Some J-Poles That I Have Known

Part 1: Why I Finally Got Interested in J-Poles and Some Cautions in Modeling Them

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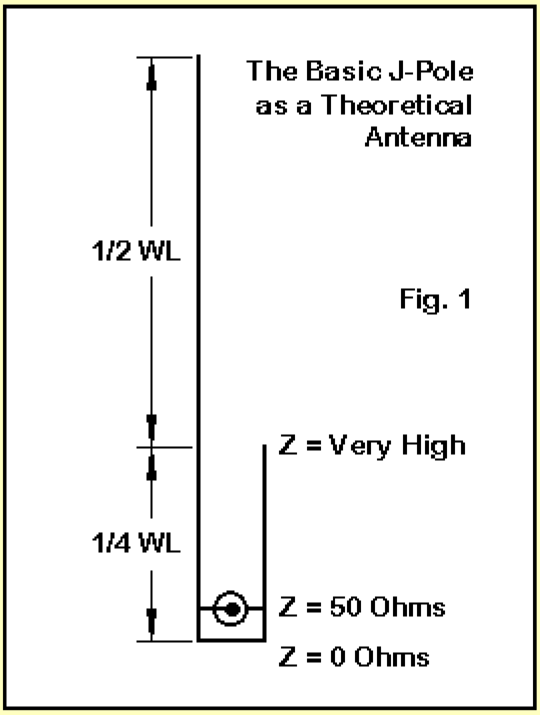
Although used on many bands from 20 meters on up, the most wide-spread use of the J-pole antenna is on 2 meters. It covers the entire band with under 2:1 SWR, provides a nearly circular azimuth pattern, requires no radials, and matches a 50-Ohm feedline with fair ease. The nearly 3/4-wavelength height of the antenna is not a significant problem for most installations. Versions of the antenna have used everything from TV twinlead to copper water pipe a materials, all with roughly equal success.

Despite the success of the antenna, disputation about the antenna persists. This disputation has largely put me off the J-pole as an object of study, since much--but certainly not all--of it has lent more smoke than fire to the understanding of J-poles. As well, almost everyone has his or her own favorite version of the J-pole. There are as many versions of the J-pole antenna as there are versions of the letter J in the collection of type fonts supplied with modern computers. Some variations are subtle, others are bold. How much differences each variation makes in actual performance seems to depend upon who has built the antenna.

Some J-Pole Background

By tradition, we tend to picture the J-pole in the manner of **Fig. 1**.



The Basic J-Pole as a Theoretical Antenna

Fig. 1

The classic J-pole has three parts of note: the radiator, the matching section, and the feedpoint.

1. The radiator is a simple vertical 1/2-wavelength element, with the physical length adjusted for the diameter of the material used. The fatter the material, the shorter the physical length of an electrical half-wavelength. As well, insulation will also create a velocity factor that shortens the physical length of an electrical half wavelength.

Ideally--with a lossless infinitesimally thin wire half wavelength radiator, the impedance at the ends will go to a theoretically indefinitely high value. In practice, with wires of significant diameter, the impedance will be high, but not indefinitely high. The actual impedance will vary with the wire thickness. If the wire end joins another wire end, then the impedance is likely to be still lower, while remaining in the high category.

2. The matching section of a J-pole consists of a parallel transmission line section about 1/4-wavelength long. A quarter-wavelength section has the property of transforming an impedance presented at one end to another impedance at the other end in accord with the simple equation

$$Z_O^2 = Z_1 \cdot Z_2 \qquad (1)$$

such that the characteristic impedance of the line forms the geometric mean between the high and low impedance values. The characteristic impedance, Zo, of the line depends on an equally familiar textbook equation:

$$Z_O = 276 \log \frac{2S}{d} \qquad (2)$$

where S is the center-to-center spacing of the parallel conductors and d is the diameter of the conductors--assuming that both conductors have the same diameter. Missing from the equation is the dielectric constant of the material surrounding and between the conductors, since the value is 1.0 for a vacuum or dry air. Hence, vinyl-covered lines such as TV twinlead may have a different Zo than an air-spaced line using the same wire size and spacing.

