Chapter 22

Antenna Supports

A prime consideration in the selection of a support for an antenna is that of structural safety. Building regulations in many localities require that a permit be obtained in advance of the erection of certain structures, often including antenna poles or towers. In general, localities having such requirements also have building safety codes that must be observed. Such regulations may govern the method and materials used in construction of, for example, a self-supporting tower. Checking with your local government building department before putting up a tower may save a good deal of difficulty later, because a tower would have to be taken down or modified if not approved by the building inspector on safety grounds.

Municipalities have the right and duty to enforce any reasonable regulations having to do with the safety of life or property. The courts generally have recognized, however, that municipal authority does not extend to aesthetic questions. The fact that someone may object to the mere presence of a pole, tower or other antenna structure because in his opinion it detracts from the beauty of the neighborhood is not grounds for refusing to issue a permit for a safe structure to be erected. Since the introduction of PRB-1 (federal preemption of unnecessarily restrictive antenna ordinances), this principle has been borne out in many courts. Permission for erecting amateur towers is more easily obtained than in the recent past because of this legislation.

Even where local regulations do not exist or are not enforced, the amateur should be careful to select a location and a type of support that contribute as much safety as possible to the installation. If collapse occurs, the chances of personal injury or property damage should be minimized by careful choice of design and erection methods. A single injury can be far more costly than the price of a more rugged support, in terms of both monetary loss and damage to the public respect for amateur radio.

This chapter has been reviewed and rewritten by Kurt Andress, K7NV.

TREES AS ANTENNA SUPPORTS

From the beginning of Amateur Radio, trees have been used widely for supporting wire antennas. Trees cost noth-

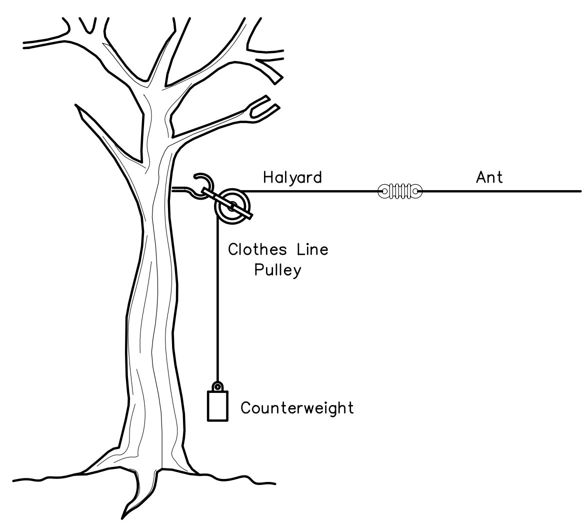


Fig 1—A method of counter weighting to minimize antenna movement and avoid its breaking from tree movement in the wind. The antenna may be lowered without climbing the tree by removing the counterweight and tying additional rope at the bottom end of the halyard. Excess rope may be left at the counterweight for this purpose, as the knot at the lower end of the halyard will not pass through the pulley.

ing to use, and often provide a means of supporting a wire antenna at considerable height. As antenna supports, trees are unstable in the presence of wind, except in the case of very large trees used to support antennas well down from the top branches. As a result, tree-supported antennas must be constructed much more sturdily than is necessary with stable supports. Even with rugged construction, it is unlikely that an antenna suspended from a tree, or between trees, will stand up indefinitely. Occasional repair or replacement usually must be expected.

There are two general methods of securing a pulley to a tree. If the tree can be climbed safely to the desired level, a pulley can be attached to the trunk of the tree, as shown in **Fig 1**. To clear the branches of the tree, the antenna end of the halyard can be tied temporarily to the tree at the pulley level. Then the remainder of the halyard is coiled up, and the coil thrown out horizontally from this level, in the direction in which the antenna runs. It may help to have the antenna end of the halyard weighted.

After attaching the antenna to the halyard, the other end is untied from the tree, passed through the pulley, and brought to ground along the tree trunk in as straight a line as possible. The halyard need only be long enough to reach the ground after the antenna has been hauled up. (Additional rope can be tied to the halyard when it becomes necessary to lower the antenna.)

The other method consists of passing a line over the tree from ground level, and using this line to haul a pulley up into the tree and hold it there. Several ingenious methods have been used to accomplish this. The simplest method employs a weighted pilot line, such as fishing line or mason's chalk line. By grasping the line about two feet from the weight, the weight is swung back and forth, pendulum style, and then heaved with an underhand motion in the direction of the treetop.

Several trials may be necessary to determine the optimum size of the weight for the line selected, the distance between the weight and the hand before throwing, and the point in the arc of the swing where the line released. The weight, however, must be sufficiently large to carry the pilot line back to ground after passing over the tree. Flipping the end of the line up and down so as to put a traveling wave on the line often helps to induce the weight to drop down if the weight is marginal. The higher the tree, the lighter the weight and the pilot line must be. A glove should be worn on the throwing hand, because a line running swiftly through the bare hand can cause a severe burn.

If there is a clear line of sight between ground and a particularly desirable crotch in the tree, it may eventually be possible to hit the crotch after a sufficient number of tries. Otherwise, it is best to try to heave the pilot line completely over the tree, as close to the centerline of the tree as possible. If it is necessary to retrieve the line and start over again, the line should be drawn back very slowly; otherwise the swinging weight may wrap the line around a small limb, making retrieval impossible.

Stretching the line out straight on the ground before throwing may help to keep the line from snarling, but it places extra drag on the line, and the line may snag on obstructions overhanging the line when it is thrown. Another method is to make a stationary reel by driving eight nails, arranged in a circle, through a 1-inch board. After winding the line around the circle formed by the nails, the line should reel off readily when the weighted end of the line is thrown. The board should be tilted at approximately right angles to the path of the throw.

Other devices that have been used successfully to pass a pilot line over a tree are a bow and arrow with heavy thread tied to the arrow, and a short casting rod and spinning reel used by fishermen. The Wrist Rocket slingshot made from surgical rubber tubing and a metal frame has proved highly effective as an antenna-launching device. Still another method that has been used where sufficient space is available is flying a kite to sufficient altitude, walking around the tree until the kite string lines up with the center of the tree, and paying out string until the kite falls to the earth. This method can be used to pass a line over a patch of woods between two higher supports, which may be impossible using any other method.

The pilot line can be used to pull successively heavier lines over the tree until one of adequate size to take the strain of the antenna has been reached. This line is then used to haul a pulley up into the tree after the antenna halyard has been threaded through the pulley. The line that holds the pulley must be capable of withstanding considerable chafing where it passes through the crotch, and at points where lower branches may rub against the standing part. For this reason, it may be advisable to use galvanized sash cord or stranded guy wire for raising the pulley.

Larger lines or cables require special attention when they must be spliced to smaller lines. A splice that minimizes the chances of coming undone when coaxed through the tree crotch must be used. One type of splice is shown in **Fig 2**.

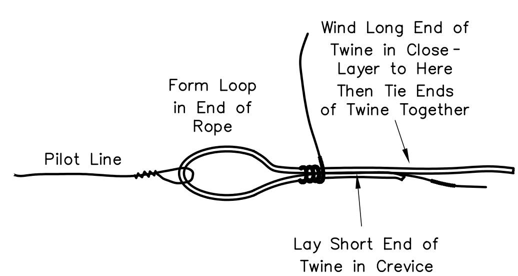


Fig 2—In connecting the halyard to the pilot line, a large knot that might snag in the crotch of a tree should be avoided, as shown.

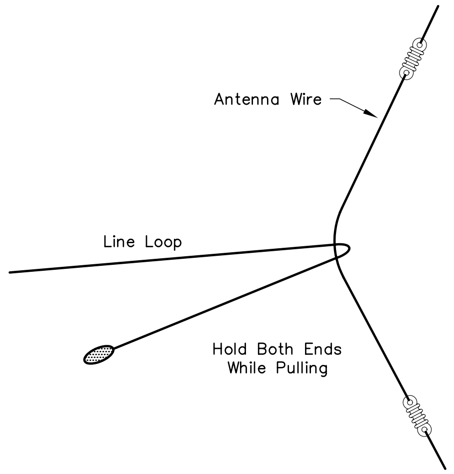


Fig 3—A weighted line thrown over the antenna can be used to pull the antenna to one side of overhanging obstructions, such as tree branches, as the antenna is pulled up. When the obstruction has been cleared, the line can be removed by releasing one end.

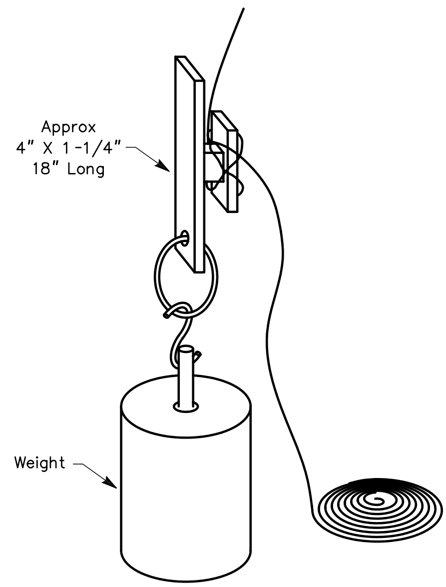


Fig 4—The cleat eliminates the need to untie a knot that may be weather hardened.

The crotch in which the line first comes to rest may not be sufficiently strong to stand up under the tension of the antenna. If, however, the line has been passed over (or close to) the center line of the tree, it will usually break through the lighter crotches and come to rest in a stronger one lower in the tree.

Needless to say, any of the suggested methods should be used with due respect to persons or property in the immediate vicinity. A child's sponge-rubber ball (baseball size) makes a safe weight for heaving a heavy thread line or fishing line.

If the antenna wire snags in the lower branches of the tree when the wire is pulled up, or if other trees interfere with raising the antenna, a weighted line thrown over the antenna and slid to the appropriate point is often helpful in pulling the antenna wire to one side to clear the interference as the antenna is being raised. This is shown in **Fig 3**.

Wind Compensation

The movement of an antenna suspended between supports that are not stable in the wind can be reduced by the use of heavy springs, such as screen-door springs under tension, or by a counterweight at the end of one halyard. This is shown in Fig 1. The weight, which may be made up of junkyard metal, window sash weights, or a galvanized pail filled with sand or stone, should be adjusted experimentally for best results under existing conditions. **Fig 4** shows a convenient way of fastening the counterweight to the halyard. It eliminates the necessity for untying a knot in the halyard, which may have hardened under tension and exposure to the weather.

TREES AS SUPPORTS FOR VERTICAL WIRE ANTENNAS

Trees can often be used to support vertical as well as horizontal antennas. If the tree is tall and has overhanging branches, the scheme of **Fig 5** may be used. The top end of the antenna is secured to a halyard passed over the limb, brought back to ground level, and fastened to the trunk of the tree.

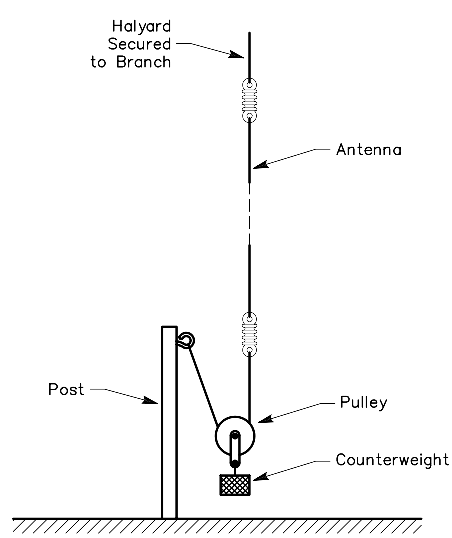


Fig 5—Counterweight for a vertical antenna suspended from an overhanging tree branch.

MAST MATERIALS

Where suitable trees are not available, or a more stable support is desired, light-duty guyed masts are suitable for wire antennas of reasonable span length. At one time, most amateur masts were constructed of lumber, but the TV industry has brought out metal masts that are inexpensive and much more durable than wood. However, there are some applications where wood is necessary or desirable.

A Ladder Mast

A temporary antenna support is sometimes needed for an antenna system for antenna testing, site selection, emergency exercises or Field Day. Ordinary aluminum extension ladders are ideal candidates for this service. They are strong, light, extendable, weatherproof and easily transported. Additionally, they are readily available and can be returned to normal use once the project is concluded. A ladder tower will support a lightweight triband beam and rotator.

With patience and ingenuity one person can erect this assembly. One of the biggest problems is holding the base down while "walking" the ladder to a vertical position. The ladder can be guyed with $^1/_4$-inch polypropylene rope. Rope guys are arranged in the standard fashion with three at each level. If help is available, the ladder can be walked up in its retracted position and extended after the antenna and rotator are attached. The lightweight pulley system on most extension ladders is not strong enough to lift the ladder extension. This mechanism must be replaced (or augmented) with a heavy-duty pulley and rope. Make sure when attaching the guy ropes that they do not foul the operation of the sliding upper section of the ladder.

There is one hazard in this system that must be avoided: Do not climb or stand on the ladder when it is being extended—even as much as one rung. Never stand on the ladder and attempt to raise or lower the upper section. Do all the extending and retracting with the heavy-duty rope and pulley!

If the ladder is to be raised by one person, use the following guidelines. First, make sure the rung-latching mechanism operates properly before beginning. The base must be hinged so that it does not slip along the ground during erection. The guy ropes should be tied and positioned in such a way that they serve as safety constraints in the event that control of the assembly is lost. Have available a device (such as another ladder) for supporting the ladder during rest periods. (See **Fig 6**.)

Fig 6—Walking the ladder up to its vertical position. Keith, VE2AQU, supports the mast with a second ladder while Chris, VE2FRJ, checks the ropes. (*Photo by Keith Baker, VE2XL.*)

After the ladder is erect and the lower section guys tied and tightened, raise the upper portion one rung at a time. Do not raise the upper section higher than it is designed to go; safety is far more important than a few extra feet of height.

For a temporary installation, finding suitable guy anchors can be an exercise in creativity. Fence posts, trees, and heavy pipes are all possibilities. If nothing of sufficient strength is available, anchor posts or pipes can be driven into the soil. Sandy soil is the most difficult to work with because it does a very poor job of holding anchors. A discarded car axle can be driven into the ground as an anchor, as its mass and strength are substantial. A chain and car-bumper jack can be used to remove the axle when the operation is done.

Above all else, keep the tower and antenna away from power lines. Make sure that nothing can touch the lines if the assembly falls. Disassemble by reversing the process. Ladder towers are handy for "quickie" antenna supports, but as with any improvisation of support materials, care must be taken to ensure safe construction.

The A-Frame Mast

A light and relatively inexpensive mast is shown in **Fig 7**. In lengths up to 40 feet it is very easy to erect and will stand the pull of ordinary wire antenna systems. The lumber used is 2 × 2-inch straight-grained pine (which many lumber yards know as hemlock) or even fir stock. The uprights can be as long as 22 feet each (for a mast slightly over 40 feet high) and the cross pieces are cut to fit. Four pieces of 2 × 2 lumber, each 22 feet long, provides more than enough. The only other materials required are five $^1/_4$-inch carriage bolts $5^1/_2$ inches long, a few spikes, about 300 feet of stranded or solid galvanized wire for guying, enough glazed porcelain compression ("egg") insulators to break up the guys into sections, and the usual pulley and halyard rope. If the strain insulators are put in every 20 feet, approximately 15 of them will be enough.

