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- "K5GO Half-Element Designs" by Stan Stockton, K5GO

Chapter 25

Antenna Materials and Construction

This chapter contains information on materials and techniques amateurs use to construct antennas. Included is a discussion of useful material types that are readily available at reasonable cost, and tips on working with and using these materials. The list of manufacturers on the CD-ROM included with this book contains information on where to purchase these materials.

The National Electric Code (NEC) of the National Fire Protection Association contains a section on amateur stations in which a number of recommendations are made concerning minimum size of antenna wire and the manner of bringing the transmission line into the station. The code in itself does not have the force of law but it is frequently made a part of local building regulations, which are enforceable. The provisions of the code may also be written into, or referred to, in fire and liability insurance documents. See the chapter **Building Antenna Systems and Towers** for more information on applying the NEC to your station's antenna system.

Although antennas are relatively simple structures, they can constitute a potential hazard unless properly constructed. Antennas and supporting ropes or wires should *never* be run under or over public utility (telephone or power) lines. Stay well clear of utility lines when erecting antennas and give yourself plenty of safety margins. Amateurs have lost their lives by failing to observe these precautions.

Basically any conductive material can be used as the radiating element of an antenna. Almost any insulating material can be used as an antenna insulator. An antenna system must also include some means to support those conductors and maintain their relative positions — the boom for a Yagi antenna, for example. The materials used for antenna construction are limited mainly by physical considerations (required strength and resistance to outdoor exposure) and by the availability of materials. Don't be afraid to experiment with radiating materials and insulators.

The two types of material most often used for antenna conductors are wire and tubing. Wire antennas are generally simple and therefore easier to construct, although arrays of multiple wire elements can become rather complex. When tubing is required, aluminum tubing is used most often because of its light weight, reasonable cost and strength. Aluminum tubing is discussed in a subsequent section of this chapter.

25.1 WIRE FOR ANTENNA SYSTEMS

25.1.1 WIRE TYPES

Solid copper wire is used for most wire antennas although the use of stranded wire is common. Solid wire is less flexible than stranded wire, but it is available "hard-drawn," which offers good tensile strength and negligible stretch. Special stranded wire with a larger-than-usual number of fine strands (such as Flex-Weave) is available for building antennas. It withstands vibration and bending in the wind better than common stranded wire and better than solid wire. Galvanized steel and aluminum wire are generally not used for antennas because of higher electrical resistance than copper. Galvanized wire also has a strong tendency to rust, and making good electrical connections to aluminum wire is difficult — it cannot be soldered directly without special solder fluxes.

Solid wire is also available with and without enamel coating. Enamel coating resists oxidation and corrosion, but bare wire is far more common. Solid wire is also available with a variety of different insulating coatings, including plastics, rubbers and PVC. Unless specifically rated for outdoor use however, wire insulation, including enamel, tends to break down when exposed to the UV in sunlight. Insulation also lowers the velocity factor of wire by a few percent (see the **Transmission Lines** chapter) making it electrically longer than its physical length — this will lower the resonant frequency of an antenna compared to one made of bare wire of equivalent diameter. In addition, insulation increases wind loading without increasing strength. If enameled or insulated wire is used, care should be taken to not nick the wire when removing the coating for an electrical connection. Wire will break at a nick when flexed repeatedly, such as by wind.

"Soft-drawn" or annealed copper wire is easy to handle and obtain. Common THHN-insulated "house wire" is soft-drawn. Unfortunately, soft-drawn wire stretches considerably under load. Soft-drawn wire should only be used in applications where there will be little or no tension, or where some change in length can be tolerated. For example, the length of a horizontal antenna fed at the center with open-wire line is not critical, although a change in length may require some readjustment of an impedance matching unit. Similarly, if the wire stretches significantly, it can be re-trimmed to the desired length. Repeated cycles of stretching followed by trimming and re-tensioning will result in loss of strength and possibly in mechanical failure.

"Hard-drawn" copper wire and CCS (copper-clad steel, usually sold as the trademarked product Copperweld) wire are more difficult to handle because of their mechanical stiffness and, in the case of CCS, the tendency to have "memory" when unrolled. These types of wire are ideal for applications where high strength for a given weight is required and/or significant stretch cannot be tolerated. Care should be exercised to make sure kinks do not develop in hard-drawn and CCS wire — the wire will have a far greater tendency to break at a kink. The "memory" or tendency of CCS wire to coil up can be reduced by suspending it a few feet above ground for a few days before final use. The wire should not be recoiled before it is installed.

The electrical quality of CCS wire varies considerably. A conductivity class of 30% or higher is desirable, meaning the wire has 30% of the conductivity of copper wire of the same diameter but for RF applications at HF it will have close to 100% conductivity due to skin effect. Copper cladding can be damaged by abrasion (typically at insulators) or sharp bends. Plastic insulators of sufficient strength are preferable to ceramic insulators when using CCS; they are soft in comparison and less likely to degrade the copper cladding over time. Induced defects in copper cladding eventually result in mechanical failure due to rusting of the steel core. Breaks in the copper cladding also form high resistance points to RF and will heat considerably when running high power. Heat accelerates oxidation (rusting).

Using Strap or Braided Conductors

Communications systems expert Frank Donovan, W3LPL, contributed these guidelines for the use of strap (solid metal) or braided conductors. Wide, flat, copper strap is the standard for grounding and bonding when flexibility isn't

Table 25.1
Copper-Wire Table

Wire Size AWG (B&S)	*Dia in Mils*[1]	*Dia in mm*	*Turns per Linear Inch Enamel*	*Feet per Pound Bare*	*Ohms per 1000 ft 25°C*[3]	*Cont.-duty current*[2,3] *Single Wire in Open Air*
1	289.3	7.348	—	3.947	0.1264	—
2	257.6	6.544	—	4.977	0.1593	—
3	229.4	5.827	—	6.276	0.2009	—
4	204.3	5.189	—	7.914	0.2533	—
5	181.9	4.621	—	9.980	0.3195	—
6	162.0	4.115	—	12.58	0.4028	—
7	144.3	3.665	—	15.87	0.5080	—
8	128.5	3.264	7.6	20.01	0.6405	73
9	114.4	2.906	8.6	25.23	0.8077	—
10	101.9	2.588	9.6	31.82	1.018	55
11	90.7	2.305	10.7	40.12	1.284	—
12	80.8	2.053	12.0	50.59	1.619	41
13	72.0	1.828	13.5	63.80	2.042	—
14	64.1	1.628	15.0	80.44	2.575	32
15	57.1	1.450	16.8	101.4	3.247	—
16	50.8	1.291	18.9	127.9	4.094	22
17	45.3	1.150	21.2	161.3	5.163	—
18	40.3	1.024	23.6	203.4	6.510	16
19	35.9	0.912	26.4	256.5	8.210	—
20	32.0	0.812	29.4	323.4	10.35	11
21	28.5	0.723	33.1	407.8	13.05	—
22	25.3	0.644	37.0	514.2	16.46	—
23	22.6	0.573	41.3	648.4	20.76	—
24	20.1	0.511	46.3	817.7	26.17	—
25	17.9	0.455	51.7	1031	33.00	—
26	15.9	0.405	58.0	1300	41.62	—
27	14.2	0.361	64.9	1639	52.48	—
28	12.6	0.321	72.7	2067	66.17	—
29	11.3	0.286	81.6	2607	83.44	—
30	10.0	0.255	90.5	3287	105.2	—
31	8.9	0.227	101	4145	132.7	—
32	8.0	0.202	113	5227	167.3	—
33	7.1	0.180	127	6591	211.0	—
34	6.3	0.160	143	8310	266.0	—
35	5.6	0.143	158	10480	335	—
36	5.0	0.127	175	13210	423	—
37	4.5	0.113	198	16660	533	—
38	4.0	0.101	224	21010	673	—
39	3.5	0.090	248	26500	848	—
40	3.1	0.080	282	33410	1070	—

[1]A mil is 0.001 inch.
[2]Max wire temp of 212° F and max ambient temp of 135° F.
[3]Ratings are for dc measurements and currents without skin effect.

Wiring Techniques

Working with antenna wire, cables, and terminals requires heavier tools and different techniques from ordinary electronic wiring. Manufacturers of tools and materials often supply "how to" tutorials on their websites and others can be found on YouTube and other Internet video sites. A comprehensive course by CED Engineering on wiring techniques can be found online at **www.cedengineering.com/upload/Wiring%20 Techniques.pdf.**

Table 25.2
Stressed Antenna Wire

American Wire Gauge	*Recommended Tension[1] (pounds)* Copper-clad steel[2]	*Hard-drawn copper*	*Weight (pounds per 1000 feet)* Copper-clad steel[2]	*Hard-drawn copper*
4	495	214	115.8	126.0
6	310	130	72.9	79.5
8	195	84	45.5	50.0
10	120	52	28.8	31.4
12	75	32	18.1	19.8
14	50	20	11.4	12.4
16	31	13	7.1	7.8
18	19	8	4.5	4.9
20	12	5	2.8	3.1

[1]Approximately one-tenth the guaranteed breaking strength. Might be increased 50% if end supports are firm and there is no danger of ice loading.
[2] Copperweld, 40% copper

required — at least 10 mm wide, wider is better. Thin, round conductors are always inferior. Properly designed grounding and bonding systems use wide, flat, copper strap everywhere except for the short lengths where flexibility is required for the last foot or two of connections to moveable equipment.

Braided conductors should not be used for grounding (connections to a facility's grounding electrodes as discussed in the chapter on **Building Antenna Systems and Towers**) and should be as short as reasonably practical. Unnecessarily long pigtails should always be avoided. Terminals should be installed on both ends of the braid conductors, firmly and securely fastened to the equipment and conductors at each end of the braid. (Use a crimp terminal specified for use with braid.)

