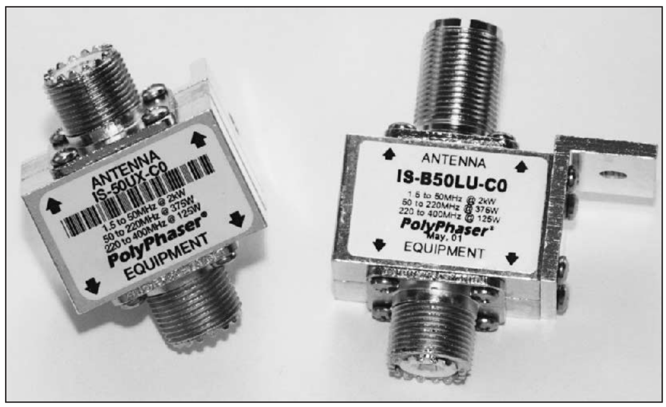


Figure 26.51 — Typical coaxial lightning arrestors from PolyPhaser. These are mounted on an cable entrance panel that is connected to a ground rod.

Running antenna feed lines and other cables directly into an upper-floor station as in Figure 26.51B creates a very difficult lightning protection challenge. An entrance panel on the upper floor will help equalize voltage differences between the cables but unless the building's steel framework is available as a low-impedance earth connection, the long bonding wire to the ground rod will result in significant voltage differences with respect to other ground-referenced wiring such as ac power. In such cases, it is best to disconnect all cables at the entrance panel when not in use or when storms are in the area.

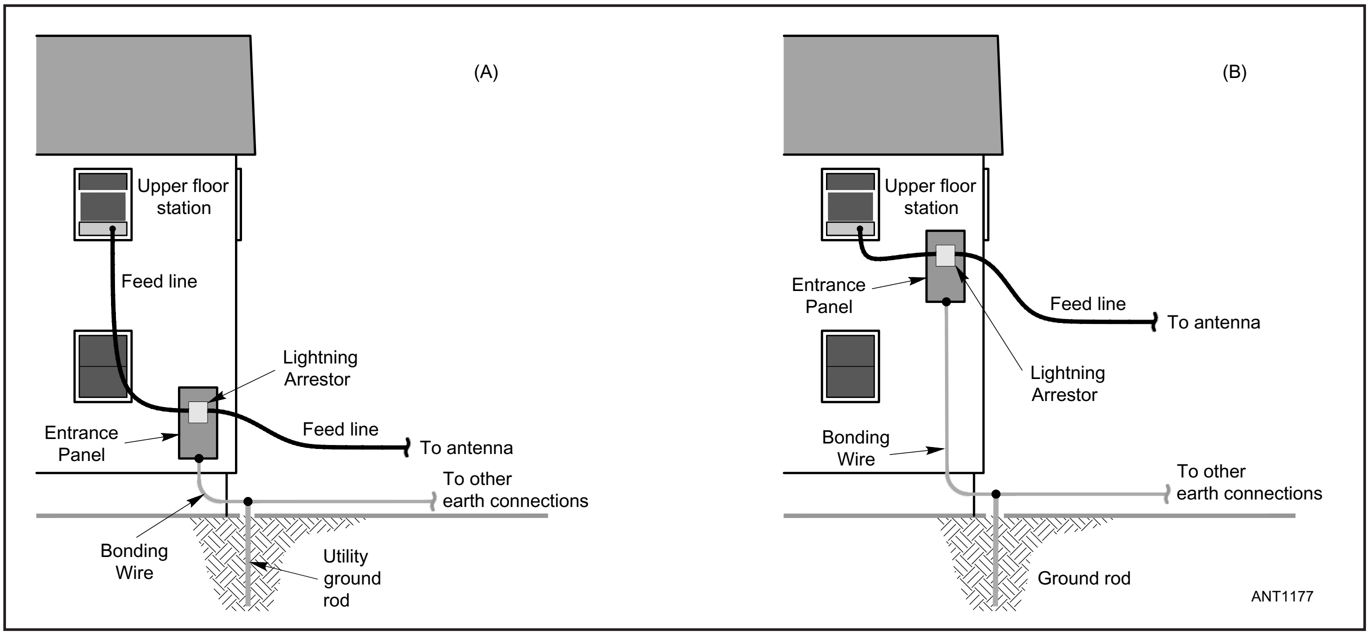


Figure 26.52 — Protecting an upper-floor station against lightning is a challenge. If possible, construct an entrance panel at ground level as in A and run feed lines (and a ground wire – not shown) to the station. If the entrance panel must be at the station level as in B, it should still be grounded but the long bonding wire will create significant voltages at the station. Disconnecting all cables when not in use on when storms are nearby is highly recommended in this case.

26.9.3 ANTENNA FEED LINE PROTECTION BOX

This project was originally published as "Antenna Feed Line Control Box" by Phil Salas, AD5X, in the August 2014 issue of *QST*. The complete article, including a parts list, all construction details, design formulas, and performance measurements, is included on the CD-ROM accompanying this book.

Design

While the design in **Figure 26.53** is not a substitute for a fully grounded entrance panel with lightning arrestors, it can make a good backup protection system, particularly for stations on upper floors of buildings or with marginal lightning protection grounding. The intent is to deal with voltage pulses caused by nearby lightning strikes and static buildup on antennas, both of which can damage equipment in the shack.

Static buildup (often termed precipitation static) on antennas can reach thousands of volts.8 This can be prevented with bleeder resistors connected from the coax center conductor to ground.

As most of the energy in a lightning strike is concentrated well below 500 kHz, the high reactance of the blocking capacitors will attenuate much of this low frequency energy. This high reactance also allows the voltage to spike. Therefore gas discharge tubes will fire for impulse voltages greater than about 800 V, shunting that energy to ground.

Normally the blocking capacitors will simply serve to pass RF current from the unit's inputs to the ANT outputs. Capacitors passing heavy current are subject to heating and will dissipate power P_d proportional to the product of the equivalent series resistance ESR and the square of the RF current I: $P_d = I^2 \times ESR$. This power dissipation can be minimized by choosing capacitors with a low dissipation factor DF. Because $ESR = DF \times X_c$ where X_c is the capacitor's reactance, the power dissipated by the capacitor can now be expressed as $P_d = I^2 \times DF \times X_c$. Stating X_c in terms of the frequency f and capacitance C yields $P_d = (I^2 \times DF) / (2\pi \times f \times C)$.

Capacitor heating can be further reduced by paralleling capacitors, which reduces the current through each capacitor. Assuming that the aggregate current remains the same, paralleling two equal-value capacitors will reduce the current through each by a factor of 2. Because the power dissipated is proportional to the square of the current, the net effect will be to reduce the individual capacitor power dissipation by a factor of 4.

