ANTENNAS

K6MHE takes us through the design and construction parameters for his J-pole antenna. The design may be simple and proven, but a little computer tweaking can make it far more efficient.

The J-Pole Revisited

BY DAN RICHARDSON*, K6MHE

The J-pole antenna has been around for decades. Its ease of construction, cost, and installation make it a favorite for the home builder. However, if conventional construction and installation methods are utilized, I have found that the performance of this antenna is less than optimum. I built my J-pole to avoid some common pitfalls, resulting in improved performance. If you are considering building a J-pole for yourself or if you presently are using one, the following information should be of interest to you.

A Bit of History

I have in my library an old government publication entitled "Antennas and Antenna Systems" (TM 11-314) printed in 1943 by the War Department, wherein the following description of the J-pole is given:

"The J antenna, so called because it resembles the shape of the letter "J," is a half-wave vertical element end-fed by a quarter-wave matching stub . . . It is intended for use with two-conductor open-wire transmission lines, a suitable value of line impedance being 600 ohms. Since the lower end of the matching stub is at zero potential with respect to earth, a direct ground may be made to this point, using a connecting wire of any convenient length, without disturbing the operation of the antenna . . . "

Today, amateurs normally use coax transmission line to feed an antenna. Otherwise, the above description and the illustration shown in fig. 1, printed over four decades ago, are essentially unchanged and still are published today in many amateur radio publications.

The operation of the J-pole is based on the assumption that the top 1/2-wavelength section is the radiation portion of the antenna, while the lower 1/4-wavelength stub is used for matching and doesn't radiate. This assumption is not entirely correct. I will endeavor to explain.

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Computer Modeling

Fortunately, today we have at our disposal inexpensive antenna-modeling software. We can, by using our computers, effectively evaluate many antenna configurations without so much as stringing a single wire. I used EZNEC[1] to model and analyze the J-pole for a closer look.

The First Scenario

I began by modeling a 2 meter J-pole at a typical backyard elevation of 30 feet above ground. The model was designed to represent the "plumber's delight" style of construction using standard 1/2 inch copper pipe and fittings. (As a reference for comparison, I also molded a 1/2-wave dipole at the same height.)

In the first analysis I molded only the antennas themselves. This was done to eliminate any possible distortions which could be caused by a supporting mast or transmission line. In other words, the antennas were just floating up there (the wonders one can do with computers) connected to nothing. I planned to add a conductive support mast and coax transmission line and evaluate their influences at a later time.

The resulting far-field elevation plots for this first scenario are shown in figs. 2 and 3. Two elevation plots are depicted for the J-pole in fig. 2, and the reference 1/2-wave dipole is shown in fig. 3. Fig. 2(A) was produced with the unconnected portion of the stub oriented to the right side; fig. 2(B) was generated by EZNEC with the stub rotated 90° azimuth (perpendicular to the view).

The 1/2-wave reference dipole's plot (fig. 3) is similar to that in fig. 2(B). However, the dipole produces a sharper dip in radiation directly overhead (180°).

EZNEC also revealed that the major lobe takeoff angle of 3° was identical for both antennas. Therefore, I used 3° for the elevation angle to compute the azimuth pattern comparisons in fig. 4. In this illustration (fig. 4) the unconnected leg of the stub is oriented towards the right (0° bearing) side. Observe that the J-pole exhibits a slight pattern shift or skewing in the same direction as the unconnected stub is positioned.

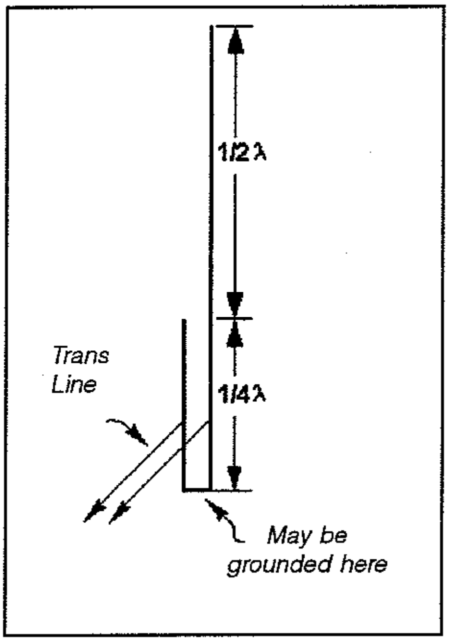

Fig. 1– Typical J-pole illustration.