Tinned, tightly woven, wide (at least 10 mm, preferably much wider), flat copper braid is an excellent bonding conductor provided it is not corroded. Skin effect may force RF to jump across each wire crossover, but there are very many tight connections in parallel.

Braid removed from coaxial cable is an exceptionally poor choice for a bonding conductor because it is round, relatively small diameter, loosely meshed and usually not tinned. It works very well inside coaxial cable because the jacket maintains tight connections in the braid mesh and protects the copper from water and other corrosion agents.

Braid of any kind should never be used outdoors, especially on antennas and towers where lightning currents might be present. The standard is wide, flat, copper strap or #2 AWG solid copper wire where lightning currents might be present. Seven or nineteen strand copper wire can be used where flexibility is required.

25.1.2 WIRE SIZE AND TENSION

Many factors influence the choice of wire type and size (gage or gauge). Important considerations include the length of the unsupported span, the amount of sag that can be tolerated, the stability of the supports under wind pressure, the amount of wind and ice loading anticipated and whether or not a transmission line will be suspended from the span. Some sag is desirable. Removing most or all sag requires additional unnecessary tension and increases the likelihood of failure. **Table 25.1** shows the wire diameter, current-carrying capacity and resistance of various sizes of copper wire. **Table 25.2** shows the recommended maximum working tension of hard-drawn and CCS wire of various sizes. The recommended working tension is approximately 10% of the minimum guaranteed breaking strength of the wire. Together with a calculation of span sag, these two tables can be used to select the appropriate wire size for an antenna.

The National Electrical Code (see the chapter **Building Antenna Systems and Towers**) specifies minimum conductor sizes for different span-length wire antennas. For hard-drawn copper wire, the Code specifies #14 AWG wire for open (unsupported) spans less than 150 feet, and #10 AWG for longer spans. CCS, bronze or other high-strength conductors may be #14 AWG for spans less than 150 feet and #12 AWG for longer runs. Lead-in conductors (for open-wire transmission line) should be at least as large as those specified for antennas.

The RF resistance of copper wire increases as the size of the wire decreases. In most common wire antenna designs however, the antenna's radiation resistance will be much higher than the wire's RF resistance and the efficiency of the antenna will be adequate. Wire sizes as small as #30 AWG, or even smaller, have been used successfully in the construction of "invisible" antennas in areas where more conventional antennas cannot be erected. In most cases, the selection of wire for an antenna will be based primarily on the mechanical properties of the wire, since the suspension of wire from elevated supports places the wire in tension.

Calculating Wire Sag

The following section is based on a *QST* "Technical Correspondence" item by Darrell Emerson, AA7FV, in the March 2014 issue of *QST.* Given the horizontal distance between two antenna masts supporting the wire, the weight

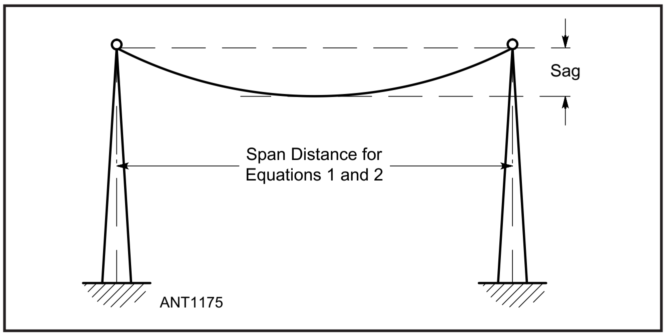


Figure 25.1 — This drawing applies to Equations 1 and 2 for calculating sag of wire antennas.

per foot of the wire and the tension in the wire, it is possible to predict the wire sag at the lowest point of the wire, halfway between the supports (**Figure 25.1**). Previous editions of the *Antenna Book* used a nomograph based on the original article "Predicting Sag in Long Wire Antennas" in the January 1966 issue of *QST*, by John J. Elengo, Jr, K1AFR. Nowadays, most radio amateurs possess computers and perhaps quite sophisticated scientific calculators. The equations to calculate wire sag are fairly trivial by today's standards, and now it is much easier to use a simple calculator to determine the wire sag than to use a nomograph.

The equation describing the catenary, the curve of a rope or chain held horizontally between two supports, was first solved in 1691 by Johann Bernoulli and others. The equation is now found in many engineering and mathematical text books. One form of the solution is:

$$\text{Wire sag} = \frac{T}{w}\left[\cosh\left(w\frac{S}{2T}\right) - 1\right] \qquad \text{(Eq 1)}$$

where

cosh = the hyperbolic cosine

T = the tension in the wire in pounds

w = the weight of the wire in pounds per foot

S = the span of the wire, here defined as the *total* horizontal distance in feet between the two supports of the wire.

(There has been some confusion in previous publications about whether S represents half the distance or the total distance between supports. In Equation 1 it represents the total distance.) Some scientific calculators include hyperbolic functions and so can compute this directly, but there is a much simpler approximation that is valid in all cases likely to be of interest to the radio amateur.

$$\text{Wire sag} = \frac{wS^2}{8T} \qquad \text{(Eq 2)}$$

Equation 2 is exactly that given in Edmund Laport's *Radio Antenna Engineering*, in his chapter on "Wire Stringing." (For sag between two supports of unequal height, see the "Miscellaneous Data" chapter of *Reference Data for Engineers* or **www.electricalengineeringinfo.com/2015/01/what-is-sag-tension-in-electrical-transmission-lines.html**)

An example calculation:

w = 0.011 (pounds per foot, 11 pounds per 1000 ft)

S = 420 feet (span, being the total distance between supports.

T = 50 pounds (wire tension).

Substituting w, S and T into the rigorous Equation 1, the computed result for sag is 4.860 feet. Using the much more convenient Equation 2, the result is 4.861 feet. The simpler formula is certainly adequate.

If the calculated sag is greater than allowable, it may be reduced by any one or a combination of the following:

1) Providing additional supports, thereby decreasing the span

2) Increasing the tension in the wire

3) Decreasing the size (gage or gauge) of the wire

These calculations do not take into account the weight of a feed line supported by the antenna wire. An IEEE tutorial on the topic can be found online at **www.ieee-tpc.org/IEEETPCTutorial_SagtensionCalcs.pdf.**

25.1.3 WIRE SPLICING AND CONNECTIONS

Wire antennas should preferably be made with unbroken lengths of wire. In instances where this is not feasible, wire sections should be spliced as shown in **Figure 25.2**. Any insulation should be removed for a distance of about 6 inches from the end of each section (take care not to nick the wire). Enamel may be removed by scraping with a knife or rubbing with sandpaper until the copper underneath is bright. The turns of wire should be brought up tight around the standing part of the wire by twisting with broad-nose pliers.

The crevices formed by the wire should be completely filled by using solder that does not contain an acid-core flux. A soldering iron or gun may not be sufficient for heavy wire or in cold temperatures; use a propane or butane torch instead. The joint should be heated sufficiently so the solder flows freely into the joint when the source of heat is removed momentarily. After the joint has cooled completely, it should be wiped clean with a cloth and then sprayed generously with acrylic to prevent corrosion.

An alternative to soldering antenna wires is the use of "split bolts" to clamp wires together as in **Figure 25.3**.

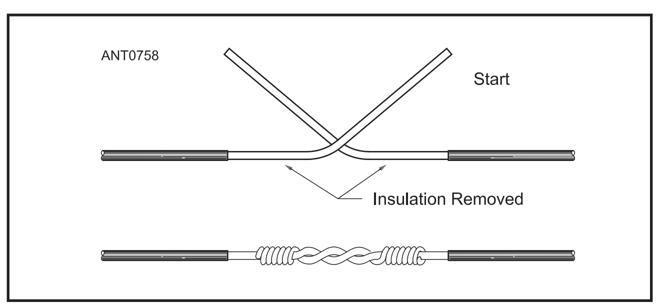


Figure 25.2 — Correct method of splicing antenna wire. Solder should be flowed into the wraps after the connection is completed. After cooling, the joint should be sprayed with acrylic to prevent oxidation and corrosion.

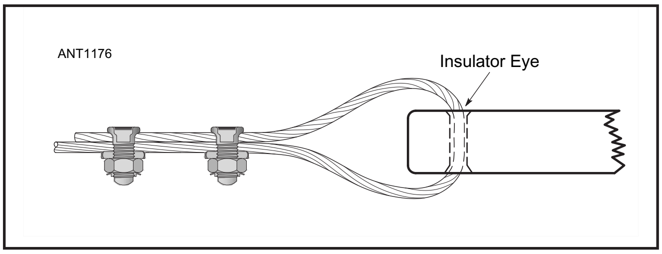


Figure 25.3 — Split bolts may be used to provide a secure connection between heavy wires, such as at an insulator or splice. Using a pair of split bolts provides a more mechanically secure connection.

This allows wire connections to be adjusted, such as when trimming a dipole length. If the proper-size split bolt is used, the connection is secure even for large conductors. Using a pair of split bolts provides a more secure attachment.

25.1.4 ANTENNA INSULATORS

To prevent loss of RF power, the antenna should be well insulated from ground, unless of course it is a shunt-fed system. This is particularly important at the outer end or ends of wire antennas, since these points are always at a comparatively high RF potential. If an antenna is to be installed indoors (in an attic, for instance) the antenna may be suspended directly from the wood rafters without additional insulation if the wood is permanently dry. Much greater care should be given to the selection of proper insulators when the antenna is located outside where it is exposed to wet weather.

Antenna insulators should be made of material that will not absorb moisture. The best insulators for antenna use are made of glass or glazed porcelain although plastic insulators are widely available and suitable for most antennas.