Schematic

When remote switch S1 is set to LOAD, power is removed from SPDT relays K1 – K4. The disposition of the relay contacts shown in the schematic is for the power off condition, which is also the state of the unit when the station is off the air. In the power off state, relays K2 – K4 connect signals ANT1 – ANT3 (J5 – J7) to chassis ground, which in turn is connected to the station single point ground via a wing nut connection on the outside of the aluminum box. This prevents static charge buildup on the antennas and also provides a path to ground for pulses due to nearby lightning strikes. Additionally, when S1 is set to LOAD, relay K1 connects KAT1 to DUMMY LOAD through SO-239 connectors J1 and J4 respectively.

When remote switch S1 is set to ANTS, +12 V is supplied to the unit through POWER input J8, which in turn is connected to the coils of relays K1 – K4. Diode D1 suppresses the kick-

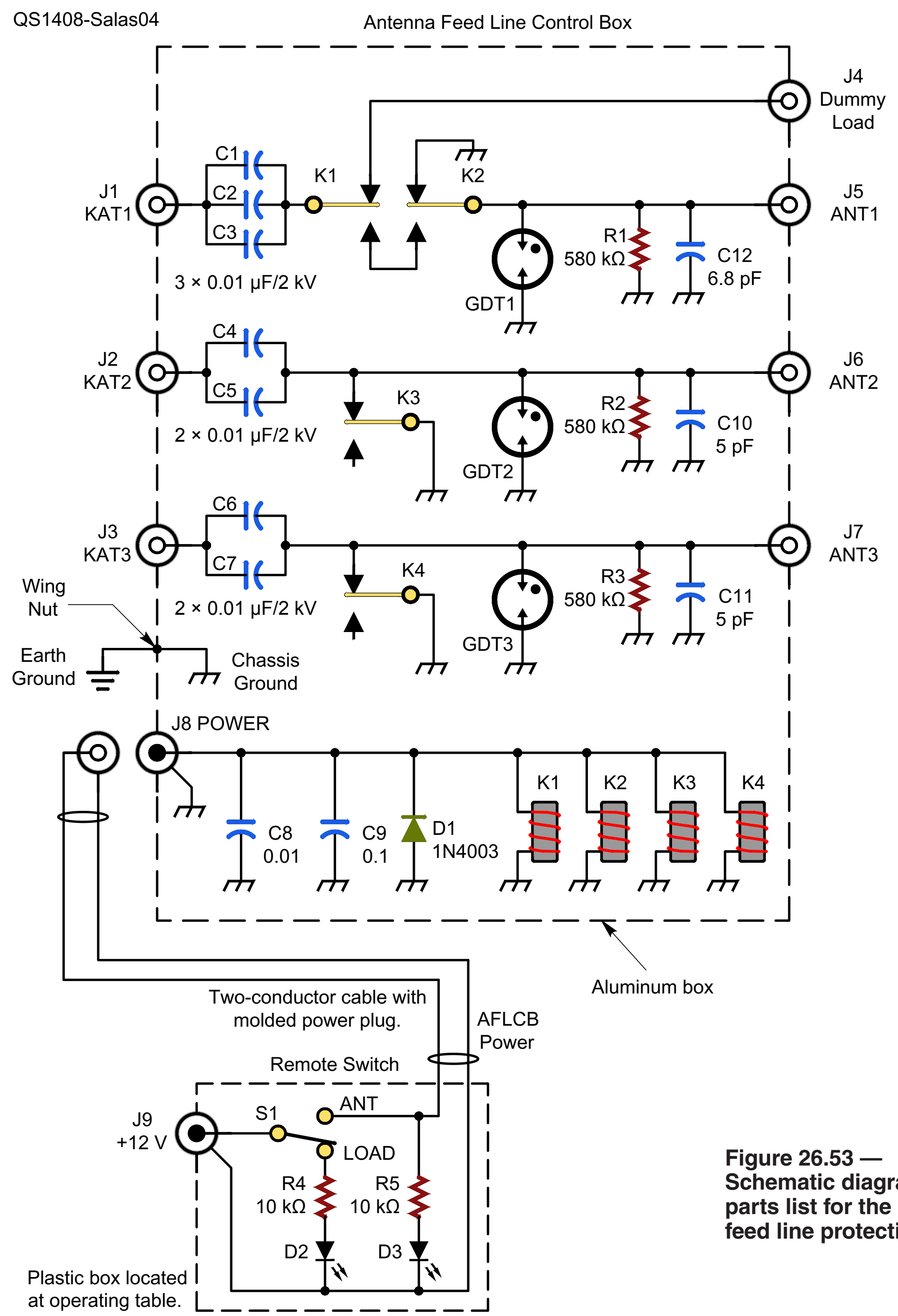


Figure 26.53 — Schematic diagram and parts list for the antenna feed line protection box.

C1 – C7 — 0.01 μF, 2 kV capacitor (Mouser 594-S103M69Z5UP63K7R).
C8 — 0.01 μF, 100 V ceramic disc capacitor (Mouser 140-100Z5-103Z-RC).
C9 — 0.1 μF, 50 V ceramic disc capacitor (Mouser 140-50U5-104M-RC).
C10, C11 — 5 pF, 1 kV capacitor (Mouser 75-561R10TCCV50).
C12 — 6.8 pF, 1 kV capacitor (Mouser 75-561R10TCCV68).
D1 — 1N4003 diode (Mouser 512-1N4003).
D2, D3 — Green LED (Mouser 941-C5SMFGJSCV14Q7S1).
GDT1 – GSD3 — Gas discharge tube 800 V (Mouser 652-2095-80-BLF).
R1 – R3 — 580 kΩ ½ W 3.5 kV resistor (Mouser 594-HVR3700005903FR5)
R4 – R5 — 10 kΩ, ¼ W resistor (Mouser 66-CMF1/41002FLFTR).
J1 – J7 — SO-239 connector (Mouser 601-25-7350).
J8, J9 — DC jack 2.1 × 5.5 mm (Mouser 163-1060-EX).
K1 – K4 — SPDT power relay (Mouser 655-RTB14012F).
S1 — SPDT toggle switch (Mouser 108-0009-EVX).
DC power cable (with compatible plug for J8) — 2.1 × 5.5 mm × 3 feet (Mouser 172-4204).
Plastic box — 1.38 × 1.38 × 0.79 inches (Mouser 546-1551MBK).
Aluminum box — 4.3 × 3.3 × 1.6 inches (Mouser 563-CU-5471).

back voltage from the relay coils when power is removed and capacitors C8 and C9 bypass any RF voltage to ground.