We tend to modify this relationship among impedances at the ends of the matching section for practical antenna reasons. By shorting out the bottom of the matching section, we send the impedance at the center of the short to zero--in theory. We also obtain an antenna that is physically connected at all points relative to discharging any static charge build-up. Finally, for J-poles constructed from tubing, we may add an extension below the J-pole proper that forms a handy mounting post.

The matching section has certain limitations as a true transmission line. The upper ends of the section see quite different impedances, one merely high, the other exceptionally high, although not indefinitely high due to the thickness of the wire used in the open-end leg. Therefore, while it is possible to obtain a generally good transmission line--one in which the currents magnitudes at any point are close to equal and the current phases are close to 180 degrees apart--a perfect balance is not feasible for standard J-pole design.

3. Since the impedance at the low end of the matching section is very low, matching a 50-Ohm line requires that we place taps across the matching section at some small distance up the line. Because currents are not perfectly equal in magnitude and perfectly out-of-phase, a theoretical J-pole may not show a 50 Ohm impedance that is perfectly resistive. However, by tap adjustment, we can arrive at an acceptable impedance, as determined by the ubiquitous SWR meter. For a more perfect match, we may alternately adjust the total radiator length and the matching section length until the impedance is virtually a purely resistive 50 Ohms at the design frequency. Normally, this procedure is easier to perform with wire versions of the J-pole than with version made from 3/4" hard copper pipe.

Because the current at the feedpoint is not perfectly balanced, builders run the danger of encountering significant common-mode currents on the transmission line. Therefore, for any version of a J-pole, a 1:1 choke balun of any acceptable design is a necessary precaution. Placed at the feedpoint, such devices tend to do a very good job of suppressing common-mode currents and preventing the feedline from playing a significant role in the radiation pattern of the antenna or in transferring disruptive RF currents to the transmitting equipment.

Theoretically, it should make no difference to which side of the matching section legs one connects the coaxial cable center conductor. However, because currents are not balanced perfectly, it may in some cases make a difference. Most builders of J-poles tend to try the connection both ways, opting for whichever they discover or believe to provide superior performance.

As we move from theory to practice, then, the J-pole is an imperfect antenna that happens to do a very good job as a practical antenna. It has served well for many decades as an omni-directional vertical antenna that most users can build from materials available in the home shop or garage--or from materials available at the local hardware depot. Because the antenna has been so successful, a myriad of builders have developed their own magic formulas for calculating the parts of the J-pole. Some of these systems work very reliably, especially if we restrict ourselves to material sizes and leg spacings from which the formulas derive.

Why I Became Interested in J-Poles

With respect to building J-poles, I had nothing to add to the many schemes by which builders might successfully construct a J-pole. Hence, I took little interest in the antenna. However, when I was asked to design a J-pole for 10 meters by a ham with very limited yard space, my interest began to increase. The design that emerged was shorter overall than the standard J-pole. As well, the matching section was longer than standard. Finally, the feedpoint was not a small distance above the bottom, but instead was directly at the bottom of the J-pole.

Since 2-meters is the most natural home of the J-pole, it would be unfair to throw in 10-meter dimensions and expect one to understand how standard and non-standard J-poles differ. So I have rescaled the 10-meter design to 2 meters--146 MHz to be exact--in order to make some preliminary comparisons with a standard design J-pole.

Consider the standard design first. The material is 3/8" aluminum, although at material diameters above about 1/8", the performance differences of aluminum and copper at 2 meters are truly insignificant. The overall length of the antenna is 57.87" or .72 wavelength. The free radiator section is 38.37" long, about .475 wavelength. This length is about normal for a dipole of this diameter. The matching section is 19.5" long, about .24 wavelength. This gives us a velocity factor of about 0.96, which again seems quite normal for air lines with a small loss factor. The center-to-center spacing is 1.2", which yields a Zo between 220 and 225 Ohms. The matching section is shorted at the bottom, with the feedpoint tapped 1.4" above the bottom.