The length of an insulator relative to its surface area is indicative of its comparative voltage stand-off and RF leakage abilities. A long thin insulator will have less leakage than a short thick insulator. Some antenna insulators are deeply ribbed to increase the surface leakage path without increasing the physical length of the insulator. Shorter insulators can be used at low-potential points, such as at the center of a dipole. If such an antenna is to be fed with open-wire line and used on several bands however, the center insulator should be the same as those used at the ends, because high RF potential may exist across the center insulator on some bands.

Insulator Stress

As with the antenna wire, the insulator must have sufficient physical strength to carry the mechanical load of the antenna without danger of breaking. Elastic line ("bungee cord" or "shock cord") or woven fishing line can provide long leakage paths and be used to provide both the end-insulator and support functions at antenna ends, subject to their ability to carry mechanical load. They are often used in antennas of the "invisible" type mentioned in the **Stealth Antennas** and **Portable Antennas** chapters. Abrasion between a woven line and a wire loop will cut through the line fairly quickly unless a fishing swivel or similar metal attachment point is used. Use of high power approaching and up to the US legal limit of 1500 W may cause sufficient leakage current to melt woven or monofilament line directly connected to a wire loop at the end of a dipole or similar antenna. A suitable antenna insulator as explained below must be used in this case.

For low-power operation with short antennas not subject to appreciable stress, almost any small plastic, glass, or glazed-porcelain insulator will do. Homemade insulators of plastic rod or sheet are usually satisfactory. Many plastics rated for outdoor use make good insulators — this includes Lucite (polycarbonate), Delrin, plexiglass, and even the high-density polyethylene (HDPE) used in cutting boards. More care is required in the selection of insulators for longer spans and higher transmitter power.

For a given material, the breaking tension of an insulator will be proportional to its cross-sectional area. It should be remembered that the wire hole at the end of the insulator decreases the effective cross-sectional area. For this reason, insulators designed to carry heavy strains are fitted with heavy metal end caps, the eyes being formed in the metal cap, rather than in the insulating material itself.

The following stress ratings of ceramic antenna insulators are typical:

- ⅝ inch square by 4 inches long — 400 pounds
- 1 inch diameter by 7 or 12 inches long — 800 pounds
- 1-½ inches diameter by 8, 12 or 20 inches long, with special metal end caps — 5000 pounds

These are rated breaking tensions. The actual working tensions should be limited to not more than 25% of the breaking rating. Plastic insulators have significantly lower tension ratings.

The antenna wire should be attached to the insulators as shown in **Figure 25.4**. Care should be taken to avoid sharp angular bends in the wire when it is looped through the insulator eye. The loop should be generous enough in size that it will not bind the end of the insulator tightly. If the length of the antenna is critical, the length should be measured to the outward end of the loop, where it passes through the eye of the insulator. (See the note below about the loop area affecting the antenna's electrical length.) Soldering should be done as described earlier for the wire splice. If CCS wire is used, care should be taken to ensure insulator holes and edges are smooth. Any roughness at contact points between

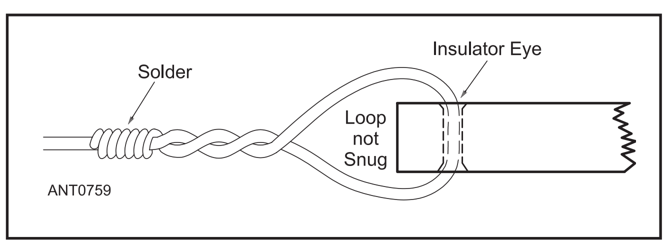


Figure 25.4 — When fastening antenna wire to an insulator, do not make the wire loop too snug. After the connection is complete, flow a non-acid core solder into the turns. When the joint has cooled completely, spray it with acrylic.

the wire and the insulator will cause the copper to be abraded away over time, exposing the wire's steel core and eventually leading to mechanical failure from rust. Assuming they are of sufficient size to handle the mechanical load, plastic insulators are a good choice for use with CCS wire.

Note that the large area of the loop through the insulator adds capacitance to the antenna. The larger the insulator loop, the more capacitance is created, and the greater its effect in lowering the resonant frequency of the antenna. This effect increases with operating frequency. When building a wire antenna, attach the insulators temporarily (without soldering) and adjust the resonant frequency of the antenna before soldering the insulator loop.

Strain Insulators

Strain or "egg" insulators have their holes at right angles, since they are designed to be connected as shown in **Figure 25.5**. It can be seen that this arrangement places the insulating material in compression rather than tension. An insulator connected this way can withstand very high mechanical load.

The principal attribute of strain insulators is that the wire will not fall or fail to carry load if the insulator breaks, since the two loops are interlocked. Insulator failure may go unnoticed however — strain insulators should be visually checked periodically. Because the wires are wrapped around each other, the leakage path is shorter than it would be otherwise and both leakage and capacitive end effects are higher compared to insulators where the wires are not interlinked. For this reason, strain insulators are typically confined to applications such as breaking up resonances in guy wires, where there is high mechanical load and where RF insulation is of minor importance.

Strain insulators are suitable for use at low-potential points on an antenna, such as at the center of a dipole. They may also be used at the ends of antennas used for low power operation.

Feed Point Insulators

Often referred to as "center insulators," the insulators used at the feed point of a wire antenna often have special features that help attach and support feed lines. A "dog bone" style insulator as in **Figure 25.6A** is the most common. To attach a coaxial feed line using this style of insulator, the cable's shield and center conductor are separated into "pigtails" that are soldered to the wire at each eye. The cable can be supported by looping it over the insulator and securing it with tape as shown in the figure. Note that the length of the separated shield and center conductor count as part of the antenna length — that may be significant at higher frequencies. The cable must be carefully waterproofed with a coating such as silicone sealant or Liquid Electrical Tape to prevent water from being wicked into the cable by the exposed shield. The "Budwig" style of insulator in Figure 25.6B includes an SO-239 so that the coaxial cable can be attached with a connector instead of soldered to the antenna. The PL-259 and exposed portion of the SO-239 connectors in this case should be waterproofed. This type of center insulator can be made from a PVC pipe cap or other plumbing fittings as shown later in this chapter.

Figure 25.7 shows a feed point insulator intended for use with parallel-wire feed line. The dog bone style of insulator may be used but cannot support the feed line in the same way as for coaxial cable. Parallel-wire line cannot be

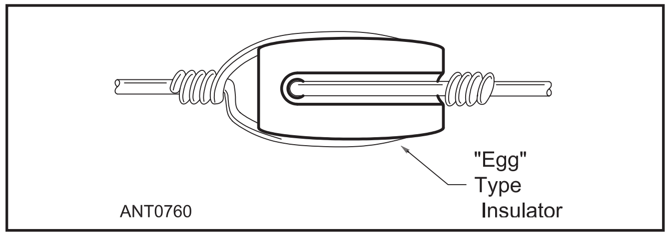
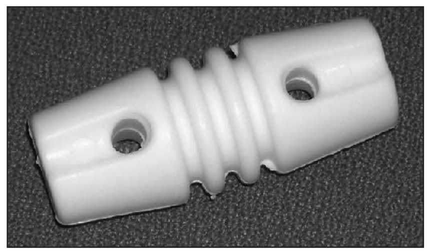
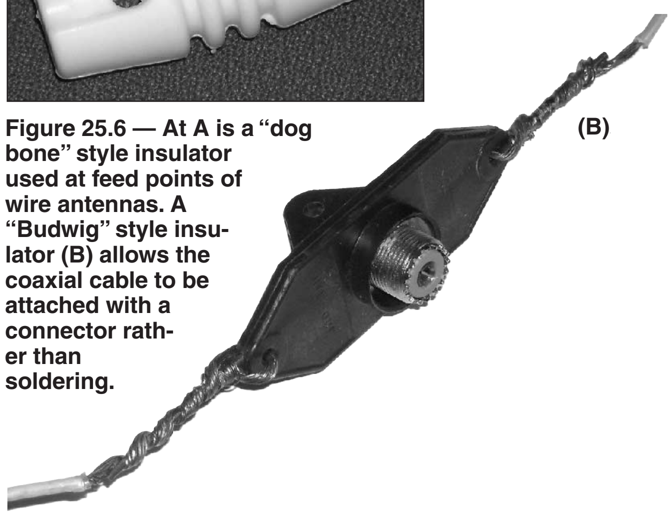


Figure 25.5 — Conventional manner of fastening wire to a strain insulator. This method decreases the leakage path and increases capacitance, as discussed in the text.



(A)



(B)

Figure 25.6 — At A is a "dog bone" style insulator used at feed points of wire antennas. A "Budwig" style insulator (B) allows the coaxial cable to be attached with a connector rather than soldering.

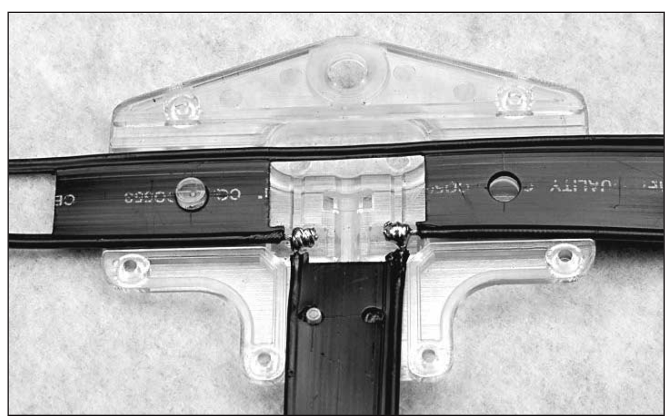


Figure 25.7 — The Ten-Tec "Acro-Bat" is made for attaching parallel-wire feed line to a wire antenna. It provides strain relief and reinforcement to the feed line to keep the conductors from breaking due to repeated flexing and bending in the wind.

looped back on itself with the conductors close together. If left unsupported, the conductors of the feed line continually flex and bend in the wind which causes them to break. The tee-style of insulator in the figure captures the parallel-wire feed line and provides mechanical support, greatly reducing breakage.