In the power on state, the ground shunt connections made by relays K2 – K4 of signals ANT1 – ANT3 are removed along with the KAT1 connection to DUMMY LOAD through K1. Then, KAT1 is connected to ANT1 via K1 and K2 and blocking capacitors C1 – C3. The author paralleled three capacitors on this port because this is his only 160 meter connection.

The paths through the unit are similar, so we'll take the path from KAT2 (J2) to ANT2 (J6) as a representative case. Capacitors C4 and C5 are wired in parallel to share RF current in order to minimize heating due to their equivalent series resistance. In the power on state, since ANT1 – ANT3 are no longer grounded, the unit is vulnerable to pulses from nearby lightning strikes and to static charge buildup on the antennas. In the event of a nearby lightning strike, the high reactance of C4 and C5 will block much of the energy from the pulse. And if the voltage spike should reach 800 V, gas discharge tube GDT2 will fire and the energy will be shunted to ground. While operating, static charge buildup is prevented by bleeder resistor R2 connected from the signal line to chassis ground.

The small-value capacitor C10 compensates for the impedance bump due to the unit's internal wiring. Without the capacitor the SWR of the unit degrades to about 1.3:1 on 6 meters when the unit is perfectly terminated. With the capacitor, the SWR is less than 1.03:1 (36 dB return loss) on 6 meters. Of course these capacitors are not really necessary as the protection box follows any antenna tuner. However any impedance bump can degrade a less-than perfect feed line SWR enough to make the difference between bypassing a tuner and the need for a tuner to be in-line, especially at the higher frequencies.

Note that the voltage ratings of the components in this path are higher than typical: R2 is rated at 3.5 kV, where an ordinary resistor is only rated for a few hundred volts; blocking capacitors C4 and C5 are rated at 2 kV and C10 is rated at 1 kV. The relays, while inexpensive, work well through 6 meters, providing 1 kV RMS of isolation between contacts, 5 kV RMS of isolation between the coil and the contacts, and contacts rated at 12 A continuous current.

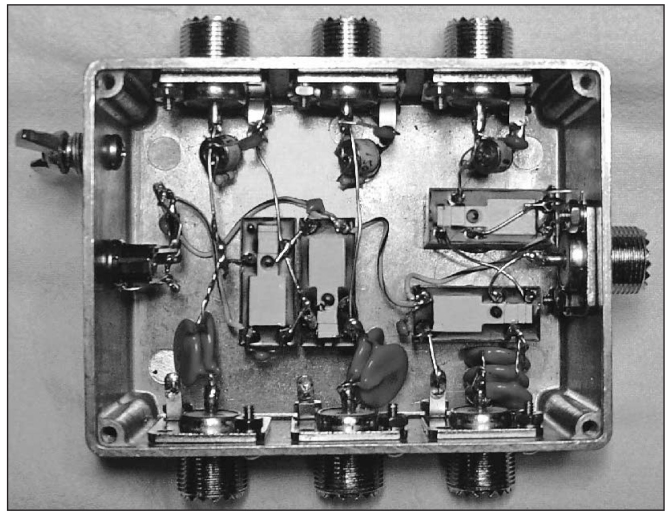


Figure 26.54 — View of parts placement inside the aluminum box housing the unit. The wing nut at the upper left connects the chassis ground of the unit to the station single-point ground at the cable entrance panel.

Construction

Figure 26.54 shows a photo of the completed unit built into a cast aluminum box that has a mounting bracket that permits it to be rigidly mounted in place. The relays (with pins up) are hot-glued to the aluminum box. A step-drill or ⅝-inch Greenlee punch works well for cutting the SO-239 connector holes. Note that there is also a ground stud consisting of a #8 stainless steel screw, nut, lock washer, and wing nut for connecting to your station's single-point ground.

26.10 CORROSION

Corrosion is one of the biggest problems in tower and antenna installations. Knowing more about it will help you to use appropriate materials and stay away from problematic combinations. For detailed information on corrosion, visit the website of Corrosion Source (**www.corrosionsource.com**), where there are a number of free reports and other downloadable documents on corrosion.

Any metal by itself will eventually oxidize due to exposure to the oxygen in the atmosphere. The aluminum in our antennas combines with oxygen to create the powdery aluminum oxide you find when you take an antenna apart, while oxidation of steel (which is iron) produces the rust that you want to avoid.

When two metals with the right properties are in contact in the presence of an electrolyte, *bimetallic corrosion* takes place. It's the same chemical process that takes place in batteries. Specifically, ions from one metal (called the *anodic* metal) flow across the joint or junction to the other metal (called the *cathodic* metal). In bimetallic joints, the more anodic metal is

Removing and Refurbishing Towers

Sooner or later every tower must come down and you may become the proud owner of such a tower! The article "Removing and Refurbishing Towers" on the CD-ROM for this book discusses some of the special concerns and techniques involved.

Table 26.6
Relative Galvanic Series In Sea Water

MORE ANODIC
Magnesium
Zinc
Galvanized steel
Aluminum
Mild Steel
Iron
50-50 lead/tin solder
Stainless Steel
Tin
Nickel (active)
Brass
Aluminum-bronze
Copper
Nickel (passive)
Silver
Gold
MORE CATHODIC

the one that loses material.

The electrolyte is typically some kind of salt or other compound (such as zinc) dissolved in water making the solution conductive. Rain (particularly acid rain), mist or condensation are sufficient for bimetallic corrosion to begin.

Galvanically incompatible metals are combinations of metals that readily corrode when in contact because of their ranking on the galvanic chart. The farther apart the metals are in the table, the faster they will corrode when in contact. When you must use different materials, it is best to use metals that are close together in **Table 26.6**. You can see that on a zinc galvanized tower, aluminum and mild steel are the most compatible. If you use materials such as copper and brass when installing your tower ground system on a galvanized tower, you can see that you will have problems with corrosion almost immediately.

One technique for avoiding corrosion on towers is to use an intermediate corrosion-resistant material between two otherwise incompatible metals. For example, to connect a copper ground conductor to a galvanized tower, use a stainless steel washer or shim between the copper and zinc galvanizing and stainless steel hardware to hold them together.

Another technique is to use *sacrificial anodes* that give up material to prevent corrosion of the main structure. A complete discussion of this technique is beyond the scope of this chapter but the recent *QST* article by Tony Brock-Fisher, K1KP, "Is Your Tower Still Safe?" covers the topic well (see the Bibliography or this book's CD-ROM).

26.10.1 ANTIOXIDANTS

Various compounds are available for combating corrosion. These are *antioxidants* and most commonly-used metals such as copper, aluminum, and steel have several products designed specifically for each of them.

For aluminum antennas, most manufacturers provide a packet of antioxidant with their products. Retarding oxidation is not only a good electrical idea but the compound also functions as an anti-seize coating, aiding you in taking the antenna apart at a later date.