An Incorrect Assumption

If the assumption that only the top 1/2-wave of the J-pole radiates and the 1/2-wave matching section doesn't, why isn't the J-pole's pattern much closer to that of the dipole? After all, aren't both antennas supposedly utilizing 1/4-wavelength radiating elements? Evidently, the matching stub must be influencing the J-pole's pattern. It does and here's why.

For negligible radiation to take place from the 1/4-wave matching stub, certain

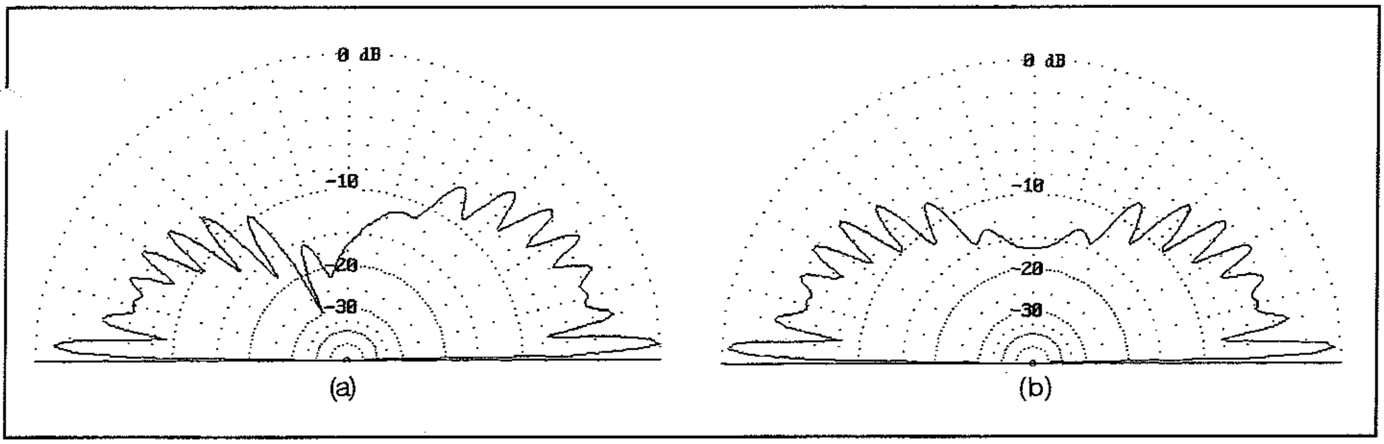

Fig. 2– Elevation plots of a J-pole mounted 30 ft. above ground. In view (A) the unconnected leg of the matching stub is located to the right side. In view (B) the unconnected leg is oriented perpendicular to the view.

conditions must be met. First, the spacing between the two parallel conductors must be very close in terms of wavelength. Second, the current in each conductor must be equal in amplitude with a phase differential of 180° (anti-phase).

Looking at the matching stub, it is obvious that at the unconnected (open) end of the stub no current exists, as that point exhibits an infinite impedance. However, what may not be readily apparent is the following: At the adjacent contrasting point of the stub, where it connects to the 1/2-wavelength element, the impedance is quite high. However, it is not infinite. Therefore, current must exist. (Indeed, if there was no current at that point, no power would be coupled to the 1/2-wavelength element.) Consequently, the current amplitudes between the parallel lines of the matching stub will not be equal. This was confirmed by examining the currents within the stub section computed by EZNEC. EZNEC's computations verified that the currents in the contrasting stub segments were not the same in amplitude. Additionally, EZNEC also reported that the phase relationships were not exactly 180°. The consequence of all of this is that some energy is radiated from the matching stub. Although the differences computed by EZNEC were not great, they were enough to produce the skewing of the J-pole's radiation patterns illustrated in figs. 2 and 4.