Insulators for Ribbon-Line Antennas

Figure 25.8A shows the sketch of an insulator designed to be used at the ends of a folded dipole or a multiple dipole made of parallel conductor line. It should be made approximately as shown, out of insulating material about ¼ inch thick. The advantage of this arrangement is that the strain of the antenna is shared by the conductors and the plastic webbing of the line, which adds considerable strength. After soldering, the screw should be sprayed with acrylic.

Figure 25.8B shows a similar arrangement for suspending one dipole from another in a stagger-tuned dipole system. If better insulation is desired, these insulators can be wired to a conventional insulator.

25.1.5 RADIAL SYSTEMS

See the chapter **Effects of Ground** for complete information on the requirements for ground radial systems, including references showing how to get the best results from a specific amount of wire.

Bare copper wire is the least expensive for radials with #18 or #20 AWG the smallest size likely to last due to mechanical abuse. Smaller wire will function electrically and is a good choice for temporary or portable installations. Good prices can be obtained by buying wire in bulk directly from a distributor. Copper will also withstand corrosive soils much better than aluminum.

When attaching radials to the antenna ground system, try to avoid direct contact with the ground due to corrosion from minerals in the ground. Tin-lead solder should not be used in connections in contact with the ground. If soldering is required, such as to a ground ring or plate, use silver-bearing plumbing solder or brazing rods. High-temperature MAPP gas torches are available at plumbing supply stores.

Radials need not be in direct contact with soil except for appearances. Shallow burial slits in a lawn can be made with an edging tool or a wire burial plow. See the previous cautions about avoiding direct contact between soil and solder joints.

Radials can also be placed on closely-cropped grass and the grass will grow over and around them in a few weeks, allowing them to lie directly on top of the soil. To hold radials firmly to the ground, landscaping staples can be used or iron rebar tie wire can be cut into 6 to 10 inch pieces and bent double.

25.1.6 CABLE SUPPORT

When a long run of feed line or control cable is suspended vertically, it is important to provide some strain relief so that the load is not all carried by a connector or terminal strip. Commercial cable support arms such as from KF7P Metalwerks (**www.kf7p.com**) are available to hold cables away from a crank-up tower or take the load of a long vertical cable run. Another popular solution is the family of Kellems grips that are widely available from electrical distributors such as Graybar (**www.graybar.com**). The smaller grips can be used with larger center insulators.

Using electrical tape or wire ties to secure cables to tower legs or other vertical supports will work but makes replacement more difficult since the tape or tie will have to be cut away. An alternative is to use pieces of solid #12 or #14 AWG wire from house wiring cable, twisted around the tower leg and the cables. Such twist-ties can be reused many times.

When running cables down a tower, place them where they will not be stepped on, snag a boot or belt, or compromise your grip on the tower. If possible, run them inside the tower. This also reduces their exposure to picking up RF from the antennas.

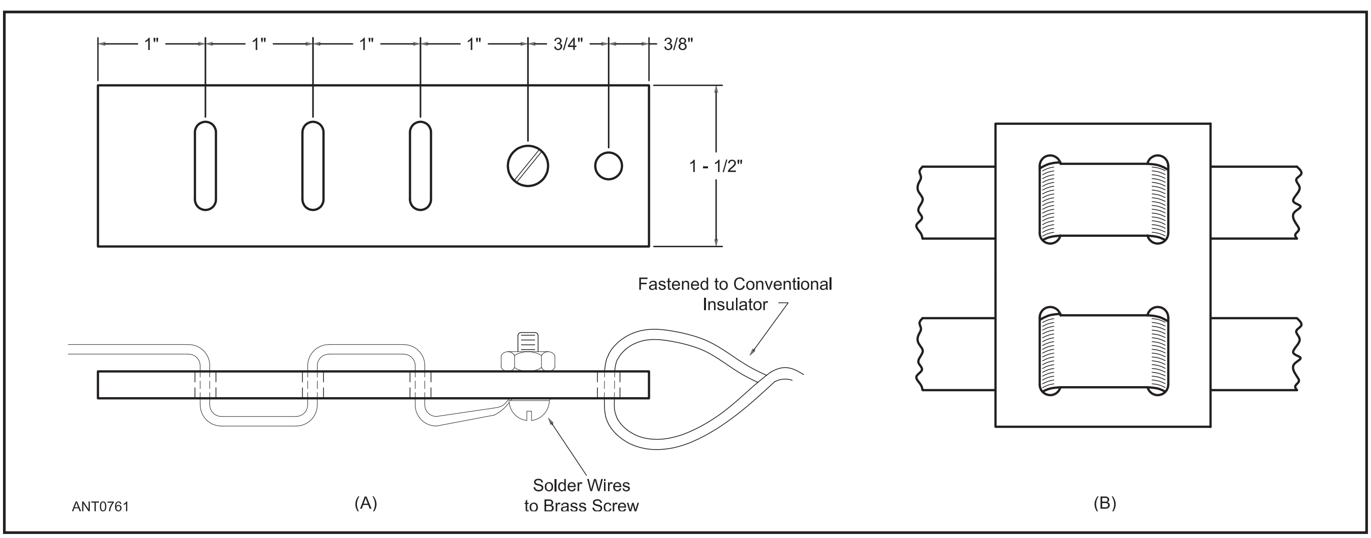


Figure 25.8 — At A, an insulator for the ends of folded dipoles, or multiple dipoles made of parallel-wire line. At B, a method of suspending one ribbon dipole from another in a multiband dipole system.

25.2 ANTENNAS OF ALUMINUM TUBING

Aluminum is a non-toxic, malleable, ductile metal with a density approximately 35% that of iron and 30% that of copper. Aluminum can be polished to a high brightness, and it will retain this polish in dry air. In the presence of oxygen, aluminum forms an oxide coating (Al_2O_3) that protects the metal from further corrosion. Direct contact between aluminum and certain metals (particularly ferrous metals such as iron or steel) in an outdoor environment can bring about galvanic corrosion of aluminum and its alloys. Some protective coating such as Noalox or Penetrox should be applied to any point of contact between dissimilar metals. (See the section on Corrosion in the chapter **Building Antenna Systems and Towers**.)

The ease with which aluminum can be drilled or sawed makes it a pleasure to work with. Aluminum alloys can be used to build amateur antennas, towers and supports. Light weight and high conductivity make aluminum ideal for these applications. Alloying typically lowers conductivity, but significantly increases tensile strength. Aluminum is typically alloyed with metals such as manganese, silicon, copper, magnesium and zinc. Cold rolling can be employed to further increase the strength.

A four-digit system is used to identify aluminum alloys, such as 6061. Aluminum alloys starting with a 6 contain di-magnesium silicide (Mg_2Si). The second digit indicates modifications of the original alloy or impurity limits. The last two digits designate different aluminum alloys within the category indicated by the first digit.

In the 6000-series, the 6061 and 6063 alloys are com-

Table 25.3
Aluminum Numbers and Alloy Types for Amateur Use

Common Alloy Numbers

Type	*Characteristics*
2024	Good formability, high strength
5052	Excellent surface finish, excellent corrosion resistance, normally not heat treatable for high strength
6061	Good machinability, good weldability
6063	Good machinability, good weldability
7075	Good formability, high strength

Common Tempers

Type	*Characteristics*
T0	Special soft condition
T3	Hard
T6	Hardest, possibly brittle
TXXX	Three digit tempers — usually specialized high strength heat treatments, similar to T6

General Uses

Type	*Uses*
2024-T3	Chassis boxes, antennas, anything that will be bent or
7075-T3	Flexed repeatedly
6061-T6	Tubing and pipe; angle channel and bar stock
6063-T832	Tubing and pipe; angle channel and bar stock

Table 25.4
Aluminum Tubing Sizes
6061-T6 (61S-T6) Round Aluminum Tube In 12-Foot Lengths