The scaled 146-MHz non-standard J-pole has a total length of 46.46" or .58 wavelength. The material is 0.195" diameter aluminum. The free-radiator (above the matching section) is 23.82" or .29 wavelength. The matching section itself is 22.64" or .28 wavelength. The matching-section legs are 0.976" center-to-center, for a calculated Zo of about 275 Ohms. The feedpoint is centered in the bottom wire connecting the two matching-section legs.

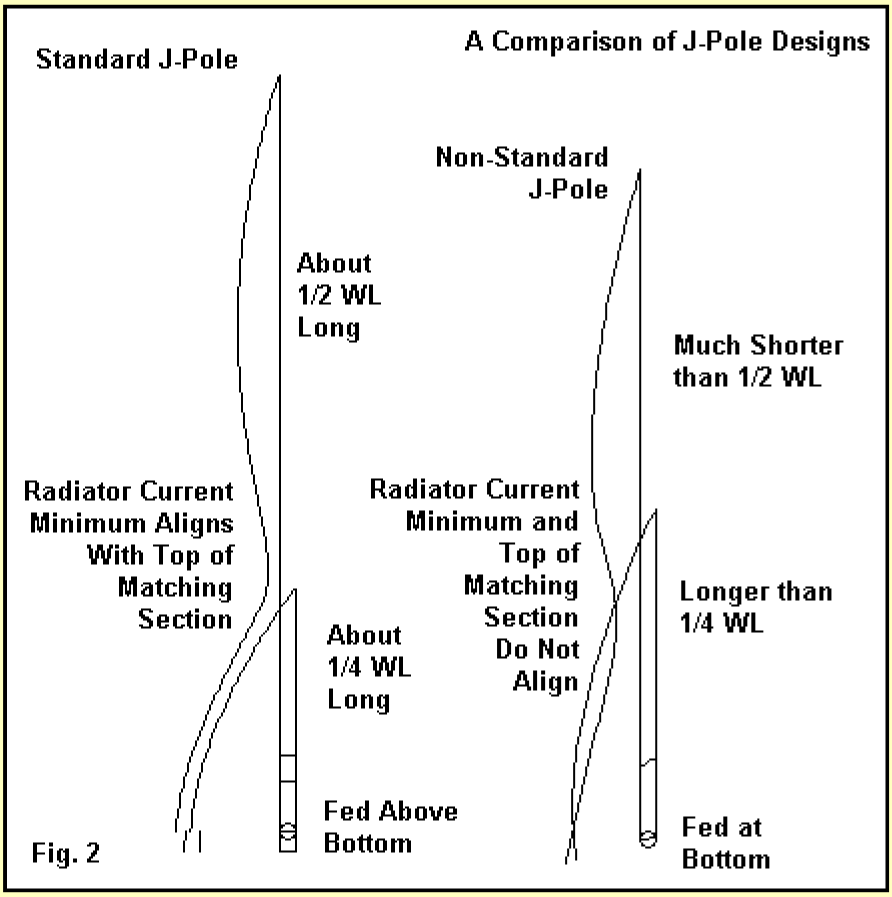


Fig. 2

Fig. 2 shows perhaps the most striking difference between the two antennas. The standard J-pole on the left shows its current minimum in close proximity to the top of the matching section. Here we can clearly see that while the current at the open end of the matching section goes to zero--or thereabouts--the current on the radiator end connected to the matching section remains well above zero. Hence, there is a small but determinate difference in the current magnitudes and phase angles, relative to a perfect transmission line. The circle near the antenna bottom represents the feedpoint, and the two lines above that circle are the current magnitudes at the bottom short and at the feedpoint line. All-in-all, the standard J-pole reflects our understanding of J-pole performance as outlined above.

On the right, we have the current distribution of the non-standard J-pole. The lower current minimum for the radiator occurs well below the top of the matching section. The current at the feedpoint, as shown by the line above the feedpoint circle, is rising in magnitude and peaks partway up the open-end matching-section leg. The length of the open-end leg of the matching line from the current peak to the upper end is almost a perfect .25 wavelength. However, the length of the radiator, counting from the upper end current minimum to the lower current minimum, is about .39 wavelength. Counting from the current minimum on the radiator side, the total length of the matching section wires is about .47 wavelength.