After selecting and purchasing the lumber—which should be straight-grained and knot-free—sawhorses or boxes should be set up and the mast assembled as shown in **Fig 8**. At this stage it is wise to give the mast a coat of primer and a coat of outside white latex paint.

After the coat of paint is dry, attach the guys and rig the pulley for the antenna halyard. The pulley anchor should be at the point where the top stays are attached so the backstay will assume the greater part of the load tension. It is better to use wire wrapped around the mast with a small through-bolt to prevent sliding down than to use eyebolts.

If the mast is to stand on the ground, a couple of stakes should be driven to keep the bottom from slipping. At this point the mast may be "walked up" by a helper. If it is to go on a roof, first stand it up against the side of the building and then hoist it, from the roof, keeping it vertical. The whole assembly is light enough for two men to perform the complete operation—lifting the mast, carrying it to its permanent berth, and fastening the guys with the mast vertical. It is entirely practical to put up such a mast on a flat area of roof that would be too small to erect a regular tower installation, one that had to be raised vertically on the same spot.

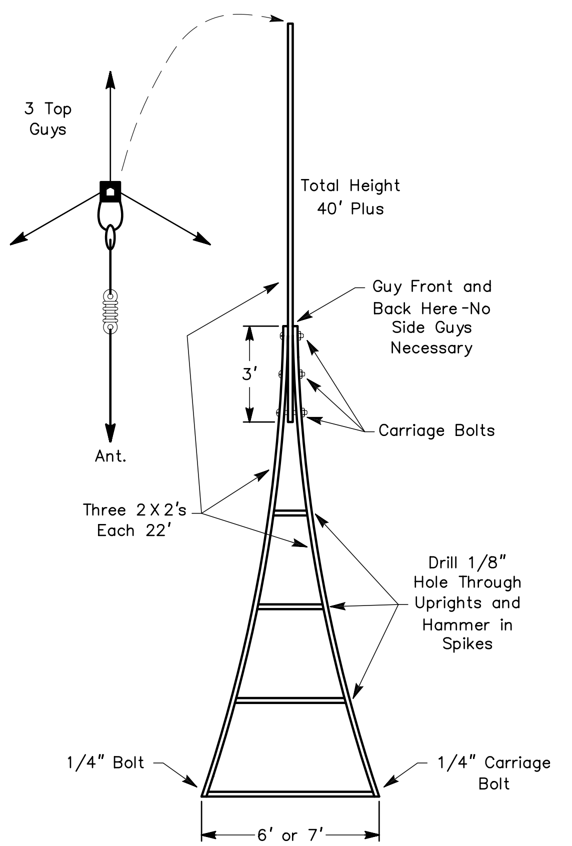


Fig 7—The A-frame mast is lightweight and easily constructed and erected.

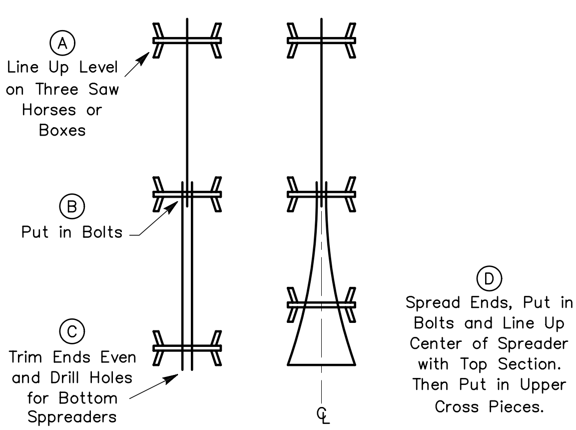


Fig 8—Method of assembling the A-frame mast on sawhorses.

TV Mast Material

TV mast is available in 5- and 10-foot lengths, $1^1/_4$ inches diameter, in both steel and aluminum. These sections are crimped at one end to permit sections to be joined together. A form that is usually more convenient is the telescoping mast available from many electronic supply houses. 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 $1^1/_4$ inches diameter, and the bottom section is $2^1/_2$ inches diameter.

Guy rings are provided at 10-foot intervals, but guys may not be required at every point. Guying is essential at the top and at least one other place near the center of the mast. If the mast has any tendency to whip in the wind, or to bow under the load of a horizontal wire antenna, additional guys should be added at the appropriate points.

MAST GUYING

Three guy wires in each set are usually adequate for a mast. These should be spaced equally round the mast. The required number of sets of guys depends on the height of the mast, its natural sturdiness (or stiffness), and the required antenna tension. A 30-foot-high mast usually requires two sets of guys, and a 50-foot mast needs at least three sets. One guy of the top set should be anchored to a point directly opposing the force exerted by the wire antenna. The other two guys of the same set should be spaced 120° with respect to the first, as shown in the inset in Fig 7.

Generally, the top guys should be anchored at distances from the base of the mast at least 60% of the mast height. The distance of the guy anchors from the mast determines the guy loads and the vertical load compressing the mast. At a 60% distance, 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. With the anchors out 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.

Whenever possible, the largest available anchor spacing should be used. The additional compression on the mast, due to 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 in a straight line.

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 the compression in 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 change by 10 to 20%.

Example: For a 30-foot high mast with three guy sets, the equal-guy locations would be every 10 feet. We can make the center span, 10 feet long, and then make the lower span 15% shorter and the top span 15% longer. While this is not an exact technical method to determine the best solution, the approach will create different mechanical resonant frequencies for the spans, with the span lengths approximately adjusted for the varying buckling requirements.

You can eliminate electrical resonance from conductive guy materials that might cause distortion of the antenna radiation pattern by breaking each guy into non-resonant lengths using strain insulators (see **Figs 9** and **10**). This subject is covered in detail later in this chapter.

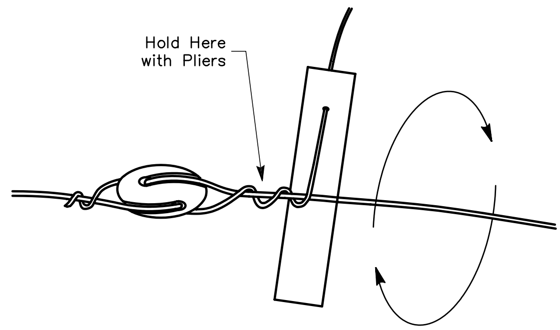


Fig 9—Simple lever for twisting solid guy wires when attaching strain insulators.

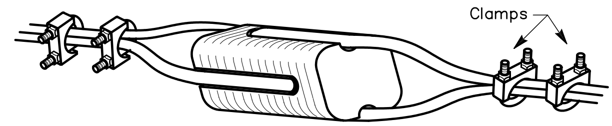


Fig 10—Stranded guy wire should be attached to strain insulators by means of standard cable clamps made to fit the size of wire used.

Guy Material

When used within their safe load ratings, you may use any of the halyard materials listed in Chapter 20 for the mast guys. Nonmetallic materials have the advantage that there is no need to break them up into sections to avoid unwanted resonant interactions. All of these 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.

Guy Anchors

Figs 11 and **12** show two different kinds of guy anchors. In Fig 11, 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. Fig 12 shows a *dead-man* type of

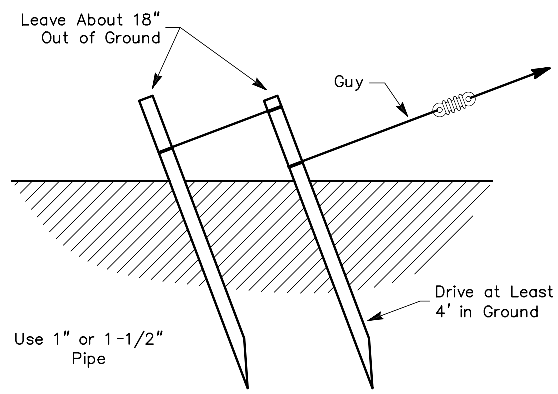


Fig 11—Driven guy anchors. One pipe is usually sufficient for a small mast. For added strength, a second pipe may be added, as shown.

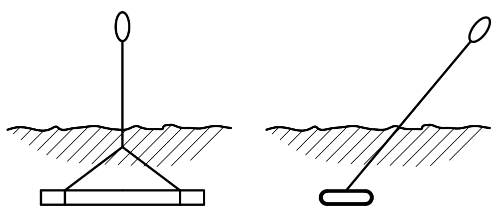


Fig 12—Buried *dead-man* guy anchor (see text).

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, like EHS guy cable. You should coat the buried part of the cable with roofing tar, and thoroughly dry it prior to burial to enhance resistance to corrosion.

Also available are some heavy auger-type anchors that screw into the earth. 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.

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, the tension needed 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 large wind events, to ensure the guys and anchors have not stretched or moved, allowing the mast to get away from the required straight alignment.

ERECTING A MAST OR OTHER SUPPORT

Masts less than 30 feet high usually can be simply walked up after blocking the bottom end securely. Blocking must be done so that the base can neither slip along the ground nor upend when the mast is raised. An assistant should be stationed at each guy wire, and may help by pulling the proper guy wire as the mast nears the vertical position. Halyards can be used in the same manner.

As the mast is raised, it may be helpful to follow the underside of the mast with a scissors rest (**Fig 13**), should a pause in the hoisting become necessary. The rest may also be used to assist in the raising if an assistant mans each leg.

As the mast nears the vertical position, those holding the guy wires should be ready to temporarily fasten the guys to prevent the mast from falling. The guys can then be adjusted until the mast is perfectly straight.

For masts over 30 feet long, a *gin pole* of some form may be required, as shown in Fig 13. Several turns of

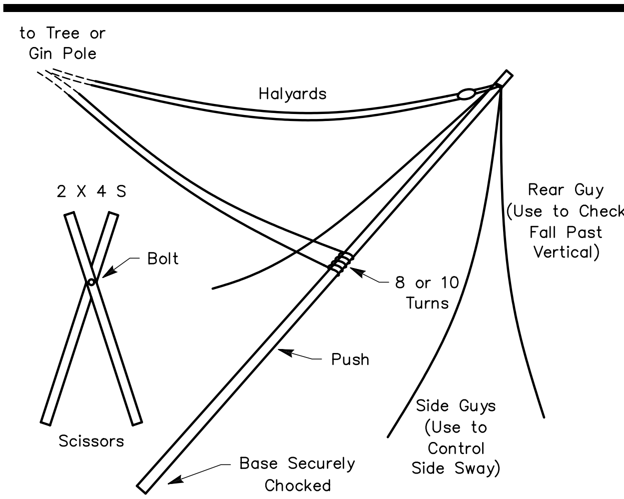


Fig 13—Pulling on a gin line fastened slightly above the center point of the mast and on the halyards can assist in erecting a tall mast. The tensions should be just enough to keep the mast in as straight a line as possible. The "scissors" may be used to push on the under side and to serve as a rest if a pause in raising becomes necessary.

rope are wound around a point on the mast above center. The ends of the rope are then brought together and passed over a tree limb. The rope should be pulled as the mast is walked up to keep the mast from bending at the center. If a tree is not available, a post, such as a 2 × 4, temporarily erected and guyed, can be used. After the mast has been erected, the assisting rope can be removed by walking one end around the mast (inside the guy wires).

Telephone poles and towers are much sturdier supports. Such supports may require no guying, but they are not often used solely for the support of wire antennas because of their relatively high cost. For antenna heights in excess of 50 feet, however, they are usually a most practical form of support.

Tower And Antenna Selection and Installation

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.

Perhaps the most important consideration for many amateurs is the effect of the antenna system on the surrounding environment. If plenty of space is available for a tower installation and if there is little chance of causing esthetic distress on the part of family members or the neighbors, the amateur is indeed fortunate. Often, the primary considerations are purely financial. For most, however, the size of the property, the effect of the system on others, local ordinances, and the proximity of power lines and poles influence the selection of the tower/antenna system considerably.

The amateur must consider the practical limitations for installation. Some points for consideration are given below:

1) A tower should not be installed in a position where it could fall onto a neighbor's property.
2) The antenna must be located in such a position that it cannot possibly tangle with power lines, either during normal operation or if the structure should fall.
3) Sufficient yard space must be available to position a guyed tower properly. The guy anchors should be between 60% and 80% of the tower height in distance from the base of the tower on level ground—sloping terrain may require larger areas.
4) Provisions must be made to keep children from climbing the support. (Poultry netting around the tower base will serve this need.)
5) Local ordinances should be checked to determine if any legal restrictions affect the proposed installation.

Other important considerations are (1) the total dollar amount to be invested, (2) the size and weight of the antenna desired, (3) the climate, and (4) the ability of the owner to climb a fixed tower.

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 EIA (Electronic Industries Assoc.) RS-222 and 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.

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. Check out the Web site at **www.championradio.com**, which contains EIA basic wind speed tables for every county in the USA. UBC speeds are available at almost every local library.

Antenna manufacturers also provide antenna data to assist in the selection process. Unfortunately, antenna mechanical designs do not always follow the same design standards used for towers. Proper antenna selection often means that you must determine the antenna surface areas yourself to avoid overloading the tower. More discussion about this follows later in this chapter.

It is often very helpful to the novice tower installer to visit other local amateurs who have installed towers. Look over their hardware and ask questions. If possible, have a few local experienced amateurs look over your 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 TOWER

Towers for supporting antennas come in a variety of different types. Each type has its own set of benefits and limitations, or conditions and requirements. Often, you can choose a particular tower type by considering issues other than pure mechanical performance. Understanding how each type of tower functions, and what its respective requirements are, are the first steps in making the best tower selection for your own situation.

Guyed Towers

The most common variety of tower is the *guyed tower* made of identical stacked sections, supported by guy cables attached to ground anchors placed symmetrically around the tower. These towers are the most economical, in terms of feet per dollar investment, and are more efficient for carrying antenna loads than non-guyed towers.

The guys resist the lateral loads on the system created by the wind. Since the guys slope down to the ground, horizontal loads due to the wind result in vertical loads applied to the tower at each tower/guy connection. The tower becomes a compression member, trying to resist the column compression generated by the guy reactions. A tower in compression can buckle, so the distance between guy connections along the tower is important.

Tower Bases for Guyed Towers

Another 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.

The configuration shown in **Fig 14A** 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

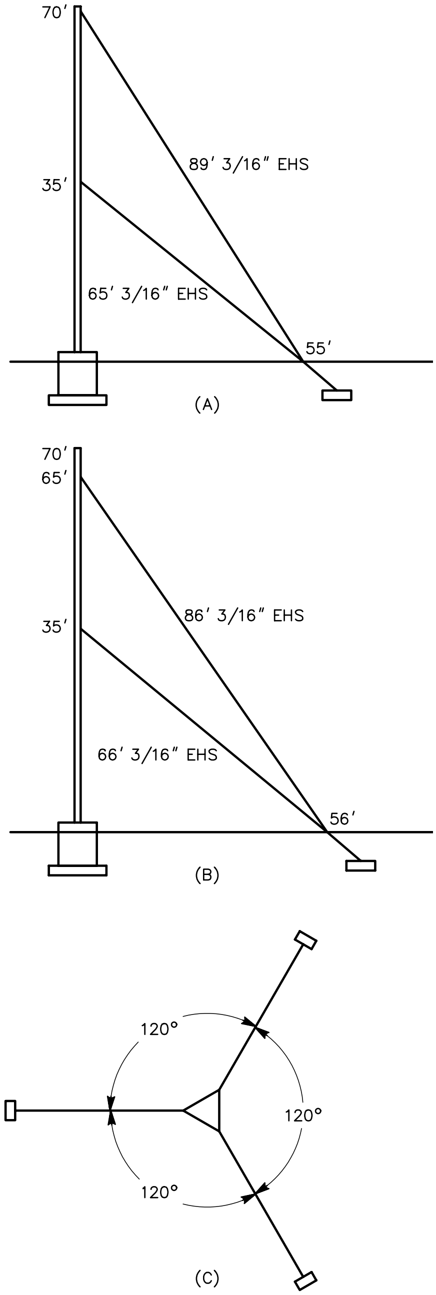


Fig 14—The proper method of installation of a guyed tower. At A, the method recommended for most amateur installations. At B, the method shown in later Rohn catalogs. This places considerable strain on the top section of the tower when large antennas are mounted on the tower.