The Bottom Line

In the azimuth comparisons in fig. 4 EZNEC calculated that the J-pole's gain varies from approximately a maximum of 1 dBd at 0° to –1/4 dBd at 180°. Broadside to the stub section (90° and 270°) the gain is about 1/2 dBd.

In spite of the fact that EZNEC's calculations indicated that the J-pole had *overall* a slight gain advantage compared to the dipole, I concluded that the performance of both antennas would be about the same. The reason is that it is generally accepted that a change of 1 dB can scarcely be perceived by a receiving station. Therefore, from a practical point of view, a receiving station would normally not be able to distinguish between the J-pole and the dipole, based on the azimuth comparisons in fig. 4, as any variation would be 1 dB or less.

I next concentrated my efforts on understanding what consequences, if any, adding a support mast and coax transmission line would have.

The Second Scenario: Adding A Supporting Mast

The next step was to model a J-pole connected to a mast. For this analysis the base of the stub section was to be directly connected to a ground-mounted conductive mast.

EZNEC uses the Nec-2 engine for computations and will not permit wires to touch ground. In order to emulate a ground connection for the mast, a ground system was

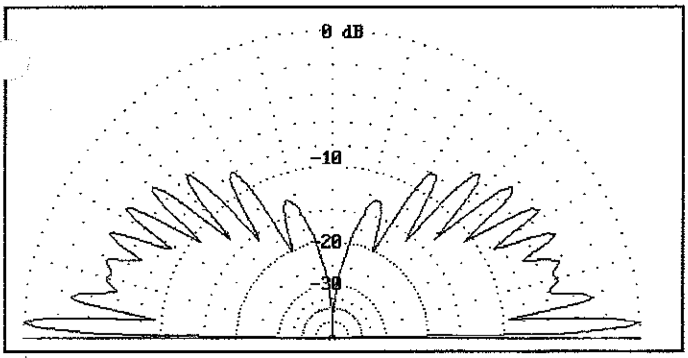

Fig. 3– Elevation plot for a 1/2-wave dipole mounted 30 ft. above ground.

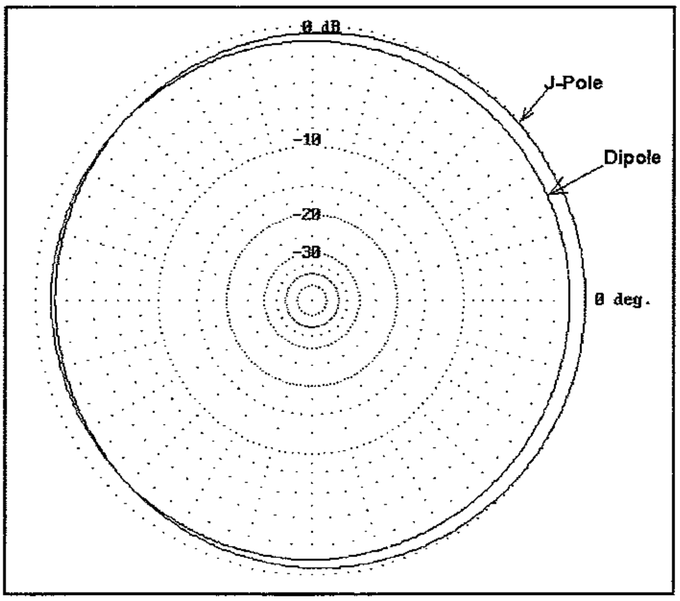

Fig. 4– Azimuth patterns at 3° elevation for a 2 meter J-pole and a 1/2-wave dipole mounted 30 ft. above ground.