Antioxidants are sometimes incorrectly called "conductive pastes or greases." In general, these antioxidant compounds are comprised of a carrier material with metallic chips in suspension. It is these conductive chips, not the carrier, that give the compound its conductive properties. What happens is that the particles will pierce the layer of oxidation while preventing corrosion by isolating the joint from the air. The compound that comes with Butternut antennas, *Butter-It's-Not*, uses copper dust in a molybdenum suspension while the paste supplied by M^2 Antennas uses copper and graphite flakes in a petroleum base. There are other commercial products available for copper joints which should be used on ground systems. Just be certain to use the right one for the job. **Table 26.7** lists several compounds and their manufacturers. In addition to using antioxidants on towers and antennas, they should be used in ground system joints as well as in marine environments.

26.10.2 RUST

Steel towers and hardware will rust unless steps are taken to prevent it. In the case of towers, use galvanized steel or aluminum. Hardware, including U-bolts, nuts, bolts and other fasteners should either be made out of stainless steel (SS) or be galvanized. Because the galvanizing process deposits a thin coating of zinc on the hardware, you can't interchange SS and galvanized nuts and bolts.

Surface rust is rust that is either deposited when you have water from a rusted piece of hardware run down a surface such as a tower leg or active rust that hasn't yet penetrated the layer of galvanizing. Neither condition is serious but you should repair those spots during your annual inspection. Use a wire brush to scrub off the rust and then spray the spot with a cold-galvanizing paint. "Cold-galvanizing" paint is available at almost any spray paint rack. Check the contents to make sure that it contains zinc. The LPS Company (**www.lpslabs.com**) makes a very good cold-galvanizing spray that is relatively expensive but adheres very well.

Table 26.7
Antioxidant Compounds

Product	*Manufacturer*	*Use with*
OX-GARD	GB Electrical — **www.gardnerbender.com**	Aluminum-aluminum, aluminum-copper
NOALOX	Ideal Industries, Inc — **www.idealindustries.com**	Aluminum-aluminum
NO-OX-ID "A-SPECIAL"	Sanchem, Inc. — **www.sanchem.com**	Steel rust preventative
Penetrox	FCI — **fciconnect.com**	Aluminum-aluminum, aluminum-copper
DE-OX	ILSCO Corporation — **www.ilsco.com**	Aluminum-aluminum, aluminum-copper

26.11 GENERAL MAINTENANCE

Having invested time and money installing your dream antenna and tower system, you'll need periodic preventive maintenance (PM) and inspections. The key is to catch anything before it becomes a problem.

If you've followed the directives and steps described in this chapter you've already taken the most important steps in ensuring the safety and reliability of your tower and antenna system. Following the manufacturer's specifications, using the right hardware, using antioxidants and following conservative designs are the true keys to success.

26.11.1 ANNUAL INSPECTION

An annual inspection is a critical part of your PM program. Most commercial companies do it religiously; many insurance companies require it as a condition of their coverage. An annual inspection entails examining everything in the tower and antenna system, including the ground system, concrete anchors and footings, and the tower structure. In addition to annual inspections, all installations should be inspected after ice storms or wind storms that exceed 60 mph.

You should correct any problems you discover in your inspection. If you're not sure about the seriousness of something you've found, talk to a knowledgeable friend or contact the manufacturer for advice. When you do a tower inspection, you should have enough supplies to redo several coax connector joints if necessary, as well as a note pad and pencil to write down any discrepancies that may require further action. You'll be able to take care of most problems on the spot, along with knowing what else you may need to finish the repairs. Push and pull on antennas and appurtenances (anything that's attached to the tower) to see if anything is loose. Something might look okay but pushing on it might reveal loose hardware or some other problem.

You should get in the habit of doing a quick visual check every time you climb the tower. Carry a wire brush, a can of cold-galvanizing spray, a roll of electrical tape, and a utility knife to perform small repairs along the way. A station notebook of relevant information found during inspection, along with exceptions and repairs is a handy reference item. The information that follows is based on commercial and *TIA-222* tower inspection standards.

Tower Structure

1) Check for damaged or faulty tower legs and braces. With welded towers such as Rohn *25G* and *45G,* the members cannot be replaced without replacing the whole section; minor bends or damage that do not alter the structural integrity can usually be tolerated.

2) Check all welds for integrity.

3) Examine the condition of the finish and any corrosion. Look for rust patches; use a wire brush and cold galvanizing paint to repair it.

4) In addition to visually checking any bolted connections, you should put a wrench to at least 10% of them to check for tightness. Any loose nuts or bolts should be retightened. Also look for missing hardware and replace it immediately.

Tower Alignment

1) The tower should be checked for plumb. A guyed tower is allowed a maximum deviation of one part in 400, or three inches per 100 feet. While a transit is the best way to check tower alignment, an electronic level will give you 0.1° accuracy, or a bubble level will indicate relative plumb. Even simpler is a long piece of string with a weight on the end, held an arm's length away from the tower; sight the string along the tower leg for a very quick and fairly accurate indication of tower plumb. For self-supporting towers, the allowed deviation allowed is 1 part in 250 or 4.8 inches in 100 feet.

2) Check the guy wires and guy insulators, using binoculars for the ones that aren't close to the ground or the tower.

3) Examine all guy wire and guy wire hardware including Preformed grips, turnbuckles, clamps, and shackles for damage. Make sure that all turnbuckle safety ties are intact.

4) Check guy wire tension with an instrument or another technique.

5) Examine the tower base and guy anchors. Look for any cracking of the concrete. Also look for evidence of movement in the soil of the anchor rods or base. Look for rust and/or corrosion. Excavate a buried anchor rod for twelve inches to inspect for hidden corrosion — some sources recommend inspecting anchor rods all the way to the concrete anchor.

Antennas, Cables and Appurtenances

1) Inspect antenna, boom-to-mast bracket and boom truss hardware for loose or missing hardware. Test nuts for tightness.

2) Look at each feed point joint and coax cable joint for compromised weatherproofing.

3) Check all cables for abrasion, binding and attachment.

4) Examine all appurtenances for missing hardware or corrosion.

Rotator

1) Check that all mounting bolts are tight and that they are not slipping in the rotator shelf or plate.

2) Check that the rotator mast clamp is securely holding the mast.

Grounding System

Do a visual inspection of the grounding system. Redo any connections that are corroded.

26.11.2 CRANK-UP MAINTENANCE

Crank-up towers are complex mechanical contrivances. While some are hand cranked, many have a motor, gearbox, cables, pulleys and limit switches — all of which should be carefully inspected twice a year.

The electric motors and gearbox are generally bulletproof and the only inspections are to check the oil level in the gearbox, the condition of the drive belt or chain (some sort of conditioner is helpful for each), and the operation of the cable drum (there are probably some Zerk grease fittings that need attention).