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).

The configuration shown in Fig 14B is from a newer (1998) Rohn catalog. It has 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 Fig 14B cannot safely withstand the same amount of horizontal top load as can the configuration shown in Fig 14A, simply because the guys start farther down from the top of the tower.

An overhead view of a guyed tower is given in Fig 14C. 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. Those interested in more generic information about guyed tower behavior can find it at **www.freeyellow.com/members3/yagistress/**.

Unguyed Towers

Another commonly used type of tower is not normally guyed—these are usually referred to as *freestanding* or *self-supporting* towers. Unguyed towers come in three different styles.

One style is comprised of stacked lengths of identical tower sections, just like those used for guyed towers. The only difference is that no guys are used. Manufacturers provide the recommended configurations and allowable loads for this type of installation in their catalogs. Unguyed towers are vastly less capable of supporting antenna loads than their guyed counterparts, but have great utility for light-duty applications—when configured within their capabilities.

The second style utilizes different tower section sizes, varying from large sections at the base and tapering down to smaller sections at the top. This style is more much more efficient for freestanding applications, because the tower is sized for the varying bending loads along the tower length, and is shown in **Fig 15**.

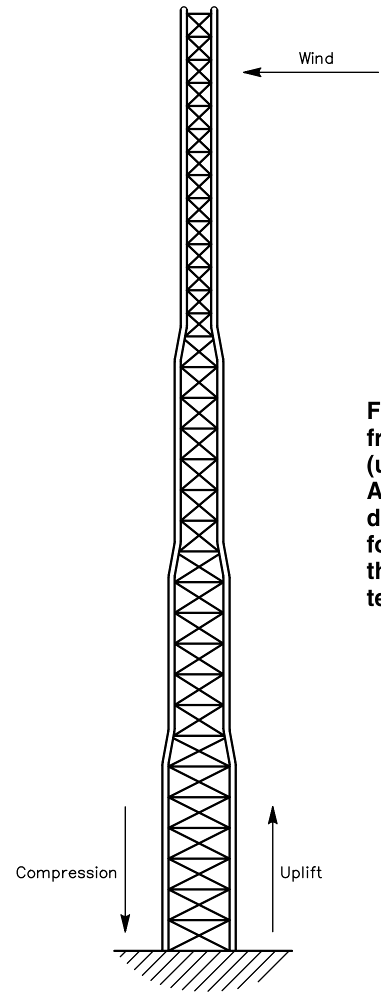


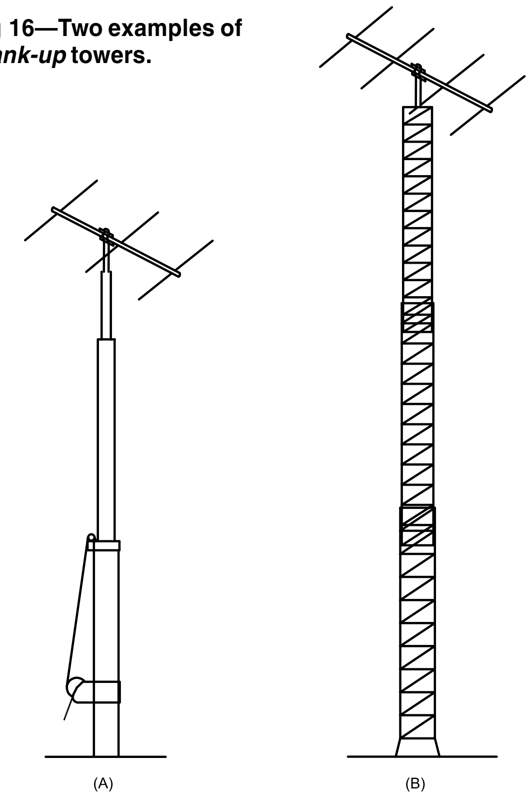
Fig 15—Typical freestanding (unguyed) tower. Arrows indicate the directions of the forces acting upon the structure. See text for discussion.

The third style of unguyed towers is commonly called a *crank-up tower*. It is a freestanding tower with telescoping sections that can be extended or retracted with a winch, cable, and pulley mechanism. This allows the tower to be raised and lowered for maintenance and antenna work. It is usually necessary to retract such towers for moderate to heavy winds. Some consider this a disadvantage because they can't operate their antennas at full height when it is windy. Two different forms of the crank-up style, freestanding tower are shown in **Fig 16**. Fig 16A shows the tubular version; Fig 16B shows the triangular space-frame version.

Some crank-up towers are used with guys and are only retracted for maintenance and antenna work. These towers are specially designed with locking mechanisms between the tower sections to carry the vertical compression created by the guys. *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.

Never climb a crank-up tower unless it is properly nested, with all load removed from the hoisting cable. For general antenna work, this can be accomplished by completely retracting it until the cable becomes loose. When servicing the rotator, the tower must be left partially extended. In this case every tower section must be

Fig 16—Two examples of *crank-up* towers.



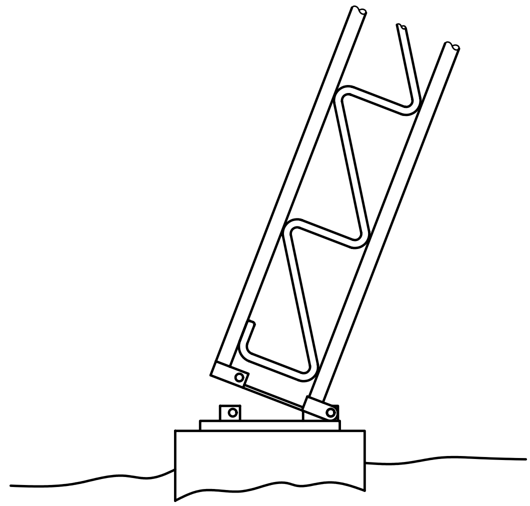


Fig 17—Fold-over or tilting base. There are several different kinds of hinged sections permitting different types of installation. Great care should be exercised when raising or lowering a tilting tower.

blocked with heavy timber or thick-wall tubes, installed through the tower bracing, until all sections are resting on the blocks and the hoisting cable becomes slack. Safely installing the blocks in an extended crank-up tower can be challenging. The object is to get all the blocks installed without a climber having to scale the unblocked tower, risking loss of limbs should the hoisting cable fail. An extension ladder, capable of reaching the required block elevations is the safest approach. If the necessary equipment or expertise is not available, the tower can be retracted, antennas removed, and leaned over, with the base tilt-over assembly, before extending it to access the rotator. Failure to properly block the tower before climbing can result in serious injury should the cable slip or break!

All freestanding towers share some unique characteristics. Each must support antenna and tower loads only by virtue of the bending strength of the tower sections and the tower footing connection to earth. Because of the large overturning moment at the tower base, freestanding towers require larger concrete footings than guyed towers. They are usually more expensive for the same load capability compared to guyed towers, simply because they require larger heavier tower sections and a larger footing to get the job done. The telescoping mechanisms in crank-up tower require more maintenance too.

Freestanding towers are quite popular, and are often the best solutions for sites with limited space and ascetic concerns. When cranked down, a telescoping tower can maintain a low-profile system, out of sight of the neighbors and family.

Tilt-Over Towers

Some 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. **Fig 17** shows a hinged base used with stacked, guyed tower sections. The hinged section can 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. 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 from horizontal to vertical positions.

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.

The AB-577 Military Surplus Tower

Another light duty tower has found acceptance among many amateurs. Available from assorted military surplus dealers is the AB-577 system. This was designed to be a portable, rapid deployment antenna support for field communications. It is a guyed mast that goes up somewhat like a crank-up. The system consists of several short sections of aluminum tubing, with special end connections for joining them. 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.

Fig 18—Installation of surplus AB-577 tower with tribander at 45 feet at K7NV. (*Photo by Kurt Andress, K7NV.*)

The standard AB-577 system, with 3 sets of guys, will support a modest triband Yagi at 45 feet. **Fig 18A** shows an installation with a Hy-Gain TH7DX at 45 feet.

TOWER BASES

Tower manufacturers can provide customers with detailed plans for properly constructing tower bases. **Fig 19** is an example of one such plan. This plan calls for a hole that is $3\frac{1}{2} \times 3\frac{1}{2} \times 6$ feet. Steel reinforcement bars are lashed together and placed in the hole. The bars are positioned so that they will be completely embedded in the concrete, yet will not contact any metallic object in the base itself. This is done to minimize the possibility of a direct discharge path for lightning through the base. Should such a lightning discharge occur, the concrete base could be damaged.

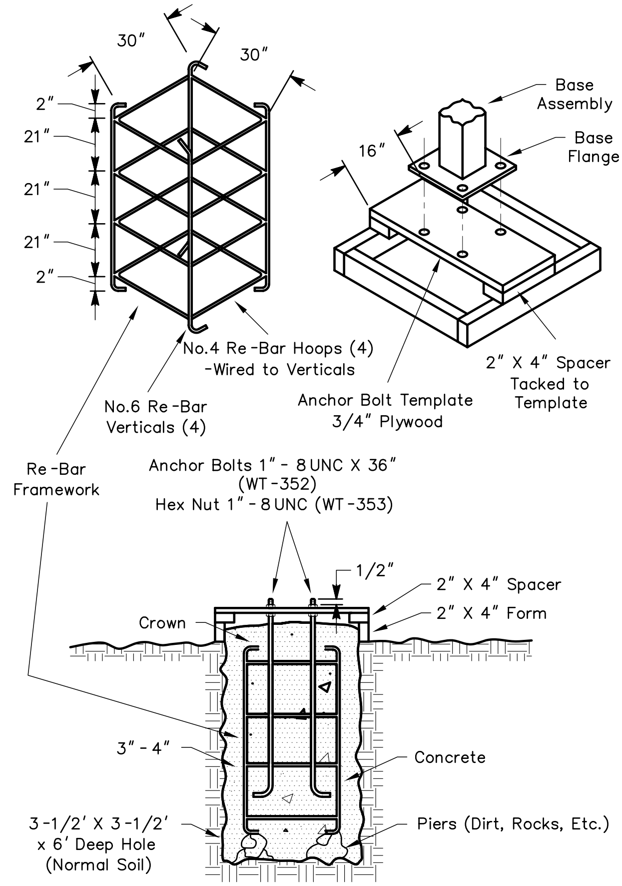


Fig 19—Plans for installing concrete base for Wilson ST-77B tower. Although the instructions and dimensions vary from tower to tower, this is representative of the type of concrete base specified by most manufacturers.

Providing suitable paths for the discharge of lightning energy safely for towers is a complex subject. Several companies offer products and guidance. The basic requirements for providing controlled discharge paths for lightning-induced current is to supply a low-impedance grid of conductors from the tower and feed lines to a field of interconnected ground rods around the base of the tower. Generally, the tower, station, and electrical service grounds need to be connected to prevent damaging potential differences from developing between the various components in the system.

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. The anchor bolts are embedded in the concrete, and aligned with the plywood template, before it hardens. The template serves to align the anchor bolts to properly mate with the tower itself. Once the concrete has

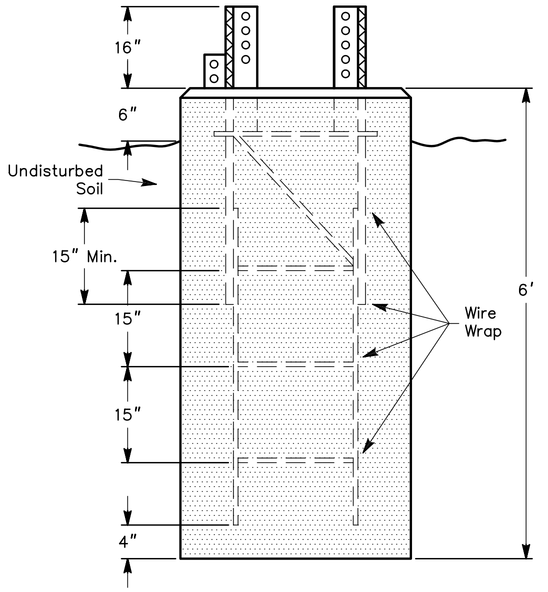


Fig 20—Another example of a concrete base (Tri-Ex LM-470).

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 Fig 19), you can bolt the first tower section on the base plate to ensure that the base is level and properly aligned. Use temporary guys 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. **Fig 20** 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.

TOWER INSTALLATION

The installation of a tower is not difficult when the proper techniques are used. A guyed tower, in particular, is not hard to erect, because each of the individual sections is relatively lightweight and can be handled with only a few helpers and some good quality rope.

The Gin Pole and Tips on Tower Building

An essential piece of hardware for working on towers is a *gin pole*. This section came from the ARRL book *Simple and Fun Antennas for Hams*. The dictionary describes a gin pole as "a device for moving heavy objects." See **Fig 21**, which shows a drawing of the Rohn "Erection Fixture" EF2545. This gin pole was designed to work with the nominal 10-foot long sections of Rohn 25 or 45 towers.

We're going to assume in the following discussion that you are installing Rohn 45, which weighs about 70 pounds. This is a lot of weight, and you must refrain from adding to that during installation. That means, for example, that you *do not* attempt to lift a 10-foot section with the guy wires attached! Neither should you attempt to lift the top section with the rotator and rotor shelf installed. The gin pole (and your ground crew) will not appreciate all that strain.