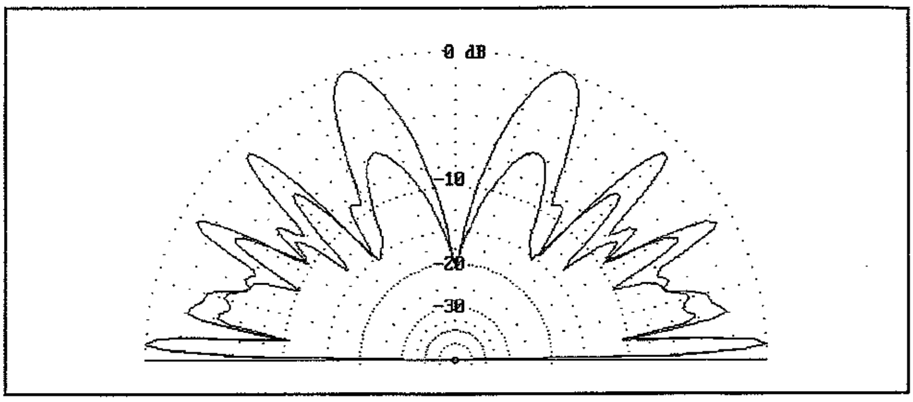

Fig. 5– Elevation comparison of two J-pole systems. The outermost plot is the conventionally built and installed J-pole, and the inner plot is a J-pole insulated from the support mast with a coaxial choke installed at the feed point (see text).