	Wall Thickness			***Approximate Weight***	
Tubing Diameter	*Inches*	*Stubs Ga.*	*ID, Inches*	*Pounds Per Foot*	*Pounds Per Length*
3/16 in.	0.035	(#20)	0.117	0.019	0.228
(0.1875 in.)	0.049	(#18)	0.089	0.025	0.330
¼ in.	0.035	(#20)	0.180	0.027	0.324
(0.25 in.)	0.049	(#18)	0.152	0.036	0.432
	0.058	(#17)	0.134	0.041	0.492
5/16 in.	0.035	(#20)	0.242	0.036	0.432
(0.3125 in.)	0.049	(#18)	0.214	0.047	0.564
	0.058	(#17)	0.196	0.055	0.660
⅜ in.	0.035	(#20)	0.305	0.043	0.516
(0.375 in.)	0.049	(#18)	0.277	0.060	0.720
	0.058	(#17)	0.259	0.068	0.816
	0.065	(#16)	0.245	0.074	0.888
7/16 in.	0.035	(#20)	0.367	0.051	0.612
(0.4375 in.)	0.049	(#18)	0.339	0.070	0.840
	0.065	(#16)	0.307	0.089	1.068
½ in.	0.028	(#22)	0.444	0.049	0.588
(0.5 in.)	0.035	(#20)	0.430	0.059	0.708
	0.049	(#18)	0.402	0.082	0.984
	0.058	(#17)	0.384	0.095	1.040
	0.065	(#16)	0.370	0.107	1.284
⅝ in.	0.028	(#22)	0.569	0.061	0.732
(0.625 in.)	0.035	(#20)	0.555	0.075	0.900
	0.049	(#18)	0.527	0.106	1.272
	0.058	(#17)	0.509	0.121	1.452
	0.065	(#16)	0.495	0.137	1.644
¾ in.	0.035	(#20)	0.680	0.091	1.092
(0.75 in.)	0.049	(#18)	0.652	0.125	1.500
	0.058	(#17)	0.634	0.148	1.776
	0.065	(#16)	0.620	0.160	1.920
	0.083	(#14)	0.584	0.204	2.448
⅞ in.	0.035	(#20)	0.805	0.108	1.308
(0.875 in.)	0.049	(#18)	0.777	0.151	1.810
	0.058	(#17)	0.759	0.175	2.100
	0.065	(#16)	0.745	0.199	2.399
1 in.	0.035	(#20)	0.930	0.123	1.476
	0.049	(#18)	0.902	0.170	2.040
	0.058	(#17)	0.884	0.202	2.424
	0.065	(#16)	0.870	0.220	2.640
	0.083	(#14)	0.834	0.281	3.372

monly used for antenna applications. Both types have good resistance to corrosion, medium strength and are widely available. A further designation like T6 denotes thermal treatment (heat tempering). In recent years 6063-T832 drawn aluminum tubing has become an attractive alternative to 6061-T6, given its good mechanical properties (typical yield strength of 35,000 psi) and comparatively low cost. Often found in commercial antennas, this alloy's low cost is derived from ubiquitous use in household items including aluminum folding chairs. More information on the available aluminum alloys can be found in **Table 25.3**.

25.2.1 SELECTING ALUMINUM TUBING

Table 25.4 shows the standard sizes of aluminum tubing that are stocked by most aluminum suppliers or distributors in the United States and Canada. Note that all tubing comes in 12-foot lengths (local hardware stores sometimes stock 6- and 8-foot lengths) and larger-diameter sizes may be available in lengths up to 24 feet. Note also that any diameter tubing will fit snugly into the next larger size, if the larger size has a 0.058-inch wall thickness. For example, ⅝-inch tubing has an outside diameter of 0.625 inch. This will fit into ¾-inch tubing with a 0.058-inch wall, which has an inside diameter of 0.634 inch. A clearance of 0.009 inch is just right for a slip fit or for slotting the tubing and then using hose clamps. Always get the next larger size and specify a 0.058-inch wall to obtain the 0.009-inch clearance.

A little figuring with **Table 25.5** will give you all the information you need to build a beam, including what the antenna will weigh. 6061-T6 aluminum has relatively high strength and good workability. It is highly resistant to corrosion and will bend without taking a "set."

	Wall Thickness			*Approximate Weight*	
Tubing Diameter	*Inches*	*Stubs Ga.*	*ID, Inches*	*Pounds Per Foot*	*Pounds Per Length*
1⅛ in.	0.035	(#20)	1.055	0.139	1.668
(1.125 in.)	0.058	(#17)	1.009	0.228	2.736
1¼ in.	0.035	(#20)	1.180	0.155	1.860
(1.25 in.)	0.049	(#18)	1.152	0.210	2.520
	0.058	(#17)	1.134	0.256	3.072
	0.065	(#16)	1.120	0.284	3.408
	0.083	(#14)	1.084	0.357	4.284
1⅜ in.	0.035	(#20)	1.305	0.173	2.076
(1.375 in.)	0.058	(#17)	1.259	0.282	3.384
1½ in.	0.035	(#20)	1.430	0.180	2.160
(1.5 in.)	0.049	(#18)	1.402	0.260	3.120
	0.058	(#17)	1.384	0.309	3.708
	0.065	(#16)	1.370	0.344	4.128
	0.083	(#14)	1.334	0.434	5.208
	*0.125	1/8 in.	1.250	0.630	7.416
	*0.250	1/4 in.	1.000	1.150	14.832
1⅝ in.	0.035	(#20)	1.555	0.206	2.472
(1.625 in.)	0.058	(#17)	1.509	0.336	4.032
1¾ in.	0.058	(#17)	1.634	0.363	4.356
(1.75 in.)	0.083	(#14)	1.584	0.510	6.120
1⅞ in.	0.058	(#17)	1.759	0.389	4.668
(1.875 in.)					
2 in.	0.049	(#18)	1.902	0.350	4.200
	0.065	(#16)	1.870	0.450	5.400
	0.083	(#14)	1.834	0.590	7.080
	*0.125	1/8 in.	1.750	0.870	9.960
	*0.250	1/4 in.	1.500	1.620	19.920
2¼ in.	0.049	(#18)	2.152	0.398	4.776
(2.25 in.)	0.065	(#16)	2.120	0.520	6.240
	0.083	(#14)	2.084	0.660	7.920
2½ in.	0.065	(#16)	2.370	0.587	7.044
(2.5 in.)	0.083	(#14)	2.334	0.740	8.880
	*0.125	1/8 in.	2.250	1.100	12.720
	*0.250	1/4 in.	2.000	2.080	25.440
3 in.	0.065	(#16)	2.870	0.710	8.520
	*0.125	1/8 in.	2.700	1.330	15.600
	*0.250	1/4 in.	2.500	2.540	31.200

*These sizes are extruded. All other sizes are drawn tubes.

25.2.2 SOURCES OF ALUMINUM TUBING

Aluminum tubing can be purchased new; suppliers are listed in the manufacturers table on the CD-ROM. Don't overlook sources for used tubing however, such as a local metal scrap yard. Some items to look for include aluminum vaulting poles, tent poles, tubing and fittings from scrapped antennas, and aluminum angle stock. Occasionally, aluminum tower sections can be found in scrap yards. Garage sales are also good sources of used tubing. By being a good scavenger, you can build up a "bone yard" of materials for antenna construction.

Aluminum vaulting poles are 12 or 14 feet long and range in diameter from 1½ to 1¾ inches. These poles are suitable for element center-sections of large beams or as booms for smaller antennas. Tent poles range in length from 2½ to 4 feet, are usually tapered and can be split on the larger end and mated with the smaller end of another pole of the same diameter. A small stainless-steel hose clamp can be used to fasten the poles at this junction. A 14- or 21-MHz element can be constructed from several tent poles in this fashion. Longer continuous pieces of tubing can be used for center sections to decrease the number of junctions and clamps.

For vertical antennas, consumer items such as window-washing and painter's poles can sometimes be used. These are not made of structural-strength tubing but are often suitable and are low cost. For larger low-band verticals, surplus irrigation pipe is often available in rural areas.

25.2.3 CONSTRUCTION WITH ALUMINUM TUBING

Although there is endless variation in the type of antennas designed and built with aluminum tubing, Yagis are by far the most common. Yagi antennas can be successfully built using rules-of-thumb for element and boom material and sizing. Some

Table 25.5
Aluminum Alloy Strength

Tubing	Tensile Strength PSI min	Yield Strength PSI min
6005A-T61 extruded	38,000	35,000
6061-T6	45,000	40,000
6061-T8 drawn	45,000	40,000
6063-T832 drawn	42,000	39,000
6063-T6 extruded	35,000	31,000
6063-T52 extruded	27,000	21,000
6082-T6*	42,100	36,300
AW-6060-T66**	31,180	23,200
AW-6005-T6**	36,260	29,000

*<5 mm wall
**<3 mm wall
Strengths shown are approximate. Consult manufacturer data sheets for specifications of materials chosen.

Table 25.6
Hose-Clamp Diameters

	Clamp Diameter (In.)	
Size No.	Min	Max
06	7⁄16	7⁄8
08	7⁄16	1
10	½	1⅛
12	⅝	1¼
16	¾	1½
20	⅞	1¾
24	1⅛	2
28	1⅜	2¼
32	1⅝	2½
36	1⅞	2¾
40	2⅛	3
	Clamp Diameter (In.)	
Size No.	Min	Max
44	2 5⁄16	3¼
48	2⅝	3½
52	2⅞	3¾
56	3⅛	4
64	3½	4½
72	4	5
80	4½	5½
88	5⅛	6
96	5⅝	6½
104	6-⅛	7

of these approaches and a set of element point designs are provided in the following paragraphs. *YagiStress*, a commercially available software program developed and supported by Kurt Andress, K7NV (**k7nv.com/yagistress**), can be used to accurately calculate the loads and survivability of Yagi designs. Designers and builders of large Yagi antennas are well advised to use modeling software such as *YagiStress* to ensure survivability of the antenna while at the same not using more material than required to achieve desired mechanical performance. *YagiStress* was used to calculate the wind-speed ratings of the half-element designs in this chapter and is based on the EIA-222-C "Structural Standard for Antenna Supporting Structures and Antennas." Antenna mechanical design spreadsheets from *Physical Design of Yagi Antennas* by David Leeson, W6NL (see Bibliography), are available from **www.realhamradio.com/Download.htm** (the URL is case-sensitive) and have been updated to EIA-222-F.

Antennas for frequencies of 14 MHz and above are usually made to be rotated. Rotatable antennas require materials that are strong, lightweight and easy to obtain. Material selection is dependent on many factors, with weather conditions typically being the most demanding requirement. High winds alone may not cause as much damage to an antenna as does ice loading. Ice in combination with high wind is typically the worst-case condition.