Pulleys are sometimes custom made by the manufacturer so you may not be able to run down to the local store and buy one. Some sheaves are made by the manufacturer and then an off-the-shelf bearing is inserted in the middle. This one you probably can replace.

Pulleys need to turn and not bind so a good thing to do is to watch the pulleys if they're exposed enough while the tower is being raised or lowered and see if there are any problems. (A simple dot or line drawn on the sheave itself will quickly show, even at a distance, whether it's turning or not.)

Crank-Up Cables

Crank-up towers depend almost entirely on their cables to operate reliably and safely. Exercise the cables by running the tower up and down a couple of times a month and don't always leave the tower in the same spot all the time, for example at the limit switches. Over time the cable can take a set if it's always at the same place so leaving it at different places spreads the wear over much more of the cable length.

The cables should be lubricated at least annually; twice a year would be even better. Do not use heavy grease or motor oil which will just attract grime and particles. Use a cable lubricant such as PreLube 6 and be sure to check for damage while you're doing the lube job. If you see any of the following, the cables should be replaced:

1) Damage in which a cable is significantly kinked or flattened.

2) Rust. This means serious rust, not surface rust that can be easily wiped or scraped off.

3) Excessive broken strands. Most crank-ups use 7×19 galvanized cable which means it has 133 strands in it. You're allowed to have six total broken strands and three in the same bundle before replacing the cable.

26.11.3 ROTATOR MAINTENANCE

Most rotator problems are first noticed as misalignment of the antennas with regard to where the control box indicator says they are pointing. With a light duty rotator, this happens frequently when the wind blows the antenna to a different heading. With no brake, the force of the wind can move the gear train and motor of the rotator, while the indicator remains fixed. Such rotator systems have a mechanical stop to prevent continuous rotation during operation, and provision is usually included to realign the indicator against the mechanical stop from inside the shack. During installation, the antenna must be oriented correctly for the mechanical stop position, which is usually North.

In larger rotator systems with an adequate brake, indicator misalignment is caused by mechanical slippage in the antenna boom-to-mast hardware. Many texts suggest that the boom be pinned to the mast with a heavy-duty bolt and the rotator be similarly pinned to the mast. There is a trade-off here. If there is sufficient wind to cause slippage in the couplings without pins, with pins the wind could break a rotator casting or transmission parts. The slippage will act as a clutch release, which may prevent serious damage to the rotator. On the other hand, you might not like to climb the tower and realign the system after each heavy windstorm.

26.11.4 WHEN SOMETHING FAILS

Failures to your installation can come in many forms, but wind is generally the common denominator. Rust, metal fatigue and overloading aren't usually a problem until the wind starts to blow. Other causes of failure could be lightning strikes, ice, vandalism or accidents.

Assess the Damage

The first thing to do is a visual inspection. Using binoculars if possible, take a look at everything from the ground to see if anything is bent or broken. If something is swinging in the wind, that's a major problem. If there is obvious damage, try to determine if it is in danger of falling. If so, evacuate the endangered area immediately and alert local emergency services. This is especially true if it looks as though it could fall on power lines, sidewalks or roadways. If you have damage that isn't an imminent danger to life or property, keep an eye on it until the storm is over to ensure that it doesn't get worse. If you have the opportunity, take some snapshots or video of the damage for documentation.

Prevent Further Damage

Your next task is to take prudent steps to prevent further damage, both to your property and to the property of others. This is not only common sense but also a requirement of the insurance company. You want to avoid or minimize the possibility of liability lawsuits for personal injury or the property damage of others. Tie anything off you can but *do not* attempt to climb the tower!

File an Insurance Claim

After the storm is over, call your homeowner's or renter's insurance agent and notify them of the loss. Do it orally first, then follow up with a letter. The insurance company may require a *"Proof of Loss."* They'll give you a claim number that you'll need to use in all written and verbal communications. Start a file with all your documentation, plus the other paperwork that you'll start accumulating. (See the article on insurance by Ray Fallen, ND8L, on this book's CD-ROM.)

Keep notes of every conversation with your insurance agent or claims adjuster with dates and times; you may have to refer to them in the future. At this point, you may want to write down all pertinent facts surrounding the loss for reference also. Send copies of your photos with your loss letter.

Estimate of Repairs

You'll make things very easy for your claims adjuster if you include an estimate of repair along with your letter and photos. The adjuster has probably never handled a radio tower loss before and will appreciate your help in getting a quote. Contact your local commercial rigger or antenna installation company and they'll give you the quote.

Insurance companies will want professional workers to perform professional repairs to your loss; they expect to pay the going rate and they expect licensed contractors to do the work. Be sure that your estimate for tower repair covers *all* of the work including: dismantling damaged parts, hauling away damaged parts and disposal, clean-up, labor for reinstallation including assembly of antennas, labor for reinstallation of tower, replacing all damaged materials including hardware, cables, rotators, and other items.

Don't be surprised if the estimate comes in quite a bit higher than you expect. Not only are you paying professionals to do all of the work, but a damaged tower or antenna system can be hazardous and a crane or other piece of equipment may be needed to remove it safely.

Stay in Your Comfort Zone

Needless to say, don't consider getting involved in the removal and repair of the damage unless you feel comfortable with it. If there is *any* doubt at all in your mind, either get the professionals in or bring in a piece of equipment such as a crane or boom truck. If anything is at a precarious or dangerous angle, don't touch it — send for the professionals!

26.12 BIBLIOGRAPHY

Source material and more extended discussions of the topics covered in this chapter can be found in the references listed below.

L. H. Abraham, "Guys for Guys Who Have To Guy," *QST*, Jun 1955, pp 33-34, 142.

K. Andress, "The K7NV Notebook", **k7nv.com/notebook**

R.W. Block, "Lightning Protection for the Amateur Radio Station," Parts 1-3, *QST*, Jun 2002, pp 56-59; Jul 2002, pp 48-52; Aug 2002, pp 53-55.

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

T. Brock-Fisher, "Is Your Tower Still Safe?," *QST*, Oct 2010, p 43-47.

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

D. Daso, "Workshop Chronicles," columns in *National Contest Journal.*

M. Frydeniund, *Lightning Protection for People and Property*, Van Nostrand Reinhold, 1993.

W. R. Gary, "Toward Safer Antenna Installations," *QST*, Jan 1980, p 56.

W. Hart, and E. Malone, *Lightning and Lightning Protection*, Interference Control Technologies, Inc, 1988

S. F. Hoerner, "Fluid Dynamic Drag," (Bricktown, NJ: Hoerner Fluid Dynamics, 1993), pp 1-10.

C. L. Hutchinson, R. D. Straw, *Simple and Fun Antennas for Hams* (Newington: ARRL, 2002).

M. P. Keown and L. L. Lamb, "A Simple Technique for Tower-Section Separation," *QST*, Sep 1979, pp 37-38.

S. Morris, *Up the Tower*, (Seattle: Champion Radio Products, 2009).

S. Morris, "Up the Tower," columns in *National Contest Journal.*

P. O'Dell, "The Ups and Downs of Towers," *QST*, Jul 1981, pp 35-39.

S. Phillabaum, "Installation Techniques for Medium and Large Yagis," *QST*, Jun 1979, pp 23-25.

PolyPhaser, see **www.smithspower.com/brands/polyphaser/services/media-library**and look for articles on lightning protection.