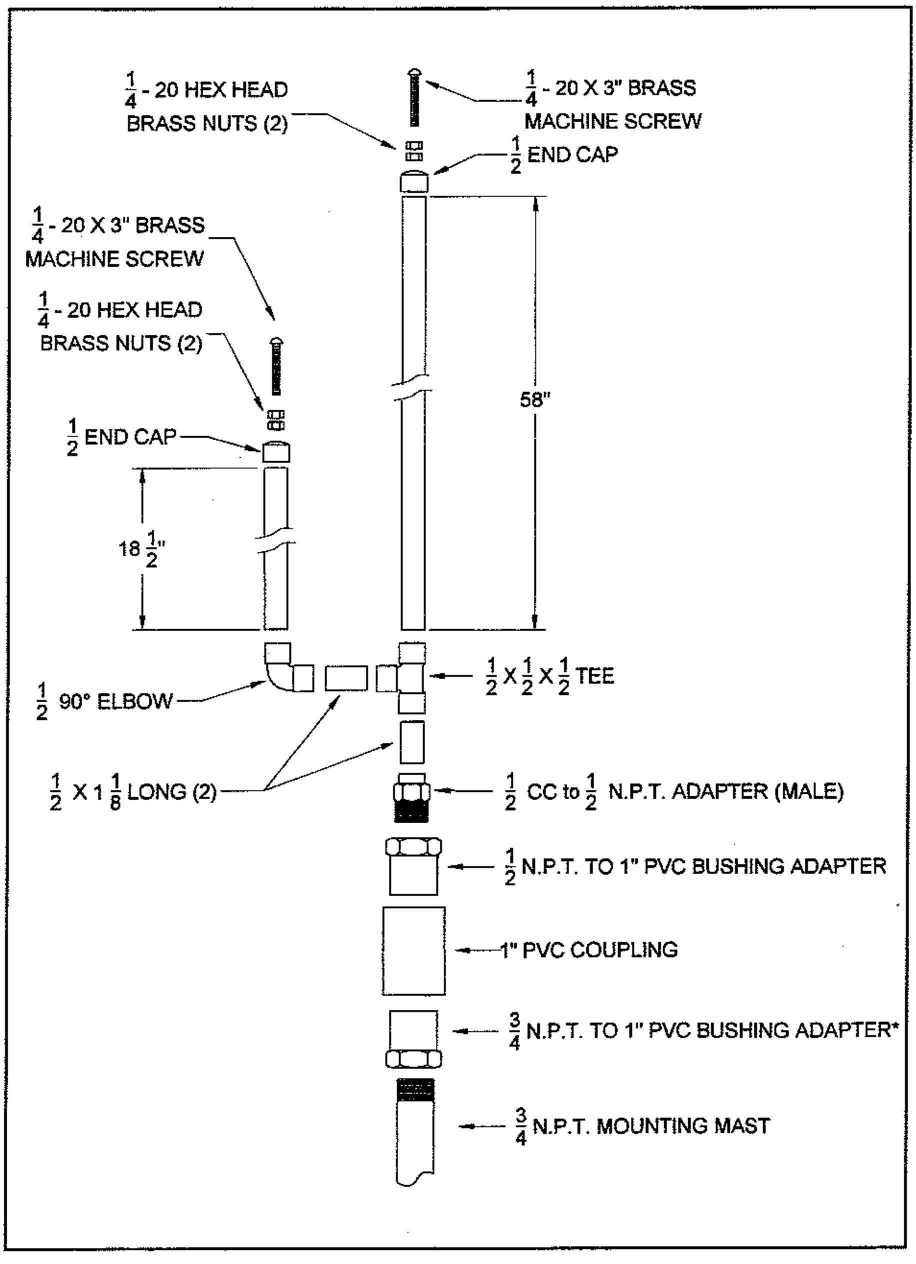

Fig. 6– Parts assembly and dimensions for a 2 meter J-pole.