Adjusting the feedpoint impedance of the design involves a juggling of the matching-section and the radiator lengths. If we hold the matching-section open end length constant and change only the length of the radiator upward, then the feedpoint resistance decreases while the feedpoint reactance increases. If we hold the total antenna length constant and increase only the length of the matching-section open-end leg, then both resistance and reactance increase at the feedpoint. The common reactance response to length increases together with the opposing resistance response to length increases permits one to find a purely resistive 50 Ohms for the feedpoint. However, since the currents on either side of the feedpoint are not balanced, a choke balun is mandatory to suppress unwanted currents on the feedline.

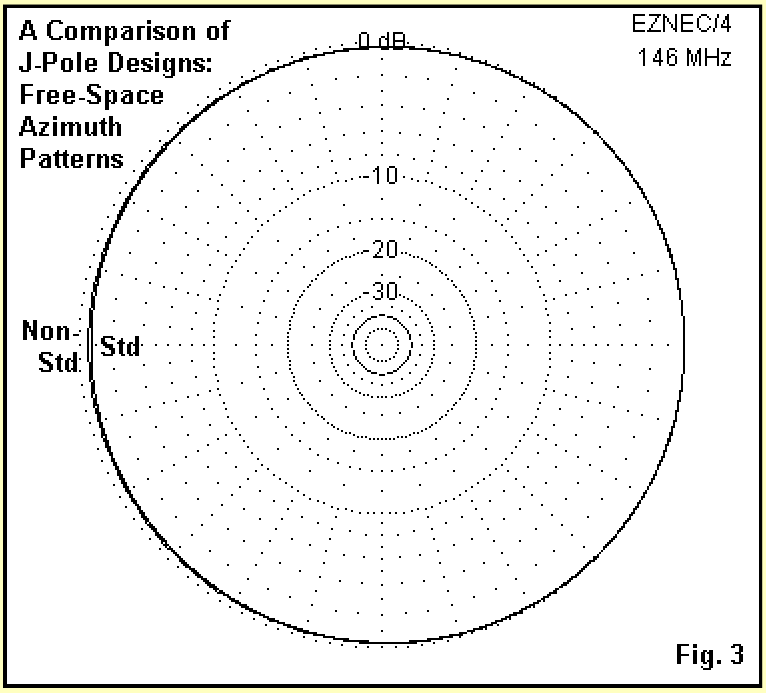
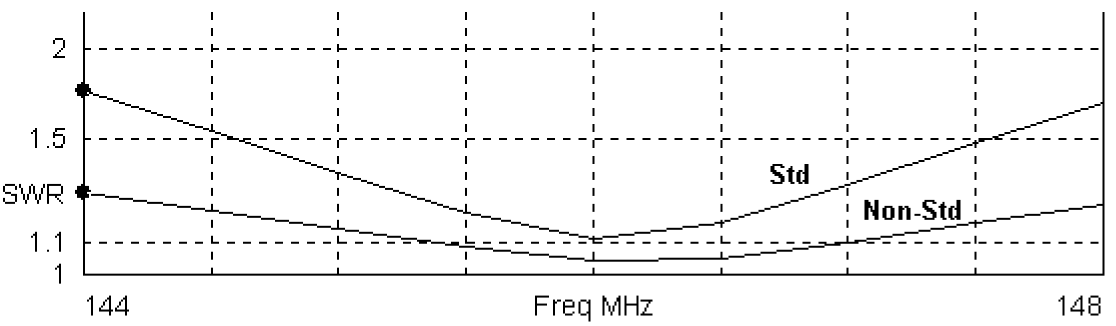


Fig. 3

In short, the non-standard design has intercepted the 50-Ohm feedpoint along a complex combination of radiator and matching line. The overlap of the open-end leg of the matching line with the radiator does not adversely affect performance, because the overlap occurs within the low-current region of the radiator. **Fig.** 3 shows the azimuth patterns for the two antennas. They both show almost identical amounts of pattern displacement toward the open-end leg of the matching section, although the overall pattern distortion from a perfect circle is far too small ever to be noticed operationally. I point out the difference because the standard J-pole design uses a slight wider spacing between the matching-section legs. It appears to be a general property of J-poles that the greater the spacing between matching-section legs, the greater the pattern distortion--or the greater the "front-to-back" ratio.