K. Rand, *Lightning Protection & Grounding Solutions for Communication Sites*, Polyphaser Corporation, 2000.

C. J. Richards, "Mechanical Engineering in Radar and Communications" (London: Van Nostrand Reinhold Co., 1969), pp 162-165.

T. Schiller, *Array of Light*, Third edition, **www.n6bt.com**.

H.G. Ufer, "Investigation and Testing of Footing Type Grounding Electrodes for Electrical Installations" IEEE Transactions Paper #63-1505, Power Apparatus Systems Vol. 83 pp 1042-1048: Oct 1964.

D. Weber "Determination of Yagi Wind Loads Using the Cross-Flow Principle," *Communications Quarterly*, Spring 1993.

B. White, E. White and J. White, "Assembling Big Antennas on Fixed Towers," *QST*, Mar 1982, pp 28-29.

L. Wolfert, "The Tower Alternative," *QST*, Nov 1980, pp 36-37.

W. C. Young., "Roark's Formulas for Stress & Strain" (New York: McGraw-Hill Co., 1989), pp 67, 96.

"How to Protect Your House and Its Contents Against Lightning," IEEE, 2005.

Lightning Protection for Engineers, National Lightning Safety Institute (NLSI), 2004.

Lightning Protection for Radio Transmitter Stations, Nautel Corporation, 1998.

Military Handbook MIL-HDBK-419A, Vol. 1(Basic Theory) and 2 (Applications), Grounding,

Bonding and Shielding for Electronic Equipments and Facilities, 1987 (**www.tscm.com/MIL-HDBK-419A.PDF**)

National Electrical Code, NFPA 70, National Fire Protection Association, Quincy, MA (**www.nfpa.org**).

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

Standards and Guidelines for Communications Sites, document 68P81089E50-B, Motorola, Inc., 2005. Also referred to as "R56" in the communications industry as it is administered by the R56 committee at Motorola.

Structural Standards for Steel Antenna Towers and Antenna Supporting Structures, TIA Standard TIA-222-G, Telecommunications Industry Association, Aug 2005 (**www.tiaonline.org**). May be purchased from IHS/Global Engineering Documents, 15 Inverness Way East, Englewood, CO, 80112-5704, 1-800-854-7179 (**www.global.ihs.com**).

APPENDIX A

DETERMINING ANTENNA AREAS AND WIND LOAD

The method for determining the flat projected area (FPA) of an antenna is quite simple. We'll use a Yagi antenna as an example. There are two worst-case areas that should be considered here. The first is the FPA of all the elements when the wind blows in the direction along the boom; that is, at right angles to the elements. The second FPA for a Yagi is when the wind is at right angles to the boom. One of these two orientations produces the worst-case exposed antenna area — all other wind angles present lower exposed areas. The idea is to take the highest of the FPAs for these two wind directions and call that the FPA of the antenna structure. See **Figure 26.55A.**

The element FPA is calculated by multiplying each element's dimension of length by its diameter and then summing the FPAs for all elements. The boom's FPA is computed by multiplying the boom's length by its diameter.

The reason for considering two potential peak-load orientations becomes clear when different frequency antennas are stacked on a mast or tower. Some antennas produce peak loads when the elements are broadside to the wind. This is typical of low-frequency Yagis, where the elements are very long lengths of aluminum tubing. On the other hand, the boom can dominate the surface area computations in higher-frequency Yagis.

The fundamentals responsible for the need to examine both potential FPAs for Yagis relates to how wind flows over a structure and develops loads. Called *The Cross-Flow Principle*, this was introduced to the communications industry by Dick Weber, K5IU, in 1993. The principle is based on the fact that the loads created by wind flowing across an antenna member only produce forces that are normal to (or perpendicular to) the major axis of the member. The resultant and component load calculations for this method are shown in Figure 26.55A.

For a Yagi, this means that wind forces on the elements act in-line with the boom, while forces on the boom act in-line with the elements. Figure 26.55B shows a force diagram for a typical Yagi. Figure 26.55C shows the FPA for a Yagi rotated through 90° of azimuth.

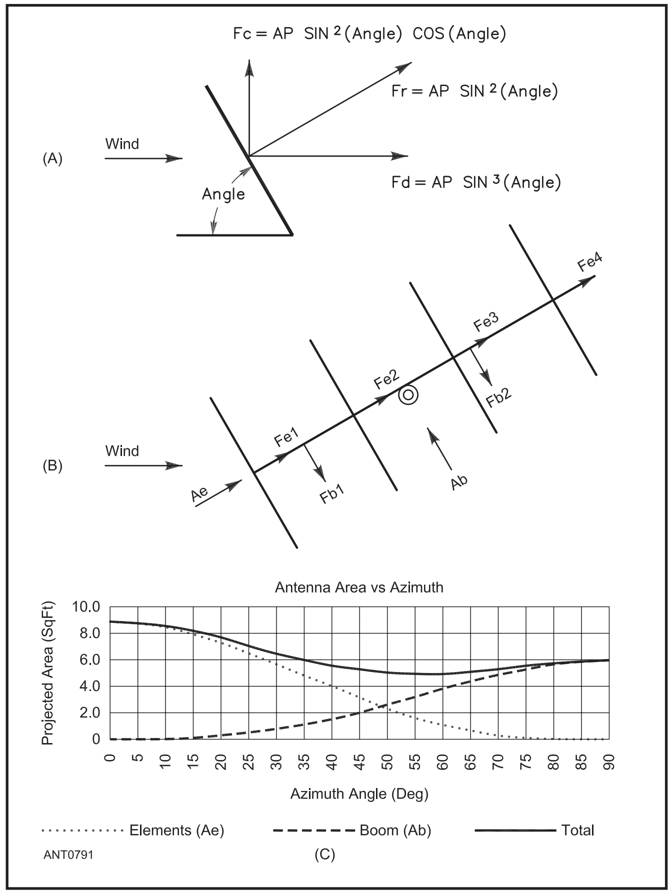


Figure 26.55 — Description of how loads are developed on a Yagi. At A, F_r is the resultant force from the wind load on a generalized member. F_d is the load acting downwind (drag) that creates the load on the tower. F_c is the lateral component of the wind load. The term A is the flat projected area (FPA), which is the broadside area normal to the wind. The term P is the wind pressure. At B, A_e is the total element area, while Ab is the total boom area. All the loads due to the wind act normal to the antenna sections— the force on element #1 (F_{e1}) acts along the axis of the boom, for example. At C, a plot of the effective FPA as a function of the azimuthal wind direction for a Yagi, ignoring drag coefficients. The Yagi in this example has 9.0 square feet of element FPA and 6.0 square feet of boom FPA. The worst-case FPAs occur with the beam pointed in the wind and with the boom broadside to the wind. To determine the actual tower loading, the actual drag coefficients and wind pressures must be used.