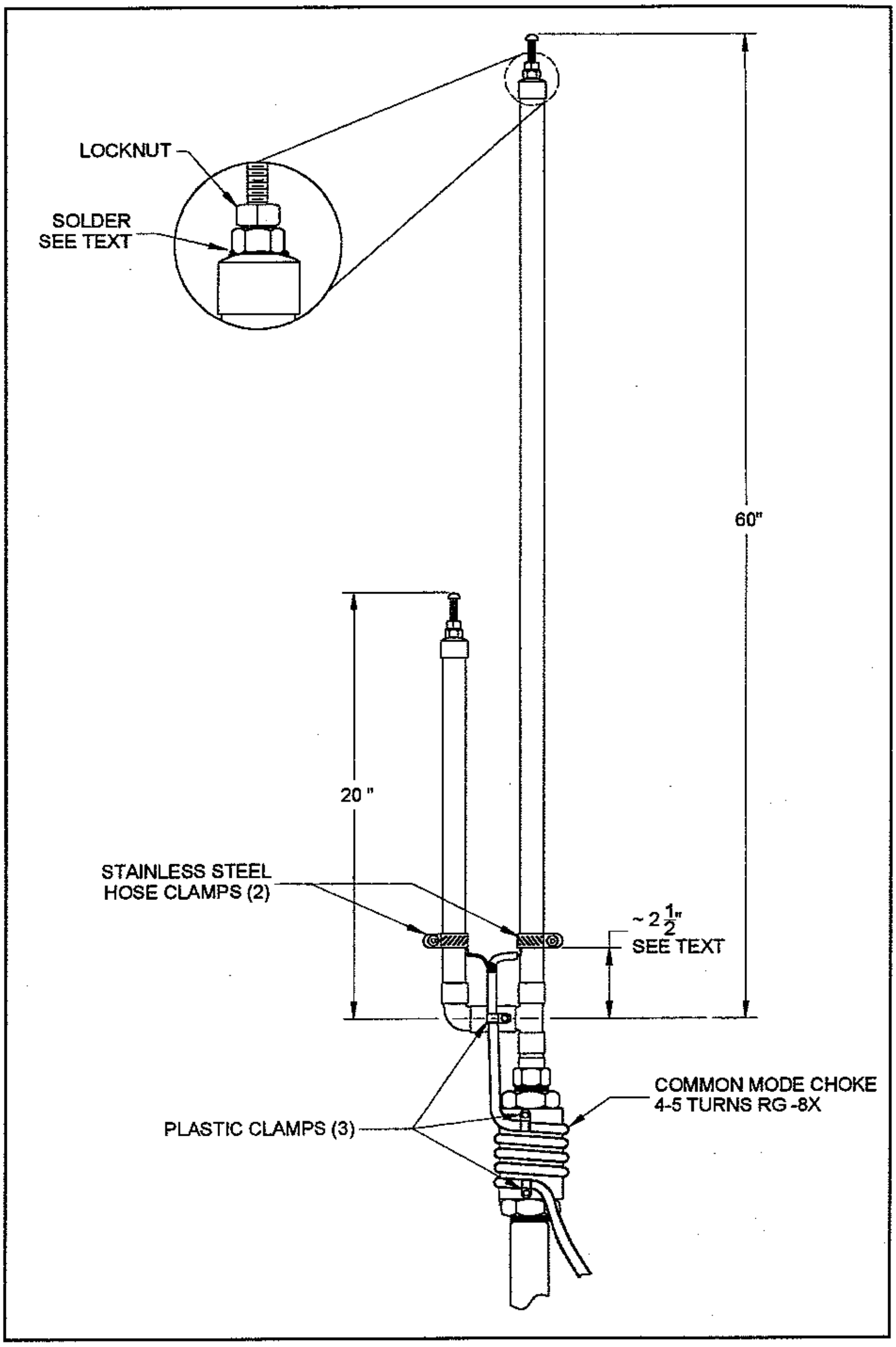

Fig. 7– The assembled J-pole with a common mode current choke formed using the coax transmission line.

modeled consisting of four 1/4-wavelength radials connected to and spreading out from the base of the mast. The base of the mast and the radials were located very close to (1/2 inch above) ground.

A series of computer-generated plot analyses were run at several mast heights varying from approximately 27 to 30 feet, including odd and even 1/4 wavelengths. As might be expected, there were variation in the elevation plots depending upon the height (length) of the mast. Most noteworthy, in all cases EZNEC reported an increase in the higher takeoff angles when the antenna was connected to the conductive mast. Consequently, based upon these analyses, I concluded mounting a J-pole to a conductive support does and will have an effect upon the performance of a J-pole. This is contrary to previous statements in many publications.

The Third Scenario: The Transmission Line

Although coax is a two-conductor transmission line, due to skin effect there are actually three conductive surfaces. One surface is the outer surface of the center conductor, the second is the inside surface of the sleeve (braid), and the third is the outside surface of the sleeve. It is this outer surface where an unwanted (common mode) current can be and usually is present.[2]

To find out to what extent the common mode current on the transmission line may affect the antenna's performance, I ran an analysis for a J-pole fed with a coaxial transmission line. In this analysis the antenna was at the same 30 foot elevation as I had used in the previous models.

To incorporate the third conductive surface of the transmission line in the antenna model, I used a method suggested by Roy Lewallen in the EZNEC manual. This entailed placing a wire very close to and running parallel with the transmission line. For this analysis the coax and the parallel wire were routed straight down from the antenna. Additionally, a mast section was not included to reduce possible misinterpretations of the analysis.

Examining EZNEC's calculations for this configuration revealed that common mode current does exist on the transmission line. The transmission line radiation resulting from the common mode current caused an increase in higher angle radiation patterns similar to that in the previous analyses of conductive masts.

At this point it was obvious that mounting a J-pole directly to a conductive mast and/or the common mode current on a coax transmission line results in producing a high proportion of signal being wasted at higher takeoff angles.

In the preceding analyses of the mast and coax transmission line we made reference to a theoretical J-pole attached to nothing—just floating up there 30 feet above ground. In the real world the antenna will be supported by something and will have a transmission line attached. What I needed now was a comparison under more realistic circumstances.