The main working part of the gin pole is the pulley

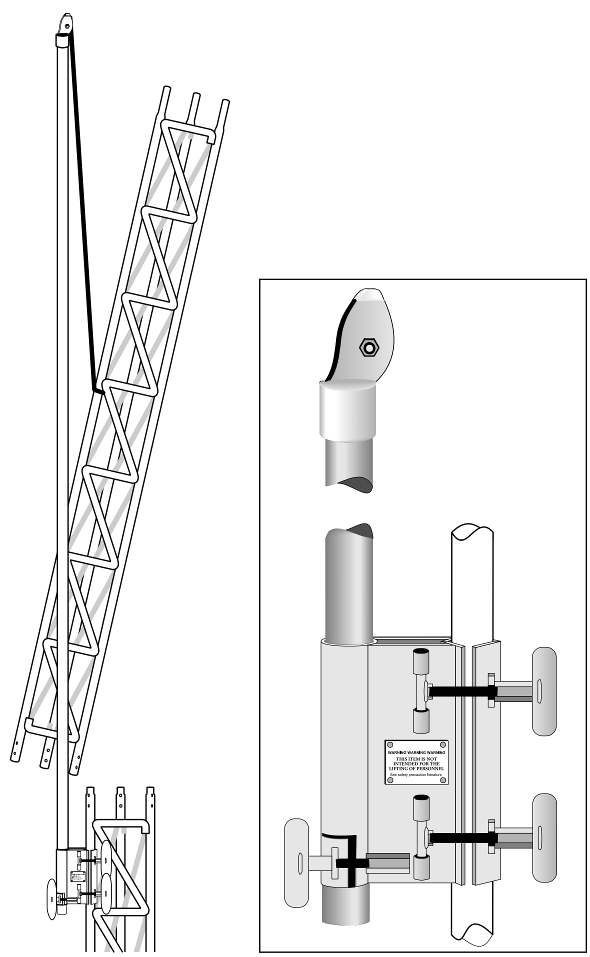


Fig 21—Drawing of Rohn "Erection Fixture" EF2545, also known commonly as a "gin pole."

mounted at the top of the 12-foot long heavy-wall aluminum tubing. This pulley has a rope going down to the ground crew through the center of the aluminum tube. At the base of the tower, the pull rope should be run through a *snatch block* attached to the tower just above ground level. This block allows the pull rope to be pulled out horizontally away from the tower base. That helps protect ground crew should a tool be dropped by the people on the tower.

An adjustable, sliding clamp towards 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 on the top 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 belted in at the top of the tower. We're also assuming that the pull rope has been threaded through the aluminum tube and the top pulley, with a knot tied to prevent it from falling back down the tube.

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 tag rope for the ground crew to tie to the gin-pole pull rope. (This tag 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 tag line rope. Friction of the rope against the top of the pulley-head assembly will prevent the gin-pole assembly from slipping down. [Note that some climbers prefer to "walk" the gin-pole up the tower rather than having it pulled up from the ground below. They free up their hands for climbing and temporarily holding the gin pole by using their belt lanyard looped around the tower as they climb.]
3. 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.
4. The T-bar handle for the tube clamp is loosened, and the aluminum tube is extended to its maximum height, as shown in Fig 21. Make sure you have tied the free end of the rope coming through the top pulley temporarily to the top of the tower, or else you'll have to lower the gin pole and go through this step again.
5. The free end of the pulley rope is then dropped to the ground, often using a weight such as a medium Crescent wrench or perhaps a hammer to keep the rope from waving about as it dangles down the tower, tangling with every imaginable thing as it proceeds downwards. It's amazing how even a tiny breeze can make an unweighted rope dance like that.
6. The ground crew then ties the free end of the rope *above* the balance point of the tower. For Rohn 25 or 45 there are eight horizontal cross braces per section. You want the crew to tie the rope to the fifth horizontal brace from the bottom. Please remember that you want the bottoms of the tower sections' legs to be pointed downwards, not flipped over, when the bottom of these legs approach you at the top of the tower section the climber is standing on.
7. Once the bottom of the rising tower section is just above the top of the legs of the bottom tower section, the climber guides the tower 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 **Fig 22**, which shows the climber guiding the new section of Rohn HBX tower onto the previous section's legs. This process is considerably easier to accomplish if each section of tower has been put together on the ground to make sure that the legs fit together easily. There's nothing more frustrating that trying to manually force-fit tower sections together at the top of a tower.

Fig 22—Climber is guiding the new section onto the top of the existing one. The gin pole attached to the left leg is bearing the weight, as the climber gives verbal instructions to the ground crew pulling on the gin-pole rope. (*Photo courtesy Mike Hammer, N2VR.*)

It seems that freight companies don't always handle heavy tower sections very gently and legs easily get bent out of alignment. A careful installer numbers tower sections in the order they've been test-fitted together on the ground, marking them with a laundry marker pen. You should also spray a small amount of WD-40 up inside mating tower legs after test-assembling them to help prevent galling and to ease fitting sections together. [Don't do this to excess—WD-40 is slippery and messy when it runs out of the bottom of tower legs.]

Another caution: Make sure before you start installing any tower that the correct ends of the bottom section's legs, "male" rather than "female," are pointed upwards. A prominent amateur (who will go unnamed) had to have Rohn make and send him a special "gender-bender" flange to turn females into males, since he had installed the base upside-down in the concrete base. You don't want to do that.

8. Once the new tower section has been guided down onto the male ends, the six pinning bolts are inserted and tightened with nuts. Note that Rohn uses two different sized bolts, with the larger diameter one on the bottom.
9. If this section of tower is one where guy wires are to be placed, they can be brought up using the gin pole rope and positioned on the tower. The maximum spacing for Rohn 25 is 30 feet between guy-wire sets, and 40 feet for Rohn 45. Thirty feet of unguyed Rohn 25 tower is wobbly, though safe. Many installers prefer to come down off the tower when setting guy-wire tension, since they do not like to be on a wobbly tower when the ground crew is moving around yanking on guy wires. Many also greatly prefer working on Rohn 45 tower, which is substantially more secure feeling and easier to stand on, with its legs 18 inches apart, while Rohn 25 legs are only 12 inches apart.
10. Finally, you 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.

Tower Safety

One of the most important aspects of any tower installation project is the safety of all persons involved. See Chapter 1 for details on important safety issues. The use of hard hats is highly recommended for all assistants helping from the ground. Helpers should always stand clear of the tower base to prevent being hit by a dropped tool or hardware. Each person working on the tower must use a good climber's safety belt.

When climbing the tower, if more than one person is involved, one should climb into position before the other begins climbing. The same procedure is required for climbing down a tower after the job is completed. The purpose is to have the non-climbing person stand still so as not to drop any tools or objects on the climbing person, or unintentionally obstruct his movements. When two persons are working on top of a tower, only one should change position (unbelt and move) at a time.

For most installations, a good-quality 1/2-inch diameter Manila hemp rope can adequately handle the workload for the hoisting tasks. The rope must be periodically inspected to assure that no tearing or chafing has developed, and if the rope should get wet from rain, it should be hung out to dry at the first opportunity. The knots used for connecting hoisting lines and hardware are critical to executing any safe installation, and special attention should be given to this detail for any work party.

Here is an important point regarding safety—the person who climbs the tower should be in charge of what happens with the ground crew. Not only does the person on the tower have a better overall view of the situation below, but also any confusion on the ground can result in serious injury to the climber.

GUY WIRES

In typical guyed tower installations, guy wires may experience loads in excess of 1000 pounds. Since the guys are the primary means of carrying the horizontal wind loads, great care should be taken in their selection and installation.

Guys come in a variety of materials and constructions. Normally, the tower manufacturer or professional engineer will specify the size and type of cable to be used. The most common type of cable used for tower guying is the EHS (Extra High Strength) galvanized steel cable. The EHS cables are very stiff and are the highest strength

Table 1
Guy Cable Comparisons

Cable	*Nominal Dia. Inches*	*Breaking Strength Lbs*	*Weight Lbs/100'*	*Elongation Inches/100'*	*%Elongation*
3/16" 1 × 7 EHS	0.188	3990	7.3	6.77	0.56%
1/4" 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" 1 × 7 EHS	0.313	11200	20.5	2.44	0.20%
HPTG11200	0.320	11200	5.5	5.45	0.45%
3/8" Fiberglass Rod	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.

cables in the wire rope family. Other steel cables are made to be more flexible for running around pulleys. While these are easier to work with when assembling, they are not as strong as the EHS type, and should be avoided for tower guying. Non-conductive guys, such as *Phillystran* or *pultruded* fiberglass rod have become popular for eliminating resonant interaction with antennas.

Do not attempt to use cheaper cables that don't meet or exceed the criteria for those specified for your installation. Using the wrong cable, or failing to install the cable properly can have disastrous results! **Table 1** shows data for several cables commonly used for tower guying. It is important to note that the minimum breaking strength of the various cables are independent of their elongation (stretch) under load.

Guy Cable Installation

Figs 23 and **24** show methods for tensioning and safety wiring guy-wire turnbuckles. **Fig 25** shows the traditional method for fixing the end of a steel guy wire. 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 one wire size larger than the cable to provide a more gentle wire bend radius. Three cable clamps follow to hold the wire securely. Be sure to follow the note in Fig 25 for which part of the clip bears against the live (loaded) cable. As a final backup measure, the individual strands of the free end are unraveled and wrapped around the guy wire. It is a lot of work, but it is necessary to ensure a safe and permanent connection.

Fig 26 shows the use of a device that replaces the clamps and twisted strands of wire. These devices are known as *dead ends*, *preformed guy grips,* or *Big Grips* and are commonly used on electrical power poles. They are far more convenient to use than are clamps, and are the recommended method for terminating Phillystran and

Fig 24—A length of guy cable is used to assure that the turnbuckles remain in place after they are tightened. This procedure is an absolute requirement in guyed tower systems. (*Photo by N4QX*)

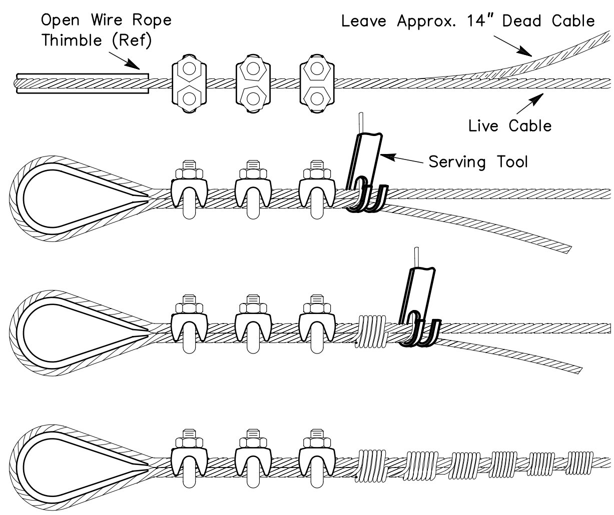


Fig 25—Traditional method for securing the end of a guy wire.

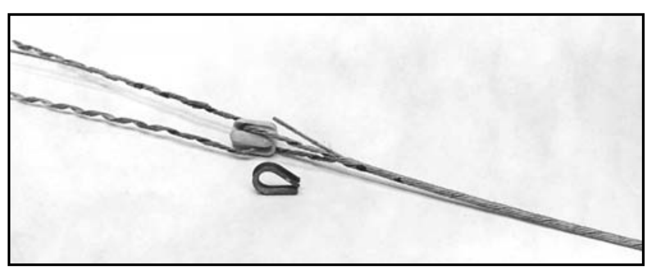


Fig 26—Alternative method for attaching guy wires using *dead ends.* The dead end on the right is completely assembled (the end of the guy wire extends beyond the grip for illustrative purposes). On the left, one side of the dead end is partially attached to the guy wire. In front, a thimble is used where a sharp bend might cause the guy wire or dead end to break.

Fig 23—Proper tension can be placed on the guy wires with the aid of a block-and-tackle system. (*Photo by K1WA*)

fiberglass-rod guys. When using the guy grips, it is imperative that the recommended end sleeves are installed over the free end of the grip to prevent ice and falling hardware from sliding down the guy and unraveling the grip connection to the guy. The guy wires must be cut to the proper length. The dead end of each wire is installed into the object to which the guy wire is being attached (use a thimble, if needed to eliminate sharp cable bends). One side of the dead end is then wrapped around the guy wire. The other side of the dead end follows. Using dead ends saves time and trouble, more than making up for their slightly higher cost.

When using the non-conductive guy materials, it is highly recommended that a 25-foot length of EHS steel cable be used at the bottom for connection to the anchor. This serves a valuable purpose. The steel cable is more resistant to damage from ground activity and brush fires, and it is the preferred material for measuring cable pre-tension with commonly available devices.

Fig 27 shows two different methods for attaching guy wires to towers. At Fig 27A, the guy wire is simply looped around the tower leg and terminated in the usual manner. At Fig 27B, 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 resisting torsional loads on the tower than the simpler installation. Rohn offers another guy attachment bracket, called a *Torque Arm Assembly*, that 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.

There are two types of commonly used guy anchors. **Fig 28A** depicts an *earth screw*. These are usually 4 to 6 feet long. The screw blade at the bottom typically measures 6 to 8 inches diameter. Fig 28B illustrates two people installing the anchor. The shaft is tilted so that it will be in line with the mean angle of all the guys connecting to the anchor. Earth screws are suitable for use in normal soil where permitted by local building codes. Information about *screw anchors* is available from the manufacturers of these devices. Information from a supplier specializing in this type of anchor can be found at **www.abchance.com**.

The alternative to earth screws is the concrete block anchor. Fig 28C shows the installation of this type of anchor; it is suitable for any soil condition, with the possible exception of a bed of lava rock or coral. Consult the instructions from the manufacturer, or your tower designer, for the precise anchor configuration.

Turnbuckles and associated hardware are used to attach guy wires to anchors and to provide a convenient method for adjusting tension. **Fig 29A** 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.

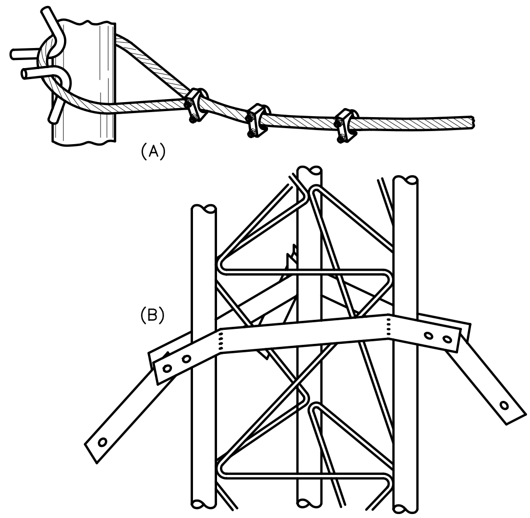


Fig 27—Two methods of attaching guy wires to tower. See text for discussion.

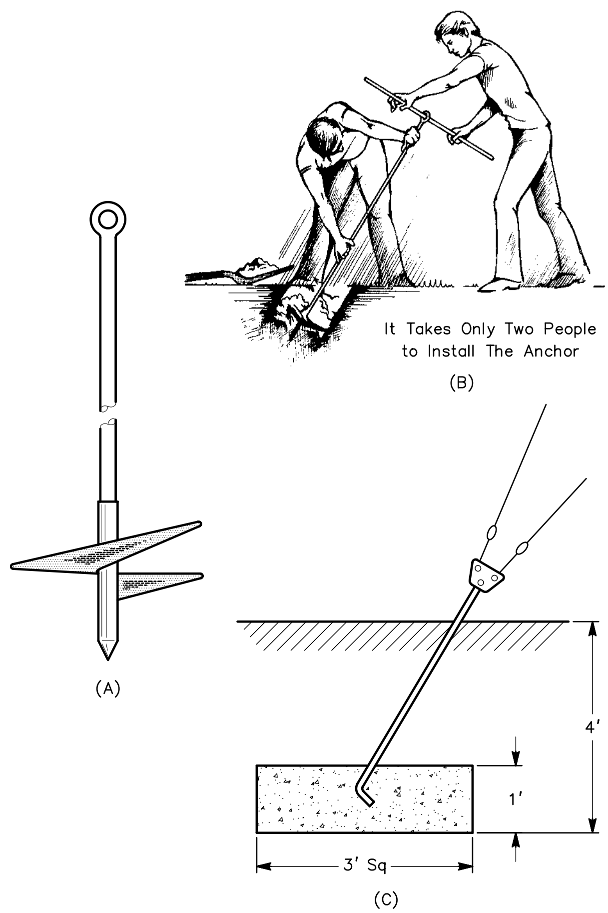


Fig 28—Two standard types of guy anchors. The earth screw shown at A is easy to install and widely available, but may not be suitable for use in certain soils. The concrete anchor is more difficult to install properly, but it is suitable for use with a wide variety of soil conditions and will satisfy most building code requirements.