As explained in Section 25.2.1, elements and booms can be made from telescoping tubing to provide the necessary total length. This is referred to as tapering. The boom diameter for a rotatable Yagi or quad should be selected to provide required structural strength and to stably support the elements. The appropriate tubing diameter for a boom depends on many factors. Among them are element weight, element length, number of elements and environmental loads, including static loads such as ice and dynamic loads, principally from wind gusts. Tubing of 1¼-inch diameter can easily support a three-element 28-MHz antenna and marginally a two-element 21-MHz antenna. A 2-inch diameter boom will be adequate for

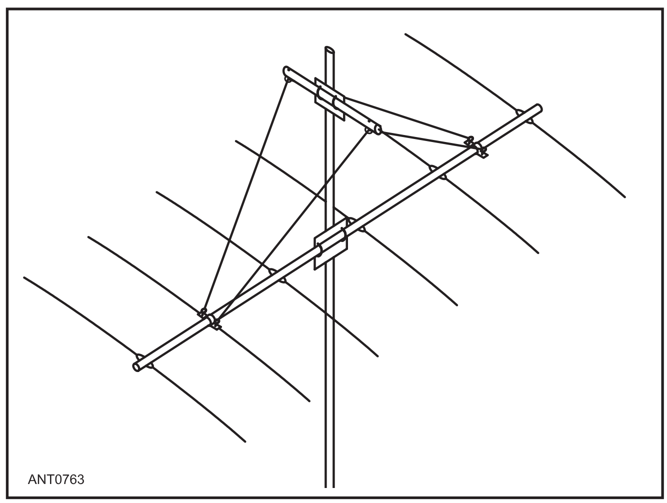
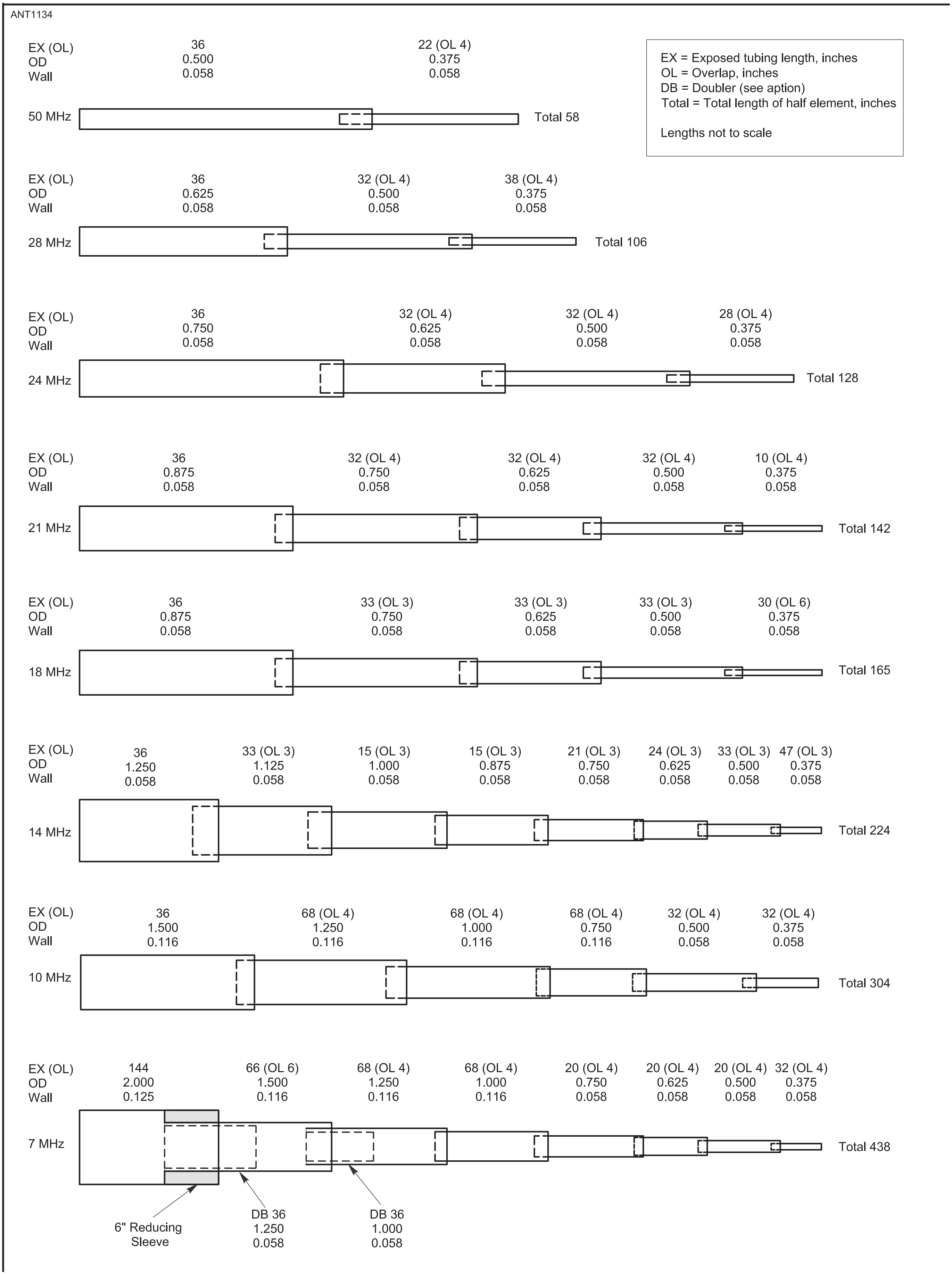


Figure 25.9 — A long boom needs both vertical and horizontal support. The cross bar mounted above the boom can support a double truss to help keep the antenna in position.

Figure 25.10 — Light-duty half-element designs for Yagi antennas. The other side of the element is identical and the center section should be a single piece twice as long as the length shown here for the largest diameter section. Tubing with 0.116-inch wall thickness consists of doubled 0.058-inch wall sections of the same length. Tubing with 0.125-inch or 0.250-inch wall thickness is 6061-T6 alloy, all other tubing is 6063-T832. Doubler (DB) sections consist of a length of tubing inserted completely into the next larger segment, flush with the inner end of that larger segment. The CD-ROM text file "K5GO Half-Element Designs" gives complete specifications for each half-element along with survivability ratings for ½ inch and 1 inch of radial ice loading.


ANT1134
EX = Exposed tubing length, inches
OL = Overlap, inches
DB = Doubler (see aption)
Total = Total length of half element, inches
Lengths not to scale
EX (OL)
OD
Wall
50 MHz
36 0.500 0.058
22 (OL 4) 0.375 0.058
Total 58
28 MHz
36 0.625 0.058
32 (OL 4) 0.500 0.058
38 (OL 4) 0.375 0.058
Total 106
24 MHz
36 0.750 0.058
32 (OL 4) 0.625 0.058
32 (OL 4) 0.500 0.058
28 (OL 4) 0.375 0.058
Total 128
21 MHz
36 0.875 0.058
32 (OL 4) 0.750 0.058
32 (OL 4) 0.625 0.058
32 (OL 4) 0.500 0.058
10 (OL 4) 0.375 0.058
Total 142
18 MHz
36 0.875 0.058
33 (OL 3) 0.750 0.058
33 (OL 3) 0.625 0.058
33 (OL 3) 0.500 0.058
30 (OL 6) 0.375 0.058
Total 165
14 MHz
36 1.250 0.058
33 (OL 3) 1.125 0.058
15 (OL 3) 1.000 0.058
15 (OL 3) 0.875 0.058
21 (OL 3) 0.750 0.058
24 (OL 3) 0.625 0.058
33 (OL 3) 0.500 0.058
47 (OL 3) 0.375 0.058
Total 224
10 MHz
36 1.500 0.116
68 (OL 4) 1.250 0.116
68 (OL 4) 1.000 0.116
68 (OL 4) 0.750 0.116
32 (OL 4) 0.500 0.058
32 (OL 4) 0.375 0.058
Total 304
7 MHz
144 2.000 0.125
66 (OL 6) 1.500 0.116
68 (OL 4) 1.250 0.116
68 (OL 4) 1.000 0.116
20 (OL 4) 0.750 0.058
20 (OL 4) 0.625 0.058
20 (OL 4) 0.500 0.058
32 (OL 4) 0.375 0.058
Total 438
6" Reducing Sleeve
DB 36 1.250 0.058
DB 36 1.000 0.058

larger 28-MHz antennas or for harsh weather conditions and for antennas up to three elements on 14 MHz or four elements on 21 MHz. It is not recommended that 2-inch diameter booms be made any longer than 24 feet unless additional support is added to carry both vertical and horizontal loads. Suitable reinforcement for a long 2-inch boom can consist of a truss or a truss and lateral support, as shown in **Figure 25.9**.

For boom lengths in excess of 24 feet, 3-inch diameter material is usually required. Three-inch diameter booms provide considerable mechanical stability as well as large clamping surface area for boom-to-element hardware. Clamping surface area is particularly important if heavy icing is anticipated, and helps prevent rotation of elements around the axis of the boom. Pinning an element to the boom with a bolt or, preferably, a swaged, hardened pin, can eliminate this possibility, but the hole introduces a stress riser that can materially reduce the strength of the boom. Element rotation about the boom axis can be minimized by mounting elements under the boom rather than on top. Pinned elements sometimes work loose and elongate the pinning holes in both the element and the boom. This is a progressive condition resulting in elements that can be so loose-fitting to the boom that their rotational positions change frequently. Although this condition typically does not adversely affect the electrical performance of a Yagi, the mechanical strength of the members involved degrades as the holes elongate. A Yagi with elements at various angles is unsightly as well.

A 3-inch diameter boom with a wall thickness of 0.065 inch is satisfactory for antennas up to about a five-element, 14-MHz array that is spaced on a 40-foot long boom. A truss is recommended for any boom longer than 24 feet.