The Fourth Scenario: The Tale of Two Systems

I concluded by running a computer analysis for two complete J-pole systems. One system was a conventionally constructed and installed J-pole. By convention,I I mean the base of the antenna is directly connected to a ground-mounted conductive mast and fed with a coax transmission line with no provisions for controlling common-mode current. In the second system the J-pole was insulated from its mast and a coaxial choke was contrived by placing a 500 ohm series inductive reactance inserted on the wire simulating the outer shield of the coax at the antenna's feed point. The antennas in both systems were mounted 30 feet above ground, and all other parameters were the same— i.e., ground conductivity, applied power, and so on.

The resulting computer elevation plots are shown in fig. 5. In this figure the patterns are viewed with the unconnected leg of the stub oriented perpendicular to the view. Note the substantially higher angle radiation (outermost pattern) of the J-pole built and installed in the conventional fashion.

Unquestionably, based on the computer analysis, for better performance of a J-pole antenna at the desirable lower takeoff angles, it should be built and installed like most other antennas. That is to say, isolate it from any conductive supporting structures and employ some method to eliminate or reduce common mode current on the coax transmission line. It was these conclusions I applied in the building of my J-pole.

Construction

I used common copper to copper and PVC plumbing components obtained at the local building supply store to build the antenna. In addition to the ease of obtaining the plumbing fittings and their reasonable cost, there is the additional benefit that an open channel is maintained throughout the antenna elements. This permits draining of any possible internal moisture condensation.

The antenna construction (dimensions and assembly) information is given in figs. 6 and 7 and should be self-explanatory. The main departure from conventional "plumber's delight" construction practice is the use of the PVC pipe fittings, which serve a double purpose. They form an assembly which is used to insulate the antenna from the mast, plus they provide an excellent coil form for fabricating a coaxial (common mode) choke. The two PVC adapters and coupling are cemented together using standard PVC pipe cement.

Another slight variation from the conventional is the incorporation of adjustment screws (stingers) at the end of the elements. This was done to make the adjusting (resonating) of the antenna a much easier task.

I found using a tube cutter to be much superior to using a hacksaw for cutting the copper wire. Using a tube cutter makes it easier to maintain dimensional accuracy and provides a good straight cut, plus deburring is not required.

Soldering Tips

A few comments may be in order for those inexperienced in soldering copper pipe fittings.

First of all, be sure that all surfaces to be soldered are clean. I used a strip of emery cloth (180 grit) about 1 inch wide and 8 to 10 inches long. While holding the copper tubing in a vise, I used the emery cloth as one would use a shoe-shine rag and polished the copper tubing until it was bright and clean.

Next, prior to assembling the components for soldering a very thin coat of soldering paste was applied to the surfaces which were to be soldered. By thin I mean that when applied, the paste could barely be detected by eye, but it could be felt by touch. Applying too much paste will make for a gooey mess and can hinder more than help while soldering.

When soldering the joints at the base of the antenna, some care is required to keep all the components properly aligned, as the heat conduction is such that most, if not all, of the joints will be molten during soldering. I happen to have a large vise which did the job nicely, but wooden blocks and clamps could be made to work equally well.

Another point or two: Avoid applying too much solder. Remember that the strength is in the joint itself, not on the outside. Putting mounds of additional solder on the outside doesn't help and makes the job look sloppy.

Finally, avoid getting the joint too hot. This can result in oxidizing the copper surfaces and burning the paste and/or resin, which results in a weak, dirty, poor-conducting joint. I used a propane torch and played the flame slowly back and forth across the joint, touching the solder to the joint successively until it flowed. The solder should melt when touched to the surfaces (joints) you are soldering, not by the direct flame of the torch. If you are inexperienced in this type of soldering, it would be good insurance to purchase a couple of extra fittings and practice soldering them a time or two until you become comfortable. It really is not difficult to do.

A good method I found for securing the nuts for the adjustment screws to the end caps was to first solder the pipe caps to the end of the elements. Following that I cleaned the top surface of each cap with emery cloth and then applied a thin coat of solder paste to the cleaned area. Holding the antenna element in a vertical position in my vise and using the propane torch, I tinned the top portion of each cap, applying just enough solder to create a small crown of solder (less than 1/32 inch high at the center) and approximately 3/8 inch diameter.