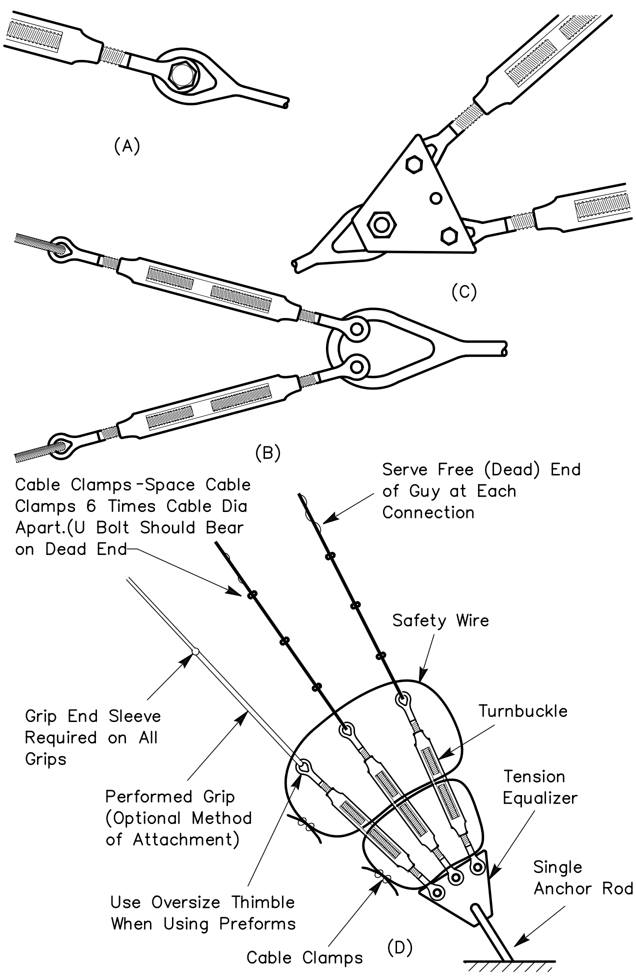


Fig 29—Variety of means available for attaching guy wires and turnbuckles to anchors.

Fig 29B 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, *equalizer plates* should be installed (Fig 29C). 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 (Fig 29D).

All guyed towers require the guys to be installed with a certain amount of pre-tension. The tower manufacturer or designer specifies the required pre-tension values, which are usually 10% of the cable breaking strength. Pre-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. The recommended method for adjusting the guys is to use a cable tension-measuring device such as the popular *Loos Guy Wire Tensioner*. The guy is gripped with a special clamp, such as the *Klein Cable Grip*, which is connected to the anchor below the eye (or equalizer plate) with a block and tackle arrangement (Fig 23) or a ratcheting 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.

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.

Resonance in Guy Wires

If 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 the 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. **Fig 30** shows wire lengths that fall within 10% of $^1/_2$-λ resonance (or a multiple of $^1/_2$ λ) for 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 Fig 30 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.

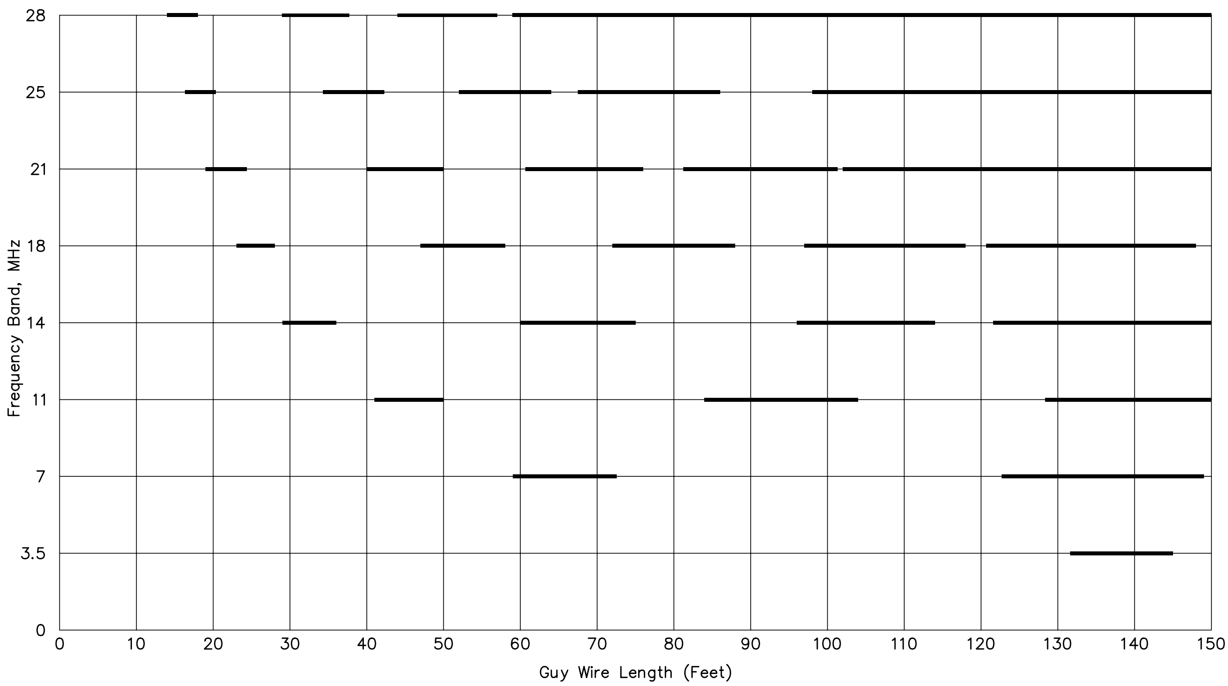


Fig 30—The black bars indicate ungrounded guy wire lengths to avoid for the eight HF amateur bands. This chart is based on resonance within 10% of any frequency in the band. Grounded wires will exhibit resonance at odd multiples of a quarter wavelength. (*By Jerry Hall, K1TD.*)

THE RIGHT TOWER FOR YOUR ANTENNA

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.

Determining Antenna Areas

The method for determining the flat projected area 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 **Fig 31A**.

The element FPA is calculated by multiplying each element's dimension of length by its diameter and then

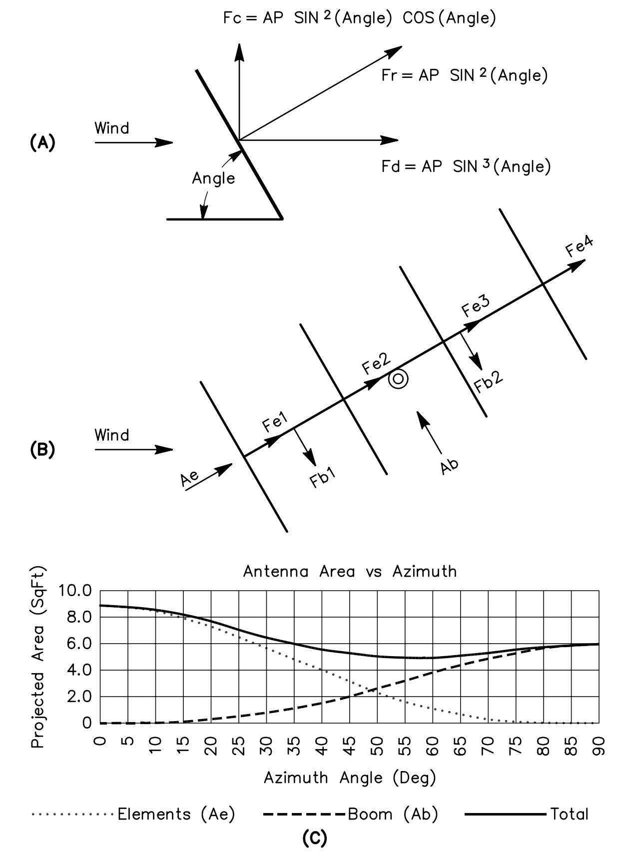


Fig 31—Description of how loads are developed on a Yagi. At A, Fr is the resultant force from the wind load on a generalized member. Fd is the load acting downwind (drag) that creates the load on the tower. Fc is the lateral component of the wind load. The term A is the flat projected area (FPA), which is the broadside area normal to the wind. The term P is the wind pressure. At B, Ae 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 (Fe1) 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.

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 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 Fig 31A.

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. Fig 31B shows a force diagram for a typical Yagi. Fig 31C shows the FPA for a Yagi rotated through 90° of azimuth.

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 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.

Fig 32A 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. Fig 32B 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

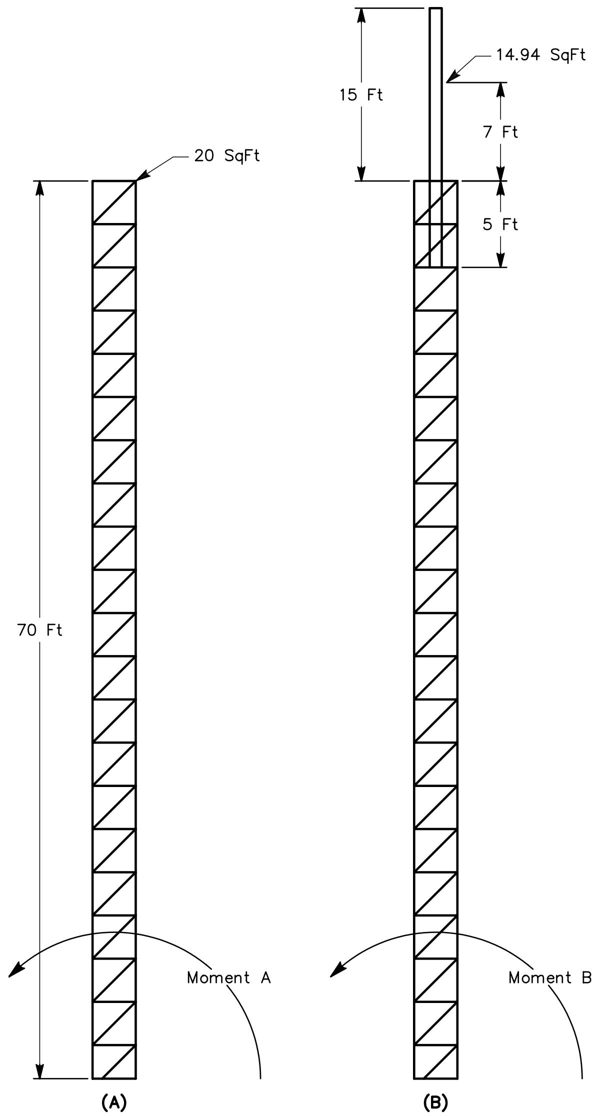


Fig 32—At A, a 70-foot tower rated for 20 square feet of antenna load at the top. At B, the same tower with a 2-inch OD × 20-foot long mast, with an antenna mounted 7 feet above the top of the tower. Both configurations produce the same tower load.

of 1 pound per square foot (1 psf). This makes the tower base moment calculation for Fig 32A:

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 Fig 32B, 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 Fig 32B 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 Fig 32B 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. Now we will consider the problem of bending the rotating mast.

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:

$$P = .00256\ V^2 \qquad \text{(Eq 1)}$$

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:

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

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:

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

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 Fig 32B, 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:

$P = .00256\ V^2 = .00256 \times (90)^2 = 20.736$ 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 × 2.50 feet^2 × 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 × 14.94 feet^2 × 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 and 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.

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. Using unknown materials renders efforts from the preceding calculations useless!

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.

ANTENNA INSTALLATION

All antenna installations are different in some respects. Therefore, thorough planning is the most important first step in installing any antenna. Before anyone climbs the tower, the whole process should be discussed to be sure each crewmember understands what is to be done. And remember that the person on the tower is in charge! Coordinate beforehand what signals and commands are used: "Up" or "Up Slowly" for raising something from the ground; "Down" or "Down Slowly" for the opposite.

"Watch Out!" or 'Watch Out Below!" works for dropped hardware or tools to alert the ground crew below. Remember, once someone is on the tower, no one should be allowed to stand near the base of the tower!

Consider what tools and parts must be assembled and what items must be taken up the tower, and plan alternative actions for possible trouble spots. Extra trips up and down the tower can be avoided by careful planning.

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 should do all the heavy work and leave the person on the tower free to guide the antenna into position. Because the ground crew does all the lifting, a large pulley, preferably on a gin pole placed at the top of the tower, is essential. Local radio clubs often have gin poles available for use by their members. Stores that sell tower materials frequently rent gin poles as well.

A gin pole should be placed along the side of the tower so the pulley is no more than 2 feet above the top of the tower (or the point at which the antenna is to be placed). Normally this height is sufficient to allow the antenna to be positioned easily. An important reason that the pulley is placed at this level is that there can be considerable strain on the gin pole when the antenna is pulled away from the tower to maneuver past guy wires.

Sometime the mast to which the antenna will be mounted is used as a place to hang the pulley. You should take care that you don't end up bending the mast by placing the pulley too high on the mast. It may be necessary to back-guy the mast on the opposite side of the tower from which the antenna is raised.

The rope (halyard) through the pulley must be somewhat longer than twice the tower height so that the ground crew can raise the antenna from ground level. The rope should be ½ or $^5/_8$ inch diameter for both strength and ease of handling. Smaller diameter rope is less easily manipulated; it has a tendency to jump out of the pulley track and foul pulley operation.

The first person to climb the tower should carry an end of the halyard so that the gin pole can be lifted and secured to the tower. Those climbing the tower must have safety belts. Belts provide safety and convenience; it is simply impossible to work effectively while hanging onto the tower with one hand.

Once positioned, the gin pole and pulley allow parts and tools to be sent up the tower. A useful trick for sending up small items like bolts and pliers is for a ground crew member to slide them through the rope strands where they are held by the rope for the trip to the top of the tower. Items that might be dislodged by contact with the tower should either be taped or tied to the halyard.
Ever present is the hazard of falling tools or hardware. It is foolish to stand near a tower when someone is working above. Ground crew member should wear hard-hats as extra insurance.

Raising the Antenna Alongside the Tower

A technique that can save much effort in raising the antenna is outlined here. First, the halyard is passed through the gin-pole pulley or the pulley mounted to the mast, and the leading end of the rope is returned to the ground crew, where it is tied to the antenna. The assembled antenna should be placed in a clear area of the yard (or the roof) so the boom points toward the tower. The halyard is then passed *under* the front elements of the beam to a position past the midpoint of the antenna, where it is securely tied to the boom (**Fig 33A**).

Note that once the antenna is installed, the tower worker must be able to reach and untie the halyard from the boom; the rope must be tied less than an arm's length along the boom from the mounting point. If necessary, a large loop may be placed around the first element located beyond the midpoint of the boom, with the knot tied near the center of the antenna. The rope may then be untied easily after completion of the installation. The halyard should be tied temporarily to the boom at the front of the antenna by means of a short piece of light rope or twine.