Per theory, there is no RF voltage at the center of a parasitic element and insulation is not required at the boom-to-element interface for elements centered on the boom. Driven elements may or may not be electrically connected to the boom depending on the feed system employed. In practice, parasitic elements are usually directly connected to the boom both mechanically and electrically for designs from HF through lower UHF. At upper UHF grounded elements are subject to detuning because the element-to-boom contact no longer acts as a point but rather as a complex shape of significant area. At HF, unanticipated and unwanted resonances, though very unlikely, can occur in center-grounded elements. Highly conservative HF designs and many UHF designs insulate all elements from the boom, typically using Garolite at HF and suitable materials such as Teflon at UHF and above.

Metal booms have a small "shortening effect" on elements that run through them. With materials sizes commonly employed, this is not more than one percent of the element length, and may not be noticeable. It is just perceptible with ½-inch tubing booms used on 432 MHz, for example. At VHF and UHF, standard design-formula lengths can be used as given and driven element matching can be adjusted at the desired operating frequency. The center frequency of an all-metal array will tend to be 0.5 to 1 percent higher than a similar system built with insulated elements.

Element Assembly

Figure 25.10 shows tapered Yagi element designs contributed by Stan Stockton, K5GO, that will survive winds in excess of 80 mi/h. With a ½-inch thickness of radial ice, these designs will withstand winds from 45 to 77 mi/h. Ice increases the surface area subject to wind loading but does not increase the strength of the element. More rugged designs are shown in **Figure 25.11**. With no ice loading, these elements will survive in 118 to 172-mi/h winds, and in winds from 78 to 92 mi/h with ½ inch of radial ice. Deviations from the designs provided require analysis with a program such as *YagiStress* to ensure survivability in the environmental conditions of interest. Except for the very largest 40 meter elements, all required tubing lengths are 6 feet or shorter that can be shipped by parcel services. The file "K5GO Half-Element Designs" showing all element segment lengths, overlaps, tubing specifications and more information on ice loading is included on this book's CD-ROM.

Figures 25.10 and 25.11 show only half elements. When the element is assembled, the largest size tubing for each element should be double the length shown in the drawing, with its center being the point of attachment to the boom. These designs are somewhat conservative, in that they are self-resonant slightly below the frequency indicated for each design. Telescoping the outside end sections to shorter lengths for resonance will increase the survival wind speeds. Conversely, lengthening the outside end sections will reduce the survival wind speeds. [See Bibliography listing for David Leeson,W6NL (ex-W6QHS), at the end of this chapter.]

Figure 25.12 shows several methods of fastening antenna element sections together. The slot and hose-clamp method shown in Figure 25.12A works well for joints that require adjustment. Generally, one adjustable joint per element half is sufficient to tune an antenna. Stainless-steel hose clamps work well and are inexpensive. Some do not have stainless steel screws however. This can be checked with a magnet. Table 25.5 shows available hose-clamp sizes. Wherever tubing sections overlap, a small amount of anti-oxidation compound such as Noalox or Penetrox should be used. This prevents aluminum oxide from forming between the tubing surfaces that can create a high impedance electrical connection and/or mechanically "freeze" the joint.

Figures 25.12B, 12C and 12D show possible fastening methods for joints that do not require adjustment. At B, machine screws and nuts hold the elements in place. At C, sheet metal screws are used. At D, rivets secure the tubing. If the antenna is to be assembled permanently, rivets are the best choice. Once in place they are permanent, although they can be drilled out if necessary. They will not work free, regardless of vibration or wind, if properly installed and seated. If aluminum rivets with aluminum mandrels are used, they will never rust. In addition, there is no danger of dissimilar-metal corrosion with aluminum rivets and aluminum antenna elements. If the antenna is to be disassembled and moved periodically, either B or C will work. If machine screws are used, however, take all possible precautions to keep the nuts from vibrating

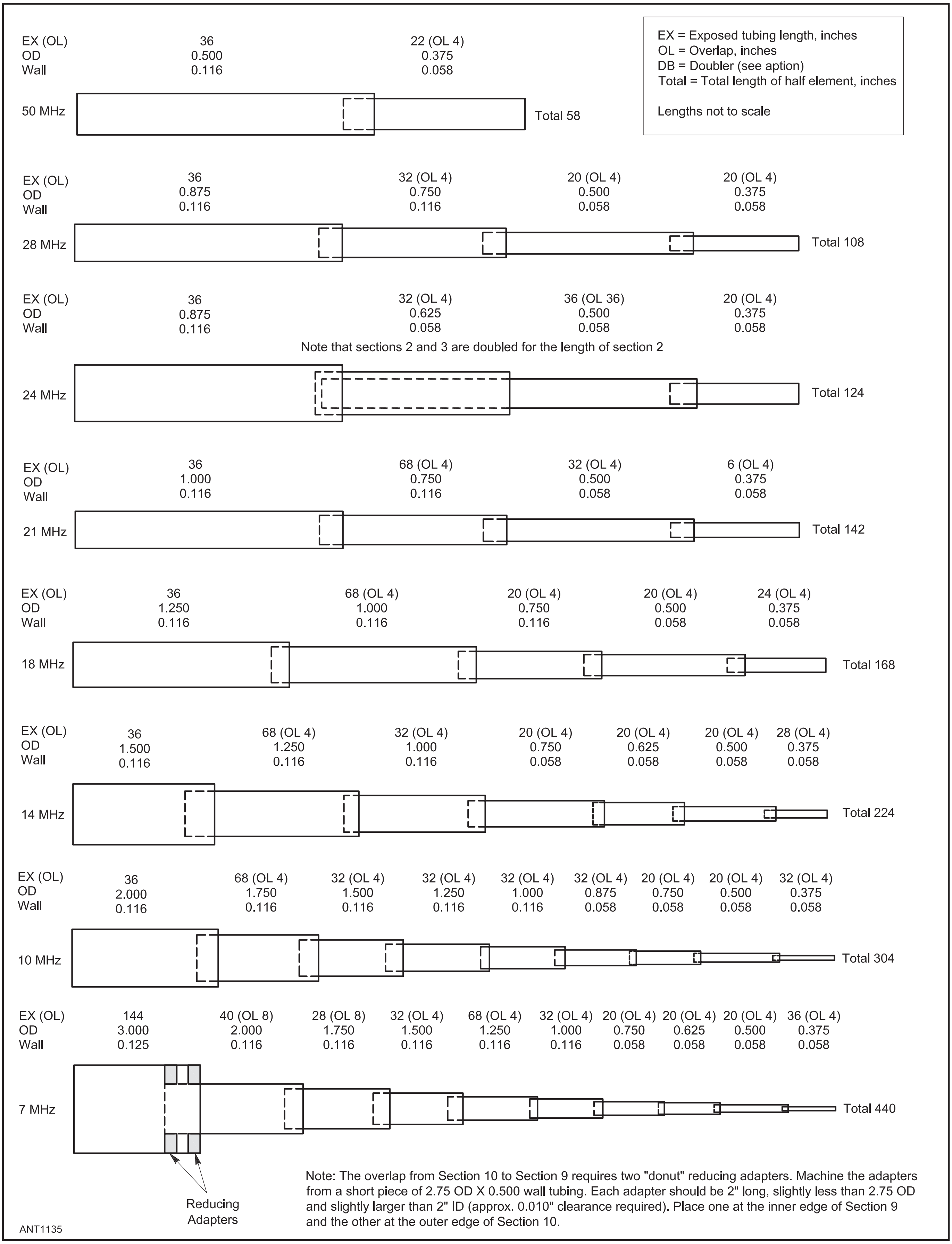


Figure 25.11 — A heavy-duty schedule of Yagi half-element segments. See the Figure 25.10 caption for details. Table 25.4 gives details of aluminum tubing sizes.

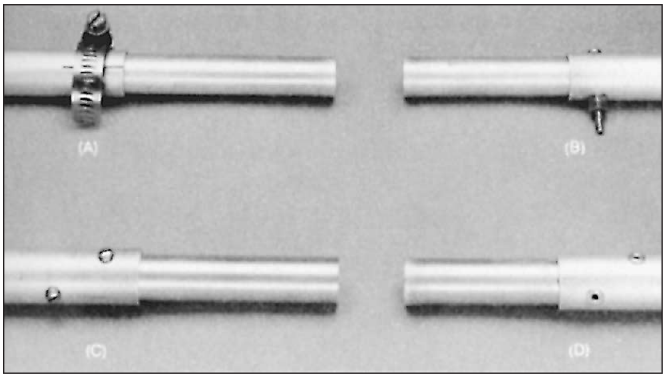


Figure 25.12 — Methods of connecting telescoping tubing sections to build beam elements. See text for a discussion of each method.

free. Use Nylock nuts or lock washers and a thread-locking compound.

Very strong elements can be made by using a double thickness of tubing, made by telescoping one size inside another for a portion of, or for the total length. This is usually done at the center of an element where more strength is desired at the boom support point, as in the 14-MHz element in Figure 25.11. Other materials can be used as well, such as wood dowels, fiberglass rods, etc.

Metal antenna elements have high mechanical Q, resulting in a tendency to vibrate in the wind. One way to dampen vibrations is by placing a piece of polypropylene or similar material line inside the element throughout its entire length. Choice of damping line material is not critical — the line will not be exposed to the sun's UV. The line will mildew or rot however if something like inexpensive clothesline is used. Cap or tape the end of the element to secure the damping line. If mechanical requirements dictate (a U-bolt going through the center of the element, for instance), the line may be cut into separate pieces for each element half.