Fig. 4



Both the standard and non-standard J-pole designs are capable of providing perfectly acceptable 50-Ohm SWR curves. **Fig. 4** overlays the curves for both designs. Had I juggled the standard design just a bit more, its curve would have been virtually indistinguishable from the curve for the non-standard design. Both antennas will easily cover 2 meters with very acceptable performance relative to antenna in the J-pole and vertical dipole class.

The free-space gain of both these antenna is in the vicinity of 2.5 dBi, just above the vertical dipole level. 2.5 dBi represents the maximum gain, and the gain on the opposite side of the pattern is .5 dB lower. At right angles to this axis, the gain is closer to the overall average: about 2.3 dBi. The slight increase over a dipole's gain (about 2.15 dBi) represents the small contribution to the pattern made by the current imbalance on the matching section. Indeed, the current imbalance tends to add more to pattern distortion than to overall antenna gain.

I have lumped together the gain values of the two J-pole designs for 146 MHz. However, if you model them, even in NEC-4, you might find a seeming difference as much as a half dB. That leads us to some notes on modeling J-poles.

Cautions in Modeling J-Poles

Modeling a J-pole antenna seems on the surface to be a straightforward task. However, casual modeling can lead to inaccurate models. So a few notes for modelers may be in order before proceeding any further in this small project.

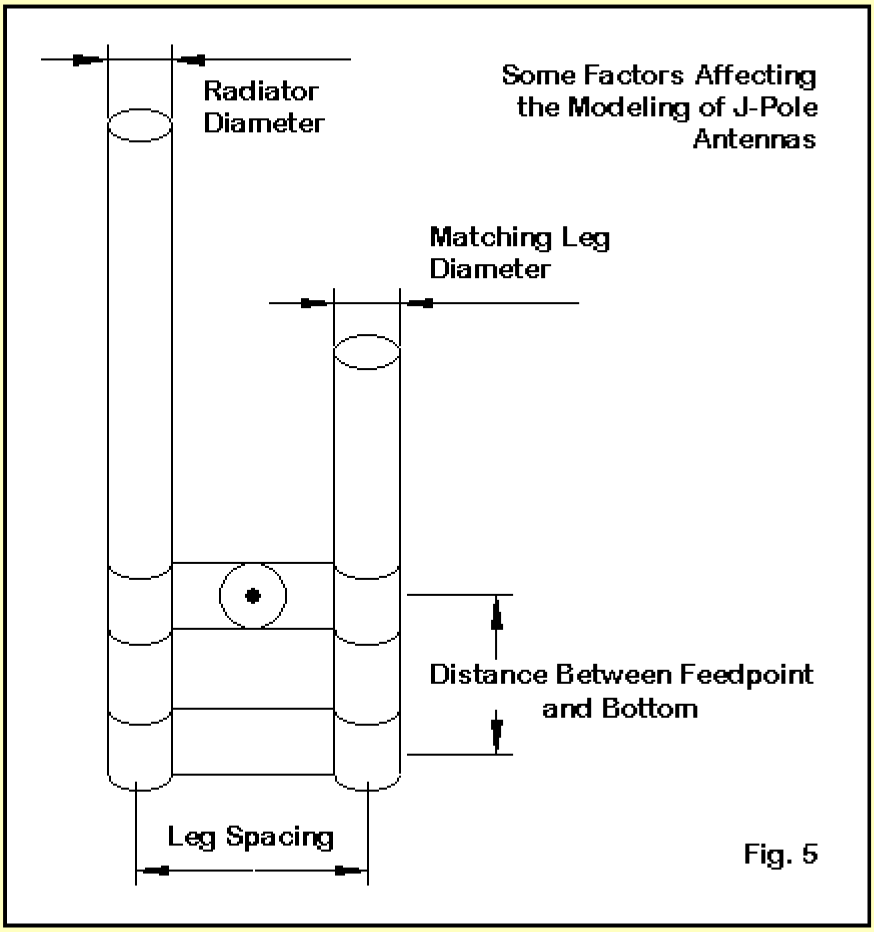


Fig. 5 shows some of the areas where we need to think through our modeling efforts. Let's go through them, one at a time.