While the antenna is being raised, the ground crew does all the pulling. As soon as the front of the antenna reaches the top of the mast, the person atop the tower unties the light rope and prevents the front of the antenna from falling, as the ground crew continues to lift the antenna (Fig 33B). When the center of the antenna is even with the top of the tower, the tower worker puts one bolt through the mast and the antenna-mounting bracket on the boom. The single bolt acts as a pivot point and the ground crew continues to lift the back of the antenna with the halyard (Fig 33C). After the antenna is horizontal, the tower worker secures the rest of the mounting bolts and unties the halyard. By using this technique, the tower worker performs no heavy lifting.

Avoiding Guy Wires

Although the same basic methods of installing a Yagi apply to any tower, guyed towers pose a special problem. Steps must be taken to avoid snagging the antenna on the guy wires. With proper precautions, however, even large antennas can be pulled to the top of a tower, even if the

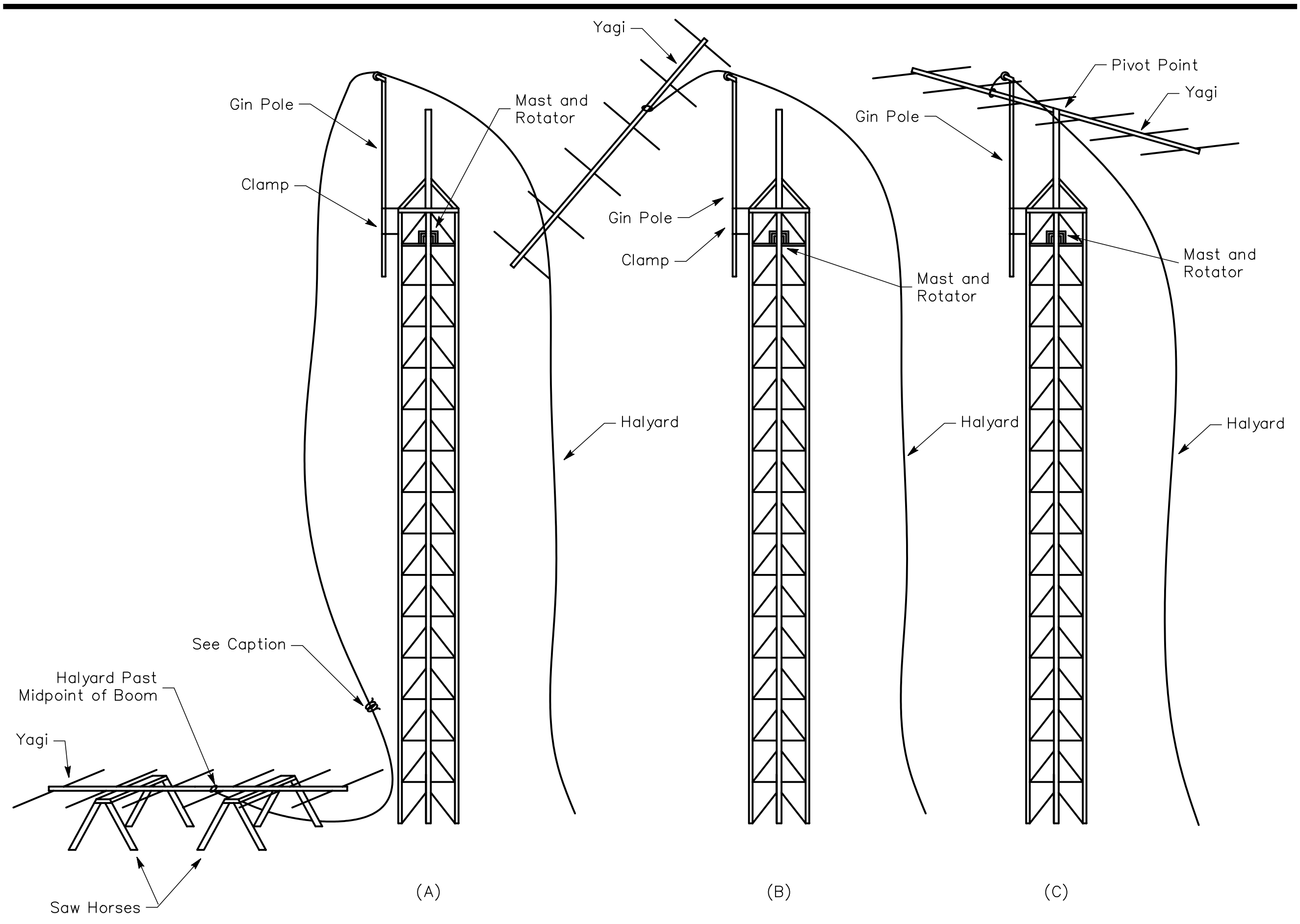
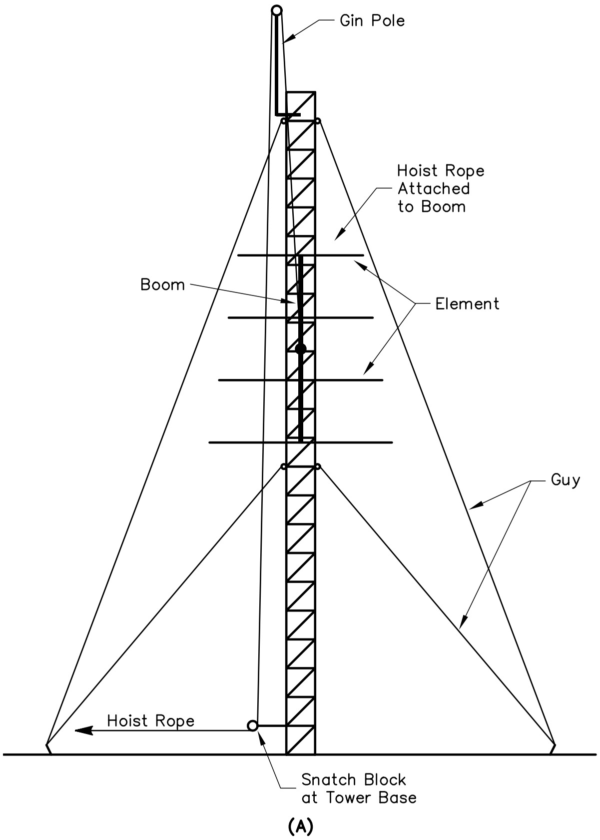
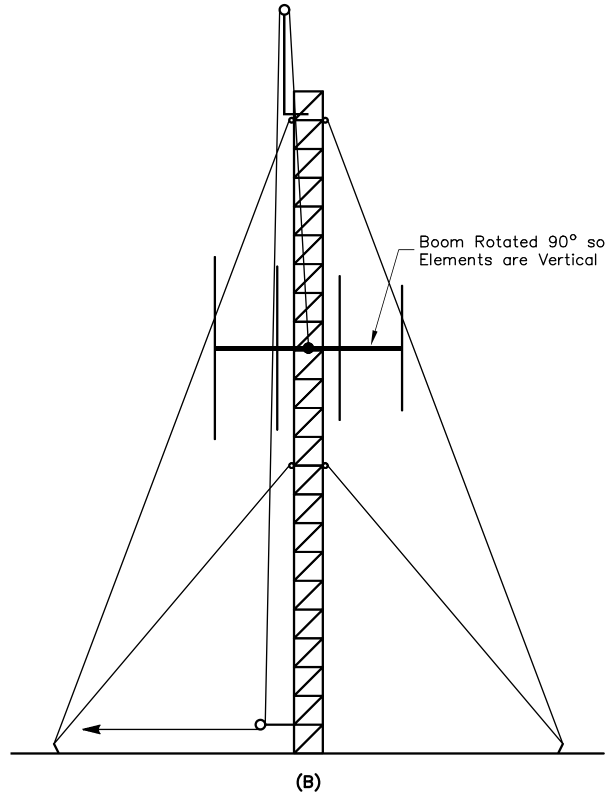


Fig 33—Raising a Yagi antenna alongside the tower. At A the Yagi is placed in a clear area, with the boom pointing toward the tower. The halyard is passed under the elements, then is secured to the boom beyond the midpoint. B shows the antenna approaching the top of the mast. The person on the tower guides it after the lifting rope has been untied from the front of the antenna. At C the antenna is pulled into a horizontal position by the ground crew. The tower worker inserts the pivot bolt and secures it. Note: A short piece of rope is tied around the halyard and the boom at the front of the antenna to stabilize the beam as it is being raised. The tower worker removes it when the boom reaches him at the top of the tower.





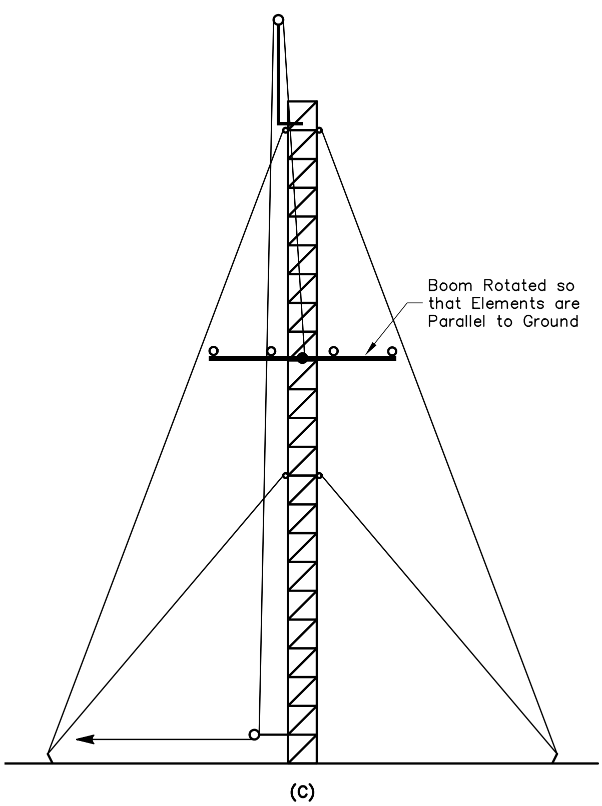


Fig 34—Building a Yagi partway down the tower. At A, the boom is lashed temporarily to the tower and elements are added, starting at the bottom. At B, the temporary rope securing the boom to the tower is removed and the boom is rotated 90° so that the elements are vertical. At C, the boom is rotated another 90°, "weaving through" guy wires if necessary, until the elements are parallel with the ground, whereupon the boom is secured to the tower.

mast is guyed at several levels.

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.

Another method is to tie a rope to the back of the antenna (but within reach of the center). The ground crews then pull the antenna out away from the guys as the antenna is raised. With this method, some crewmembers 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. The beam is especially vulnerable when it begins to tip into the horizontal position. If the crew continues to pull out and down against the antenna, the boom can be broken. Another problem with this approach is that the antenna may rotate on the axis of the boom as it is raised. To prevent such rotation, long lengths of twine may be tied to outer elements, one piece on each side of the boom. Ground personnel may then use these *tag lines* to stabilize the antenna. Where this is done, provisions must be made for untying the twine once the antenna is in place.

A third method is to tie the halyard to the center of the antenna. A crewmember, wearing a safety belt, walks the antenna up the tower as the crew on the ground raises it. Because the halyard is tied at the balance point, the tower worker can rotate the elements around the guys. A tag line can be tied to the bottom end of the boom so that a ground worker can help move the antenna around the guys. The tag line must be removed while the antenna is still vertical.

A fourth method is to build the antenna on the tower and then swing it into position. (See also the section below on the PVC Mount.) 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.

Fig 34 illustrates the steps involved. A pull 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 pull 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 boom up or down using the pull 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 **Fig 35**.

As usual, the gin-pole pull 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 pull rope to the top end of the boom for stability.

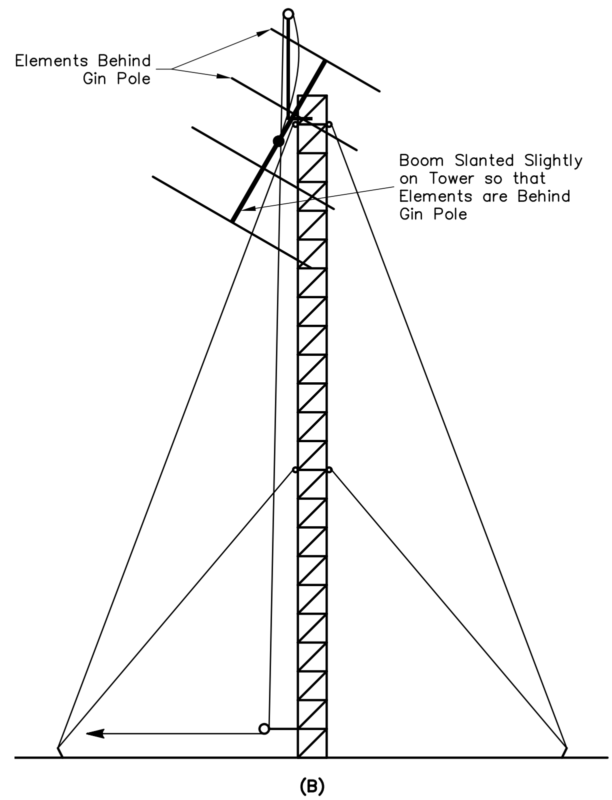


Fig 35—Building a Yagi at the top of the tower. The length of the gin pole must be longer than 1/2 the boom so that the boom can be hoisted upwards to the place where it is mounted to the mast. Usually the boom is initially lashed to the tower slanted slightly from vertical so that the top element ends 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.

The boom is temporarily secured to the tower with 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 pull 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 (with perhaps the center element closest to the mast-to-boom bracket left on the ground until later), 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.

Using a Tram

Another method to get a large Yagi to the top of the tower safely is a *tram*. A tram supports the antenna *under* the tram wire, using a pulley riding on the tram wire. The antenna can thus move more freely—without the friction it would have riding on top of a track rope, as described previously. This puts considerably less strain on the tram wire itself and on the mast to which it is tied on the tower. Some installers prefer to use a wire-rope tramline for its reduced sag.

The tram method uses an easily constructed fixture mounted to the boom of the Yagi to stabilize it from rotating away from the desired attitude as the antenna is raised. A guy-wire cable or heavy rope is fixed to the mast about two feet above the point where the antenna will mount to the mast. A come-along is often used at the ground end to tension the tram wire properly. It is often necessary to back-guy the mast to make sure it doesn't get bent, since the horizontal forces acting on the mast can be considerable in any tram (or track) operation. (Note that the tram technique works well for side-mounted antennas also, where back-guying is not necessary if you are reasonably close to a guy set, as is usually the case.)

Fig 36 is a photograph of a tram fixture built by Kurt Andress, K7NV. This consists of a pulley riding on top of the tramline. This pulley is attached using a caribiner or shackle to two equal-length wires connected to the boom to make an inverted-V shaped *sling*. The two sling wires are secured to the boom using angle irons and muffler clamps so that the antenna is perfectly balanced in the horizontal plane. Balance is very important to make sure the antenna rises properly on the tram without having the boom rotate downward on one end or the other.