Antenna Placement on the Mast/Tower

Another important consideration is where the antenna(s) will be placed on the tower. As mentioned before, most generic tower specifications assume that the entire antenna load is applied at the top of the tower. Most amateur installations have a tubular mast extending above the tower top, turned by a rotator mounted down inside the tower. Multiple Yagi antennas are often placed on the mast above the tower top, and you must make sure that both the tower and the mast can withstand the wind forces on the antennas.

For freestanding towers, you can determine how a proposed antenna configuration compares to the tower manufacturer's rating by using an *Equivalent Moment* method. The method computes the bending moment generated at the base of the tower by wind loads on the tower's rated antenna area located right at the top of the tower and compares that to the case when the antenna is mounted on a mast sticking out of the top of the tower.

The exact value of wind pressure is not important, so long as it is the same for both comparisons. The wind load on the tower itself can be ignored because it is the same in both comparisons and the drag coefficients for the antennas can also be

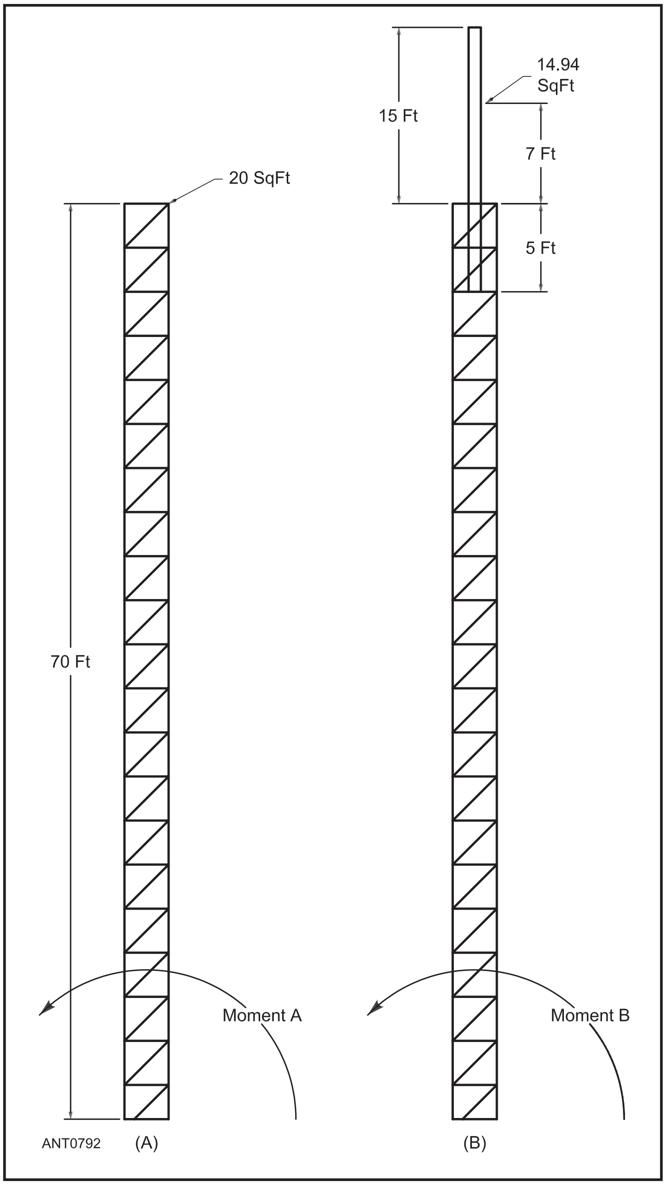


Figure 26.56 — At A, a 70-foot tower rated for 20 square feet of antenna load at the top. At B, the same tower with a 2-inch OD, 20-foot long mast, with an antenna mounted 7 feet above the top of the tower. Both configurations produce the same tower load.

ignored if all calculations are performed using flat projected antenna areas, as we've recommended previously.

Keep in mind that this approach does not calculate *actual* loads and moments relevant to any specific tower design standard, but it does allow equivalent comparisons when the wind pressure is constant and all the antenna areas are of the same type. An example is in order.

Figure 26.56A shows a generic tower configuration, with a concentrated antenna load at the top of the tower. We'll assume that the tower manufacturer rates this tower at 20 square feet of flat projected antenna area. Figure 26.56B shows a typical amateur installation with a rotating mast and an antenna mounted 7 feet above the top of the tower. To make the calculations easy, we select a wind pressure of 1 pound per square foot (1 psf). This makes the tower base moment calculation for Figure 26.56A:

Antenna load = 20 feet^2 × 1 psf = 20 pounds
Base moment = 70 feet × 20 pounds = 1400 foot-pounds.

This is the target value for the comparison. An equivalent configuration would produce the same base moment. For the configuration in Figure 26.56B, we assume a tubular 2-inch diameter mast that is 20 feet long, mounted 5 feet down inside the tower. Note that the lattice structure of the tower allows the wind to "see" the whole length of the mast and that we can consider the force distributed along the mast as being a single force concentrated at the mast's center. The flat projected area of the mast by itself, without the antenna, is:

Mast area = 20 feet × 2 inches / 12 inches/foot = 3.33 square feet

The center of the mast is located at a height of 75 feet. Using the same 1-psf-wind load, the base bending moment due to the mast alone is:

Base moment (due to mast) = 3.33 feet^2 × 1 psf × 75 feet = 249.75 foot-pounds

Including the mast in the configuration reduces the allowable antenna load. The remaining target base moment left for the antenna is found by subtracting the moment due to the mast from the original target value:

New base target moment = 1400 − 249.75 foot-pounds = 1150.25 foot-pounds.

The antenna in Figure 26.56B is located at a height of 77 feet. To obtain the allowable antenna area at this elevation we divide the new base target moment by the antenna height, yielding an allowable antenna load of:

1150.25 foot-pounds / 77 feet = 14.94 pounds.