Antennas for 50 MHz need not have elements larger than $\frac{1}{2}$-inch diameter, although up to 1 inch is used occasionally. At 144 and 222 MHz the elements are usually $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. For 432 MHz, elements as small as $\frac{1}{16}$ inch diameter work well if made of stiff rod. Aluminum welding rod of $\frac{3}{32}$ to $\frac{1}{8}$ inch diameter is fine for 432-MHz arrays, and $\frac{1}{8}$ inch or larger is good for the 222-MHz band. Aluminum rod or hard-drawn wire works well at 144 MHz.

Tubing and rod sizes recommended in the paragraph above are usable with most formula dimensions for VHF/UHF antennas. Larger diameter material reduces Q and increases bandwidth; smaller diameter material raises element and overall antenna Q and reduces bandwidth. Much smaller diameters than those recommended will require longer elements, particularly for antennas for 50-MHz and above.

Element Taper and Electrical Length

The builder should be aware of one important aspect of telescoping or tapered elements. When the element diameter tapers, as shown in Figures 25.10 and 25.11, the electrical length is not the same as it would be for a constant diameter element of the same total length. Length corrections for tapered elements are discussed in the chapter on **HF Yagi and Quad Antennas**.

25.3 OTHER MATERIALS FOR ANTENNA CONSTRUCTION

25.3.1 WOOD AND BAMBOO

Wood is very useful in antenna work. It is available in a great variety of types and sizes. Rug poles of wood or bamboo make fine booms. Bamboo is quite satisfactory for spreaders in quad antennas.

Round wood stock (doweling) is found in many hardware stores in sizes suitable for small arrays. Wood is good for the framework of multi-bay arrays for the higher bands, as it keeps down the amount of metal in the active area of the array. Square or rectangular boom and frame materials can be cut to order in most lumber yards if they are not available from the racks in suitable sizes.

Wood used for antenna construction should be well seasoned and free of knots or damage. Available materials vary, depending on local sources. Your lumber dealer can help you better than anyone else in choosing suitable materials. Joining wood members at right angles can be done with gusset plates, as shown in **Figure 25.13**. These can be made of thin outdoor-grade plywood. Construction with round material can be handled in ways similar to those used with metal components, such as with U-bolts.

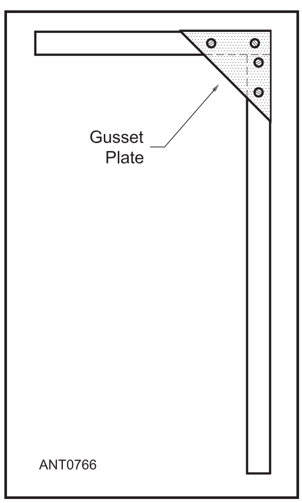


Figure 25.13 — Wood members can be joined at right angles using gusset plates.

In the early days of radio, hardwood was used as insulating material for antennas, such as at the center and ends of dipoles, or for the center insulator of a driven element made of tubing. Wood dowels cut to length were the most common approach. To drive out moisture and prevent the subsequent absorption of moisture into the wood, it was treated before use by boiling in paraffin. Of course today's technology has produced superior materials for insulators in terms of both strength and insulating qualities. However, the technique is worth consideration in an emergency situation or if low cost is a prime requirement. “Baking” the wood in an oven for a short period at 200° F should drive out any moisture. Then treatment as described in the next paragraph should prevent moisture absorption. The use of wood insulators should be avoided at high-voltage points if high power is being used.

All wood or bamboo used in outdoor installations should be protected from the weather with varnish or paint. A good grade of marine spar varnish or UV-stable polyurethane varnish will offer protection for years in mild climates, and one or more seasons in harsh climates. Epoxy-based paints also offer good protection. Bamboo can also be protected by wrapping it with electrical tape. Spray varnish is sometimes applied after wrapping with tape and will provide excellent longevity.

25.3.2 PLASTICS

Plastic tubing and rods of various sizes are available from many building-supply stores. The uses for the available plastic materials are limited only by your imagination. PVC pipe and electrical conduit is quite useful for antenna construction at VHF and UHF. For permanent antennas, be sure the plastic will withstand UV exposure or paint it.

Plastic plumbing and irrigation fittings can also be used to enclose baluns and as the center insulator or end insulators of a dipole, as shown in **Figure 25.14**. The same fittings and adapters can be used to create a portable antenna that is assembled using friction fits between pipe and fittings.

Plastic or Teflon rod can be used as the core of antenna loading coils, including for mobile antennas (**Figure 25.15**), but the material for this use should be selected carefully. Some plastics, particularly PVC, become warm in the presence of a strong RF field. This can result in the core deforming or even catching fire. Where high RF fields are anticipated, fiberglass or Teflon solid rod, or open polycarbonate cylinders are recommended. Home goods stores frequently carry inexpensive drinking glasses made of polycarbonate, in a variety of sizes. These make excellent coil forms for high-power RF applications.

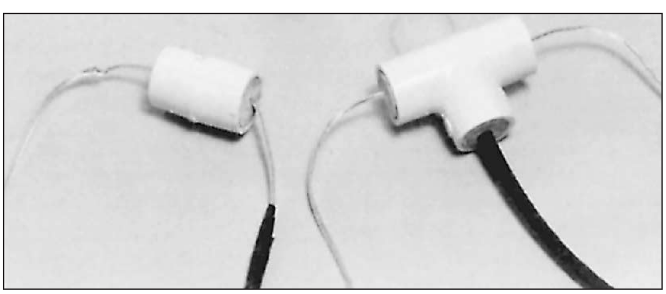


Figure 25.14 — Plastic plumbing parts can be used as antenna center and end insulators.

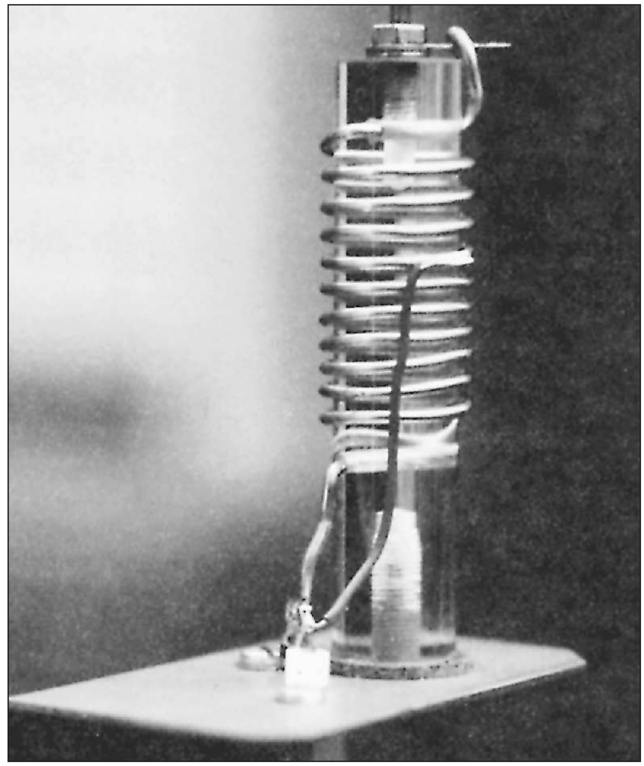


Figure 25.15 — A mobile-antenna loading coil wound on a polystyrene rod.

25.3.3 FIBERGLASS

Fiberglass is lightweight, withstands harsh weather well, and has excellent insulating qualities. Fiberglass rod and tubing are excellent for the nonconductive structure of an antenna. Fiberglass poles are the preferred material for spreaders for quad antennas, for example. Fiberglass rod or tubing can be used as the boom for VHF and UHF antennas. Extendable fiberglass poles have become very popular as supports for portable wire antennas. The SteppIR family of tunable Yagi antennas use fiberglass tubes with flexible metal tape inside as the elements.

Fiberglass should be painted or coated to protect it from exposure to UV when used outdoors. UV breaks down the resin holding the glass fibers together and the surface begins to shed fibers, leading to cracks and water ingress.

Whenever working with fiberglass materials — sawing, cutting, sanding, drilling — gloves and eye protection against loose fiber fragments should be used. If heavy dust is being generated, a dust mask should be worn.

A disadvantage of hollow fiberglass poles is that they may be crushed rather easily. Fracturing occurs at the point where the pole is crushed, causing it to lose its strength. A crushed pole is next to worthless. Some amateurs have repaired crushed poles with fiberglass cloth and epoxy, but the original strength is nearly impossible to regain. Inserting a wooden dowel into the tubing provides additional crush resistance.

25.4 HARDWARE

Antennas should be assembled with good quality hardware intended for outdoor use. Stainless steel is a good choice for long life. Rust will quickly attack plated steel hardware, making nuts difficult, if not impossible, to remove. If stainless-steel muffler clamps and hose-clamps are not available, steel hardware can be plated or painted with a good zinc-chromate primer and a one or more finish coats. Rust inhibiting paints are also good protection. When using stainless-steel hardware, use an anti-seize compound on the threads to prevent the threads from jamming due to galling of the thread surfaces.

Galvanized steel generally has a longer life than plated steel, but this depends on the thickness of the galvanizing coat. In harsh climates rust will usually develop on galvanized fittings in a few years. For the ultimate in long-term protection, galvanized steel should be further protected with zinc-chromate primer and then paint or enamel before exposing it to the weather. Cold-galvanizing spray is useful in repairing damage to galvanized surfaces and preventing rust. It is available in home goods stores.

Good quality hardware is expensive, but over time is less expensive and much less frustrating than poor quality "equivalents." Antennas built of high quality hardware need to be taken down and refurbished much less often. When the time does come to repair or modify an antenna, rusty hardware, particularly at the top of a tower, will seem in retrospect to have been a very poor investment.

25.5 BIBLIOGRAPHY

Source material and more extended discussion of topics covered in this chapter can be found in the following references:

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