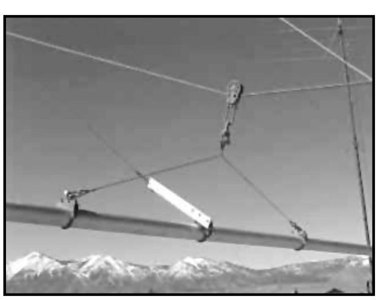


Fig 36—Photo of the tram system used by Kurt Andress, K7NV. (*Photo by K7NV.*)

The hoisting rope running through the tower-mounted gin-pole pulley (and used by the ground crew to pull the antenna up to the tower on the tram line) is attached to a 2-foot piece of angle iron. This is attached to the boom with a muffler clamp. Note that the angle iron is rotated slightly from horizontal so that the plane of the elements is tilted upwards—this allows the elements to clear the guy wires as the antenna is raised. (While the antenna is close to the ground, the angle iron is adjusted so that the elements remain horizontal. Once they are clear of the ground, the angle iron is readjusted to align the elements in the proper direction to clear the guy wires on the tower.) The force of the pull rope along the angle iron also stabilizes the antenna from yawing from side-to-side. Note in Fig 36 that the angle iron is mounted just off-center from where the boom-to-mast plate will be attached so that it clears the mast as the antenna nears the top of the tower. **Fig 37** diagrams how the tram and hoisting line are rigged to the mast.

The tower person directs the activity of the ground crew below and guides the antenna to the mast. Once the end of the pull rope reaches the mast, the tower man ties the boom temporarily to the mast so that he can undo the pull rope from the tram-fixture angle iron and retie it around the boom. Then the antenna can be raised to the point where it can be mounted to the mast.

This technique has been employed to raise Yagis with booms as long as 42 feet at the N6RO contest station on towers as high as 130 feet. As with the track, the tram system requires a good deal of open real estate. While it sounds complicated to set up, you can raise some rather large antennas in less than an hour, once you get the hang of the operation.

THE PVRC MOUNT

The methods described above for hoisting antennas are sometimes not satisfactory for really large, heavy arrays. The best way to handle large Yagis is to assemble them on top of the tower. One way to do this easily is by using the *PVRC Mount*. Many members of the Potomac Valley Radio Club have successfully used this method to install large antennas. Simple and ingenious, the idea involves offsetting the boom from the mast to permit the boom to tilt 360° and rotate axially 360°. This permits the entire length of the boom to be brought alongside the tower, allowing the elements to be attached one by one. (It also allows any part of the antenna to be brought alongside the tower for antenna maintenance.)

See **Figs 38** through **42**. The mount itself consists of a short length of pipe of the same diameter as the rotating mast (or greater), a steel plate, eight U bolts and four pinning bolts. The steel plate is the larger, horizontal one shown in Fig 38. Four U bolts attach the plate to the rotating mast, and four attach the horizontal pipe to the plate. The horizontal pipe provides the offset between the antenna boom and the tower. The antenna boom-to-mast plate is mounted at the outer end of the short pipe. Four bolts are used to ensure that the antenna ends up parallel to the ground, two pinning each plate to the short pipe. When the mast plate pinning bolts are removed and the

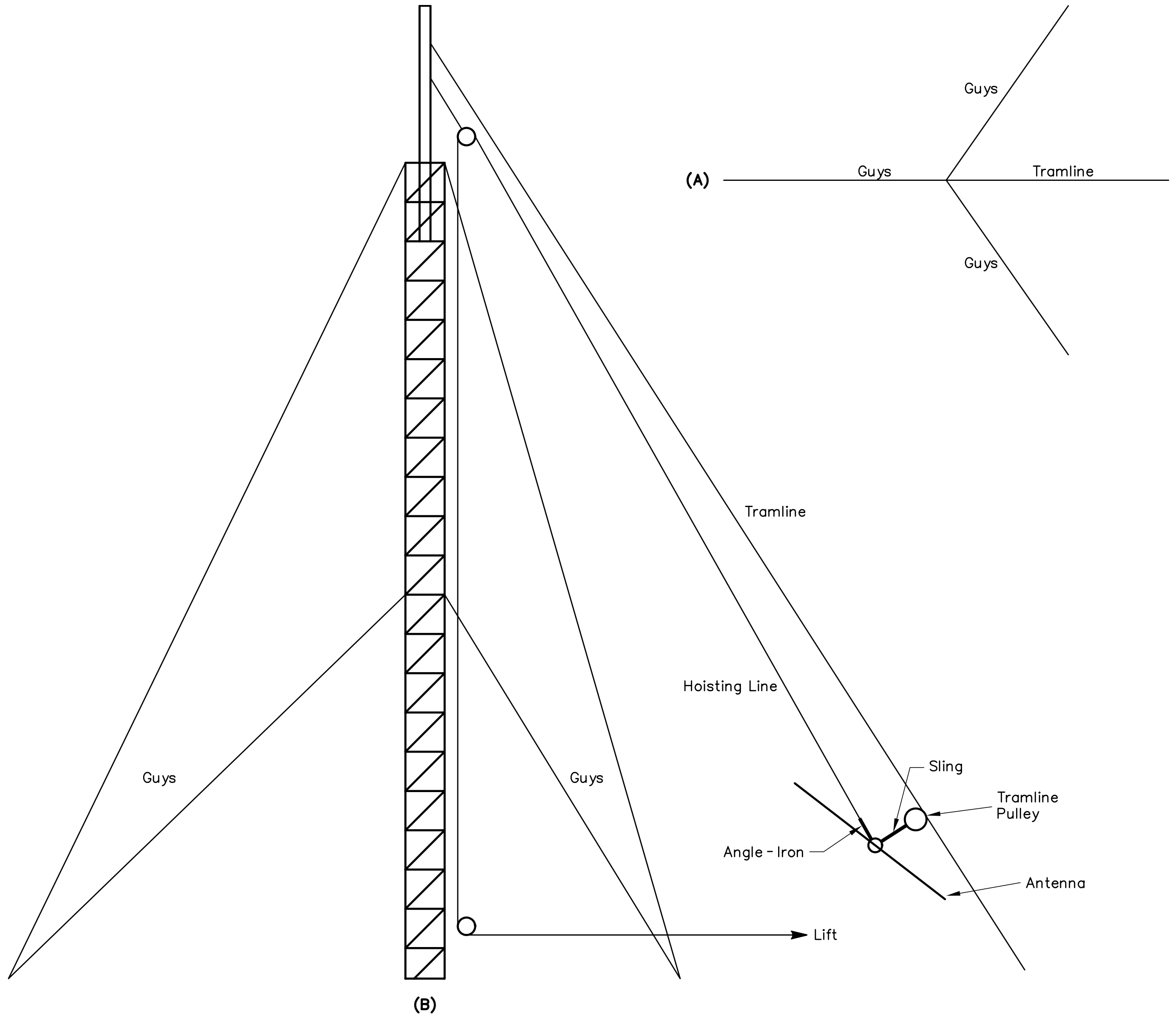


Fig 37—At A, bird's-eye view of tram system used to bring large Yagi antennas from the ground to the top of the tower. At B, side view of rigging used for tramline and hoisting line, along with the sling and tram fixture used to hold the Yagi on the tramline.

four U bolts loosened, the short pipe and boom plate can be rotated through 360°, allowing either half of the boom to come alongside the tower.

First assemble the antenna on the ground. Carefully mark all critical dimensions, and then remove the antenna elements from the boom. Once the rotator and mast have been installed on the tower, a gin pole is used to bring the mast plate and short pipe to the top of the tower. There, the top crew unpins the horizontal pipe and tilts the antenna boom plate to place it in the vertical plane. The boom is attached to the boom plate at the final balance point of the assembled antenna. It is important that the boom be rotated axially so the bottom side of the boom is closest to the tower. This will allow the boom to be tilted without the elements striking the tower.

During installation it may be necessary to loosen one guy wire temporarily to allow for tilting of the boom. As a safety precaution, a temporary guy should be attached to the same leg of the tower just low enough so the assembled antenna will clear it.

The elements are assembled on the boom, starting with those closest to the center of the boom, working out alternately to the farthest director and reflector. This procedure must be followed. If all the elements are put first on one half of the boom, it will be dangerous (if not impossible) to put on the remaining elements. By start-

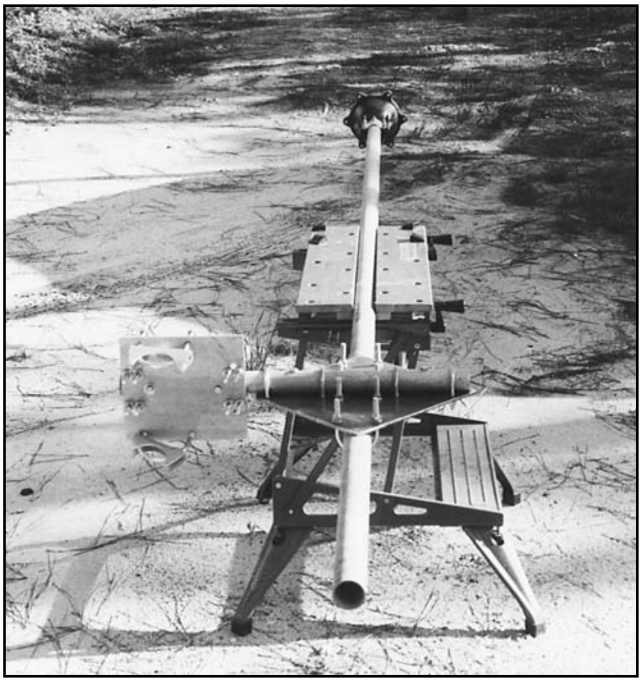


Fig 38—The PVRC mount, boom plate, mast and rotator ready to go. The mast and rotator are installed on the tower first.

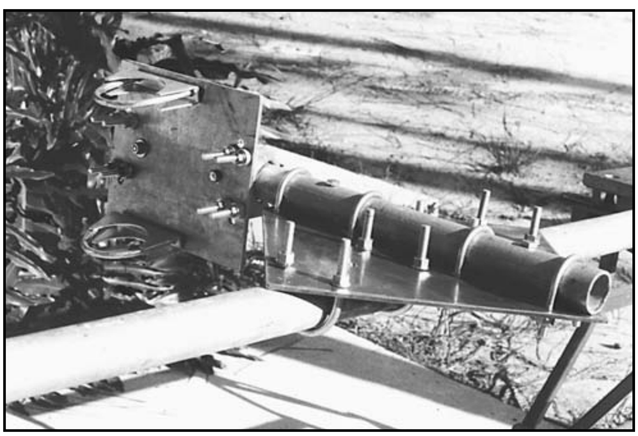


Fig 39—Close-up of the PVRC mount. The long pipe (horizontal in this photo) is the rotating mast. The U bolts in the vertical plate at the left are ready to accept the antenna boom. The heads of two locking pins (bolts) are visible at the midline of the boom plate. The other two pins help secure the horizontal pipe to the large steel mast plate. (The head of the bolt nearest the camera blends in with the right hand leg of the U bolt behind it.)

ing at the middle and working outward, the balance point of the partly assembled antenna will never be so far removed from the tower that tilting of the boom becomes impossible.

When the last element is attached, the boom is brought parallel to the ground, the horizontal pipe is

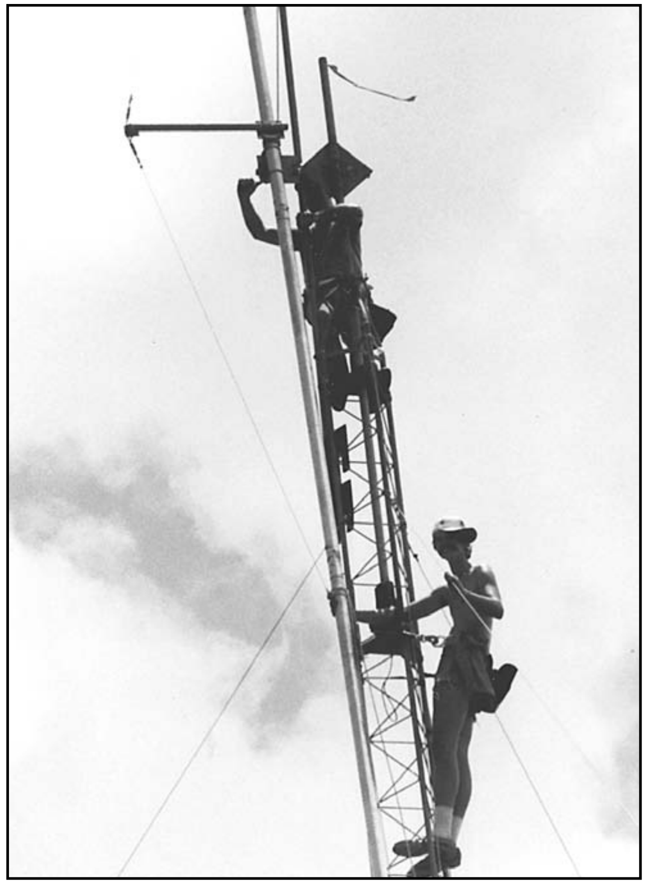


Fig 40—Working at the 70-foot level. A gin pole makes pulling up and mounting the boom to the boom plate a safe and easy procedure.

pinned to the mast plate, and the mast plate U bolts tightened. At this point, all the antenna elements will be positioned vertically. Next, loosen the U bolts that hold the boom and rotate the boom axially 90°, bringing the elements parallel to the ground. Tighten the boom bolts and double check all the hardware.

Many long-boom Yagis employ a truss to prevent boom sag. With the PVRC mount, the truss must be attached to a pipe that is independent of the rotating mast. A short length of pipe is attached to the boom as close as possible to the balance point. The truss then moves with the boom whenever the boom is tilted or twisted.

A precaution: Unless you have a really strong rotator, you should consider using this mount mainly for assembling the antenna on the tower. The offset between the boom and the mast with this assembly can generate high torque loads on the rotator. Mounting the boom as close as possible to the mast will minimize the torque when the antenna is pointed into the wind.

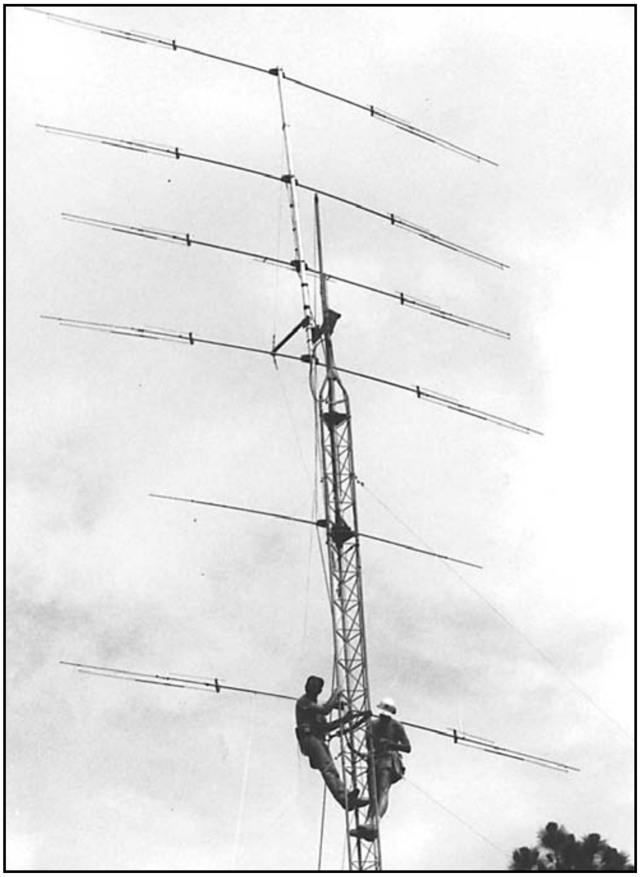


Fig 41—Mounting the last element prior to positioning the boom in a horizontal plane.