Since we chose a wind load of 1 psf, the allowable antenna FPA has been reduced to 14.94 square feet from 20 square feet. If the projected area of the antenna we are planning to mount in the new configuration is less than or equal to this value, we have satisfied the requirements of the original design. You can use this equivalent-moment method to evaluate different configurations, even ones involving multiple antennas on the mast or situations with additional antennas placed along the tower below the tower top.

For guyed towers, the analyses become much more rigorous to solve. Because the guys and their behaviors are such a significant portion of the tower support mechanism, these designs can become very sensitive to antenna load placements. A general rule of thumb for guyed towers is never to exceed the original tower-top load rating, regardless of distributed loads along its length. Once you redistribute the antenna load placements along a guyed tower, you should do a fresh analysis, just to be sure.

You can run evaluations using the above method for antennas placed on the mast above a guyed tower top. The use of the Equivalent-Moment method for antennas mounted below the top of a guyed tower, however, can become quite suspect, since many generic tower designs have their intermediate guys sized for zero antenna loads lower down the tower. The proper approach in this case is to have a qualified mechanical engineer check the configuration, to see if guy placement and strength is adequate for the additional antennas down the tower.

Mounting the mast and antenna as shown in **Figure 26.56B** increases tower loads in the region of the mast. You should investigate these loads to ensure that the tower bracing in that area is sufficient.

APPENDIX B

CALCULATING THE REQUIRED MAST STRENGTH

When you mount antennas on a mast above the tower top, you should examine the bending loads on the mast to ensure that it will be strong enough. This section explains how to perform mast stress calculations for a single sustained wind speed. This procedure does not include height, exposure and gust-response factors found in most tower design standards.

Here are some fundamental formulas and values used to calculate the bending stress in a mast mounted in the top of a tower. The basic formula for wind pressure is:

$$P = 0.00256\ V^2 \qquad \text{(Eq 1)}$$

where

P is the wind pressure is in pounds per square foot (psf)

V = wind speed in miles per hour (mph)

This assumes an air density for standard temperature and atmospheric pressure at sea level. The wind speed is not the Basic Wind Speed discussed in other sections of this chapter. It is simply a steady state (static) wind velocity.

The formula for calculating the force created by the wind on a structure is:

$$F = P \times A \times C_d \qquad \text{(Eq 2)}$$

where

P = the wind pressure from Eq 1

A = the flat projected area of the structure (square feet)

C_d = drag coefficient for the shape of the structure's members.

The commonly accepted *drag coefficient* for long cylindrical members like the tubing used for the mast and antenna is 1.20. The coefficient for a flat plate is 2.0.

The formula used to find the *bending stress* in a simple beam like our mast is:

$$\sigma = (M \times c) / I \qquad \text{(Eq 3)}$$

where

σ = the stress in pounds per square inch (psi)

M = *bending moment* at the base of the mast (inch-pounds)

c = ½ of the mast outside diameter (inches)

I = *moment of inertia* of the mast section (inches^4)

In this equation you must make sure that all values are in the same units. To arrive at the mast stress in pounds per square inch (psi), the other values need to be in inches and pounds also. The equation used to find the moment of inertia for the round tubing mast section is:

$$I = \pi/4\ (R^4 - r^4) \qquad \text{(Eq 4)}$$

where

I = Moment of Inertia of the section (inches^4)

R = Radius of tube outside diameter (inches)

r = Radius of tube inside diameter (inches)

This value describes the distribution of material about the mast *centroid*, which determines how it behaves under load. The equation used to compute the *bending moment* at the base of the mast (where it is supported by the tower) is:

$$M = (F_M \times L_M) + (F_A \times L_M) \qquad \text{(Eq 5)}$$

where

F_M = wind force from the mast (pounds)

L_M = Distance from tower top to center of mast (inches)

F_A = Wind force from the antenna (pounds)

L_A = Distance from tower top to antenna attachment (inches)

L_M is the distance to the center of the portion of the mast extending above the tower top. Additional antennas can be added to this formula by including their F × L. In the installation shown in **Figure 26.56B**, a wind speed of 90 mph, and a mast that is 2 inches OD, with a 0.250-inch wall thickness, the steps for calculating the mast stress are:

1) Calculate the wind pressure for 90 mph, from Eq 1:

$$P = .00256\ V^2 = .00256 \times (90)^2 = 20.736 \text{ psf}$$

2) Determine the flat projected area of the mast. The portion of the mast above the tower is 15 feet long and has an outside diameter of 2 inches, which is 2/12 feet.

Mast FPA, A_M = 15 feet × (2 inches / 12 inches/feet) = 2.50 square feet.

3) Calculate the wind load on the mast, from Eq 2:

Mast Force, $F_M = P \times A \times C_d = 20.736$ psf $\times$ 2.50 feet^2 $\times$ 1.20 = 62.21 pounds

4) Calculate the wind load on the antenna: From Eq 2:

Antenna Force, $F_A = P \times A \times C_d = 20.736$ psf $\times$ 14.94 feet^2 $\times$ 1.20 = 371.76 pounds

5) Calculate the mast *Bending Moment*, from Eq 5:

$M = (F_M \times L_M) + (F_A \times L_A)$ = (62.21 pounds × 90 inches) + (371.76 pounds × 84 inches) = 36827 inch-pounds

where

L_M = 7.5 feet × 12 inches/foot = 90 inches
L_A = 7.0 feet × 12 inches/foot = 84 inches.

6) Calculate the mast *Moment of Inertia*, from Eq 4:

$$I = \frac{\pi}{4}(R^4 - r^4) = \frac{\pi}{4}(1.0^4 - 0.75^4) = 0.5369 \text{ inches}^4$$

where, for a 2.0-inch OD and 0.250-inch wall thickness tube, R= 1.0 and r = 0.75.

7) Calculate the mast *Bending Stress*, from Eq 3:

$$\sigma = \frac{M \times c}{I} = \frac{36827 \text{ inch-pounds} \times 1.0 \text{ inches}}{0.5369} = 68592 \text{ psi}$$

If the yield strength of the mast material is greater than the calculated bending stress, the mast is considered safe for this configuration and wind speed. If the calculated stress is higher than the mast yield strength, a stronger alloy, or a larger mast, or one with a thicker wall is required.

When evaluating a mast with multiple antennas attached to it, special care should be given to finding the worst-case condition (wind direction) for the system. What may appear to be the worst load case, by virtue of the combined flat projected antenna areas, may not always be the exposure that creates the largest mast bending moment. Masts with multiple stacked antennas should always be examined to find the exposure that produces the largest mast bending moment. The antenna flat projected areas at 0° and 90° azimuths are particularly useful for this evaluation.

One way of reducing the net wind torque on a mast holding multiple antennas is to mount antennas on opposite sides of the mast. This alternate mounting scheme causes the wind torque from each antenna to cancel at least partially, reducing the total torque experienced by the mast.