Next the brass 1/4-20 nut was prepared by partially screwing the nut onto a screw and then grabbing the head of the screw in a vise so that the face of the nut was held in an upright position. I then cleaned and applied a thin coat of soldering paste to the face of the nut.

Next I applied heat using the propane torch, tinning the face of the nut with solder. However, before the solder had solidified, I used a small wire brush and brushed the face of the nut, leaving only a flash coating of solder. After cooling I removed the nut from the screw, and again clamping the antenna element vertically in my vise, placed the nut (tinned side) upon the end cap where I had previously applied the crown of solder. After carefully aligning the nut on the end cap, I slowly applied heat from the propane torch, playing the flame back and forth until I could see that the solder had fused. (*Note: No additional solder was added as it was not needed, and furthermore, had I attempted to torch the nut with the solder, chances are the nut would have moved, ruining the alignment.*)

For the final step I waited until after everything had cooled. Then, using a hand drill with #7 (.201 OD) drill bit, I drilled through the end cap using the threaded hole of the nut as a guide. After the drilling was complete, I passed a 1/4-20 tap through the nut to clean out any possible solder that might have been lodged in the threads and threaded the end cap.

Tuning

Element lengths and the transmission-line connection points are shown in fig. 7. I suggest you use these dimensions as a starting point, and then, if necessary, adjust the element lengths and/or feed points for minimum SWR indication on the portion of the band you desire. An antenna analyzer such as the Autek Research model RF-5 or the MFJ model 249 or 259 will work great. You can also use an SWR meter.However, using an analyzer makes the job much easier.

The final step was to seal the end of the coax at the antenna to prevent moisture penetration. I used a product called Liquid Electrical Tape[3], which I purchased at the local hardware store. This is a liquid vinyl coating that is brushed on and when cured, makes an excellent weather seal. To inhibit any possible wicking action, I completely covered all exposed portions of shield, foam dielectric, and center conductor. As an added precaution I also covered the stainless-steel clamps, including a portion of the antenna elements extending to about 1/2 inch on each side of the clamps.

Summary

Mounting a J-pole directly to a conductive mast and feeding the antenna with coax without some method of preventing or reducing common mode current on the transmission line will result in producing a high proportion of the signal being wasted at high take-off angles. For better ground-wave communication a J-pole should be isolated from any conductive supporting structures and a method of eliminating or greatly reducing the common mode current on a coax transmission line is required.

The J-pole which I built and which is presented in this article incorporates those features and provides a good, cost-effective antenna.

Asides

I maintained the spacing between the parallel elements of the stub section as close as possible using the plumbing fittings. During modeling the J-pole I had found that the more the spacing between the parallel conductors of the stub was increased, the more skewing of the azimuth pattern resulted.

Additionally, it has been suggested by some that increasing the top portion of a J-pole to 5/8 wavelength would improve performance. Running an analysis using that configuration resulted in a much higher imbalance in current amplitudes and phase relationships within the stub section. This produced considerably greater pattern skewing and distortions. Therefore, I concluded that using 5/8-wavelength top section of a J-pole would not be a good choice.

Acknowledgements

The information in this article is certainly not original on my part. I merely used computer-generated antenna patterns to restate and confirm what is known by most, if not all, professional engineers, but not many amateurs.

My thanks to the comments from Tom Rauch, W8JI, and others on the Internet antenna forum for spurring me into further investigating the antenna. Until that point I had always adhered to "conventional wisdom" regarding the operation of the J-pole published in many amateur publications.

Footnotes

1. EZNEC, Roy Lewallen, W7EL, P.O. Box 6658, Beaverton, OR 97007.

2. For a more detailed discussion of the common mode current problem with coax transmission lines, see Walter Maxwell, W2DU's article "Some Aspects of the Balun Problem" *QST,* March 1983.

3. Liquid Electrical Tape manufactured by Star brite, Fort Lauderdale, Florida, 33314. ■