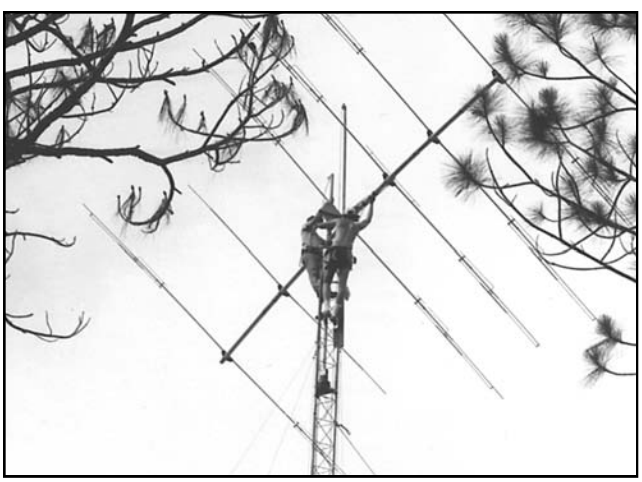


Fig 42—The U bolts securing the short pipe to the mast plate are loosened and the boom is turned to a horizontal position. This puts the elements in a vertical plane. Then the pipe U bolts are tightened and pinning bolts secured. The boom U bolts are then loosened and the boom turned axially 90°.

THE TOWER ALTERNATIVE

A cost saving alternative to the ground-mounted tower is the roof-mounted tripod. Units suitable for small HF or VHF antennas are commercially available. Perhaps the biggest problem with a tripod is determining how to fasten it securely to the roof.

One method of mounting a tripod on a roof is to nail 2 × 6 boards to the undersides of the rafters. Bolts can be extended from the leg mounts through the roof and the 2 × 6s. To avoid exerting too much pressure on the area of the roof between rafters, place another set of 2 × 6s on top of the roof (a mirror image of the ones in the attic). Installation details are shown in **Figs 43** through **46**.

The 2 × 6s are cut 4 inches longer than the outside distance between two rafters. Bolts are cut from a length of ¼-inch-threaded rod. Nails are used to hold the boards in place during installation, and roofing tar is used to seal the area to prevent leaks.

Find a location on the roof that will allow the antenna to turn without obstruction from such things as trees, TV antennas and chimneys. Determine the rafter locations. (Chimneys and vent pipes make good reference points.) Now the tower is set in place atop three 2 × 6s. A plumb line run from the top center of the tower can be used to center it on the peak of the roof. Holes for the mounting bolts can now be drilled through the roof.

Before proceeding, the bottom of the 2 × 6s and the area of the roof under them should be given a coat of roofing tar. Leave about 1/8 inch of clear area around the holes to ensure easy passage of the bolts. Put the tower back in place and insert the bolts and tighten them. Apply tar to the bottom of the legs and the wooden supports, including the bolts. For added security the tripod can be guyed. Guys should be anchored to the frame of the house.

If a rotator is to be mounted above the tripod, pressure will be applied to the bearings. Wind load on the antenna will be translated into a "pinching" of one side of the bearings. Make sure that the rotator is capable of handling this additional stress.

ROTATOR SYSTEMS

There are not that many choices when it comes to antenna rotators for the amateur antenna system. Making the correct decision as to how much capacity the rotator must have is very important to ensure trouble-free operation. Manufacturers generally provide an antenna surface-area rating to help the purchase choose a suitable rotator. The maximum antenna area is linked to the rotator's torque capability.

Some rotator manufacturers provide additional information to help you select the right size of rotator for the antennas you plan to use. Hy-Gain provides an *Effective Moment* value. Yaesu calls theirs a *K-Factor*. Both of these ratings are torque values in foot-pounds. You can compute the effective moment of your antenna by multiplying the antenna turning radius by its weight. So long

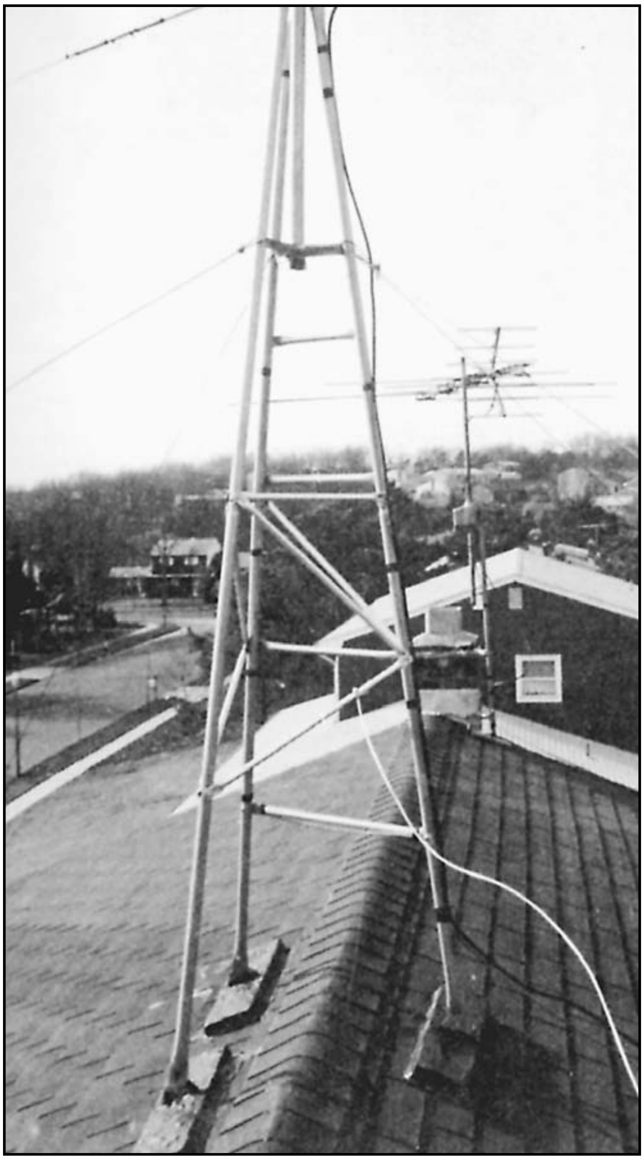


Fig 43—This tripod tower supports a rotary beam antenna. In addition to saving yard space, a roof-mounted tower can be more economical than a ground-mounted tower. A ground lead fastened to the lower part of the frame is for lightning protection. The rotator control cable and the coaxial line are dressed along two of the legs. (*Photo courtesy of Jane Wolfert.*)

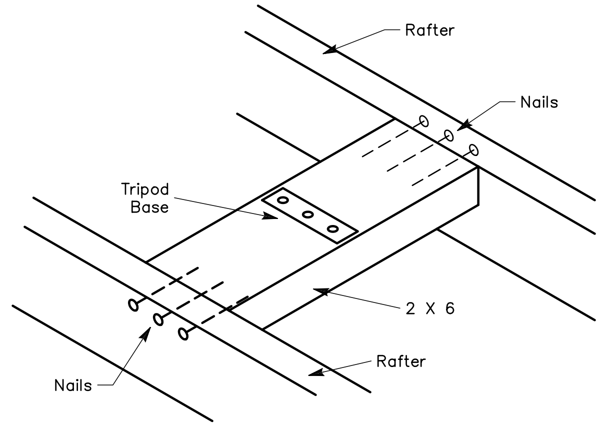


Fig 44—This cutaway view illustrates how the tripod tower is secured to the roof rafters. The leg to be secured to the crosspiece is placed on the outside of the roof. Another cross member is fastened to the underside of the rafters. Bolts, inserted through the roof and the two cross pieces, hold the inner cross member in place because of pressure applied. The inner crosspiece can be nailed to the rafter for added strength.

Fig 45—Three lengths of 2 × 6 wood mounted on the outside of the roof and reinforced under the roof by three identical lengths provide a durable means for anchoring the tripod. A thick coat of roofing tar guards against weathering and leaks.

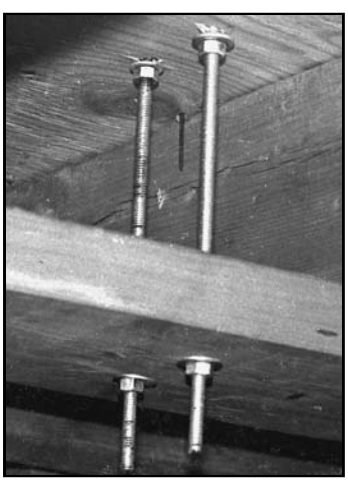


Fig 46—The strengthened anchoring for the tripod. Bolts are placed through two 2 × 6s on the underside of the roof and through the 2 × 6 on the top of the roof, as shown in Fig 43.

as the effective moment rating of the rotator is greater than or equal to the antenna value, the rotator can be expected to provide a useful service life.

There are basically four grades of rotators available to the amateur. The lightest-duty rotator is the type typically used to turn TV antennas. Without much difficulty, these rotators will handle a small 3-element tribander array (14, 21 and 28 MHz) or a single 21- or 28-MHz monoband three-element antenna. The important consideration with a TV rotator is that it lacks braking or holding capability. High winds turn the rotator motor via the gear train in a reverse fashion. Broken gears sometimes result.

The next grade up from the TV class of rotator usually includes a braking arrangement, whereby the antenna is held in place when power is not applied to the rotator. Generally speaking, the brake prevents gear damage on windy days. If adequate precautions are taken, this group of rotators is capable of holding and turning stacked monoband arrays, or up to a five-element 14-MHz system. The next step up in rotator strength is more expensive. This class of rotator will turn just about anything the most demanding amateur might want to install.

A description of antenna rotators would not be complete without the mention of the *prop pitch* class. The prop pitch rotator system consists of a surplus aircraft propeller blade pitch motor coupled to an indicator system and a power supply. There are mechanical problems of installation, however, resulting mostly from the size and weight of these motors. It has been said that a prop pitch rotator system, properly installed, is capable of turning a house. Perhaps in the same class as the prop pitch motor (but with somewhat less capability) is the electric motor of the type used for opening garage doors. These have been used successfully in turning large arrays.

Proper installation of the antenna rotator can provide many years of trouble-free service; sloppy installation can cause problems such as a burned out motor, slippage, binding and casting breakage. Most rotators are capable of accepting mast sizes of different diameters, and suitable precautions must be taken to shim an undersized mast to ensure dead-center rotation. It is very desirable to mount the rotator inside and as far below the top of the tower as possible. The mast absorbs the torsion developed by the antenna during high winds, as well as during starting and stopping.

Some amateurs have used a long mast from the top to the base of the tower. Rotator installation and service can be accomplished at ground level. A mast length of 10 feet or more between the rotator and the antenna will add greatly to the longevity of the entire system by allowing the mast to act as a torsion shock absorber. Another benefit of mounting the rotator 10 feet or more below the antenna is that any misalignment among the rotator, mast and the top of the tower is less significant. A tube at the top of the tower (a sleeve bearing) through which the mast protrudes almost completely eliminates any lateral forces on the rotator casing. All the rotator must do is support the downward weight of the antenna system and turn the array.

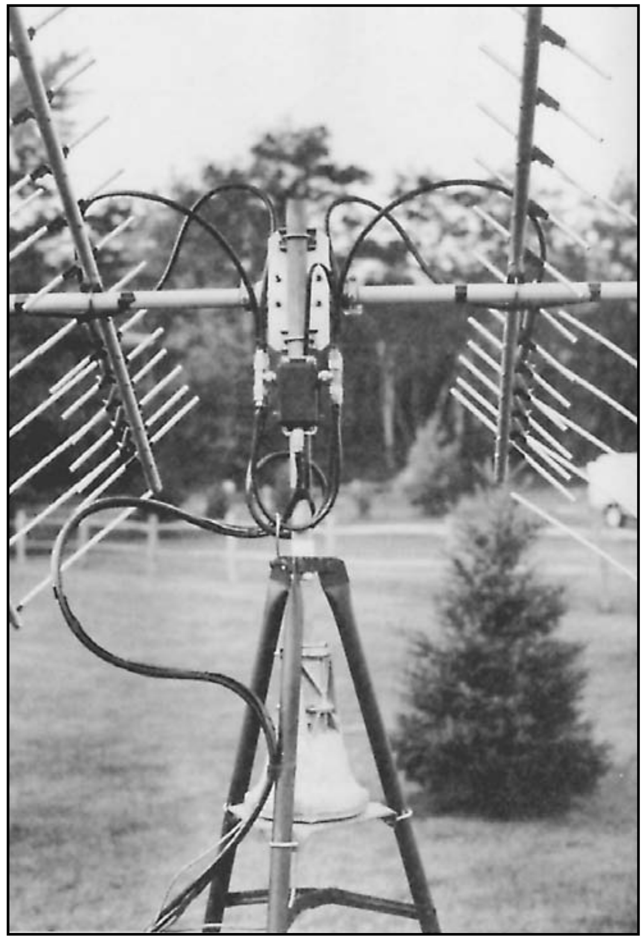


Fig 47—Rotator loop for UHF Yagi array. The feed coax is bundled with a control cable for the polarization relay. The coax/control-cable loop is taped to the rotating mast and to the top of the tower with vinyl electric tape to allow the array to be rotated.

While the normal weight of the antenna and the mast is usually not more than a couple of hundred pounds, even with a large system, one can ease this strain on the rotator by installing a thrust bearing at the top of the tower. The bearing is then the component that holds the weight of the antenna system, and the rotator need perform only the rotating task.

Don't forget to provide a loop of coax to allow your beam to rotate properly. Make sure you position the rotator loop so that it doesn't snag on anything. **Fig 47** shows a rotator loop for an elliptically polarized UHF Yagi array. Note that the coax loop is taped to the rotating mast above the top of the tower and to the tower itself.

Indicator Alignment

A problem often encountered in amateur installations is that of misalignment between the direction indicator in the rotator control box and the heading of the antenna. 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. The slippage will act as a clutch release, which may prevent serious damage to the rotator. On the other hand, the amateur might not like to climb the tower and realign the system after each heavy windstorm.

BIBLIOGRAPHY

Source material and more extended discussions of the topics covered in this chapter can be found in the references listed below and in the texts listed at the end of Chapter 2.

L. H. Abraham, "Guys for Guys Who Have To Guy," *QST*, Jun 1955.

K. Baker, "A Ladder Mast," *QST*, Jun 1981, p 24.

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

S. F. Hoerner, "Fluid Dynamic Drag," published by author, Bricktown, New Jersey, 1965, pp 1-10.

C. L. Hutchinson, "A Tree-Mounted 30-Meter Ground-Plane Antenna," *QST*, Sep 1984, pp 16-18.

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.

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

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

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

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

A. B. White, "A Delayed Brake Release for the Ham-II," *QST*, Aug 1977, p 14.

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, p 36.

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

Structural Standards for Steel Antenna Towers and Antenna Supporting Structures, TIA/EIA Standard TIA/EIA-222-F, Electronic Industries Association, Mar 1996. May be purchased from Telecommunications Industry Association (TIA), Standards and Technology Department, 2500 Wilson Boulevard, Arlington VA, 22201 or Global Engineering Documents, 15 Inverness Way East, Englewood, CO, 80112-5704, 1-800-854-7179.