1. The source wire: the source wire connects the two legs and should run from a wire junction to a wire junction. This forces each leg of the matching section to be split into at least 2 wires, one above and one below the source wire. The source wire itself should have at least 3 segments initially. (After checking all parts of the model, you might reduce it to a single segment for closely spaced legs, but confirm that this modeling move makes no significant change in the source impedance relative to a more heavily segmented source wire.

For closely-spaced matching-section legs, the length of the source wire segments may set the standard segment length used throughout the model.

2. The distance between the source wire and the bottom shorting wire along the matching-section legs: depending on the antenna design, this distance may be either shorter or longer than the space between the legs. 1-segment wires are usable, but in coordination with the length of the segments in the source wire. Since these wires form right angles, it is good practice to have segments in these wires be as equal in length as circumstance permits.

3. *The wire radius/diameter*: the ratio of the length of the segments to the diameter of the wire in all wires should be at least 2:1. In some fat-wire/close-spaced J-pole designs, it may be difficult to

achieve this ratio. If the design permits, then the ratio should be higher than 2:1. 4:1 is not too high for the angularity of parts of the J-pole structure.

4. *Feed and shorting portions of the model*: the wires forming the matching-section legs and the shorting and source wires for the design should be of the same diameter. NEC (-2 or -4) has difficulties with angular junctions of dissimilar diameter wires. Moreover, the segment lengths should be long enough so that the angularly intersecting wire does not penetrate more than about 25-30% into the end of the wire to which it connects.

5. *Tapered-diameter radiators*: although tapered diameter elements are common in practical dipoles, they will yield inaccurate models on NEC-2. Because the J-pole structure falls outside the limitations imposed on the Leeson correction facility of programs like EZNEC and NEC-Win Plus, that maneuver is blocked from the modeler. For most purposes, using the diameter of the matching-section legs for the entire structure is the best course to follow, with the knowledge that the radiator section length will require field adjustment if it uses an element diameter tapering schedule.

NEC-4 can model stepped-diameter elements with quite good accuracy, so long as the steps are relatively small.

6. *The Average Gain Test*: subject all models to the average gain test--a facility available on both EZNEC 3.0 and NEC-Win Plus. The average gain test (AGT) provides a figure of merit for the model as well as a gain adjustment for the reported output value. A basic AGT result might be .995 or 1.012. you can translate those numbers into dB by taking 10 times the log of the AGT value. This would give values of -.02 dB and +.05 dB for the two same AGT values. These new values tell you by how much to increase or decrease the reported gain of the model to arrive at a reasonably accurate figure. AGT values greater than 1 indicate that the reported gain is too high and must be decreased by the AGT adjustment. AGT values less than one indicate that the reported gain is too and must be adjusted upward by the amount of the AGT in dB.

If the AGT value is less than about .85 or more than 1.15, then even the adjusted values may be suspect. The situation may call for refinements of the model before proceeding further.

Consider the standard and non-standard designs that we compared earlier. NEC-4 reported the maximum gain of the standard model as 2.99 dBi in free space. However, the model showed and AGT value of 1.131 or 0.53 dB. If we reduce the gain as indicated by the test, the truer maximum gain of the standard model is about 2.46 dBi. In contrast, the non-standard model reported a maximum gain of 2.56 dBi in free space. The AGT value was 0.999, for a 0-dB adjustment. Hence, despite initial appearances of a half-dB advantage for the standard version, the adjusted values show the two design to promise virtually identical performance.

7. *Reading J-pole gain from models*: because we expect a J-pole to behave like a vertical dipole with a circular pattern, do not mistake the maximum gain for the gain in every direction. You can estimate the average gain around the near circle in two ways. First, you can check the gain in the opposite direction from the bearing of maximum gain and average the two. Second, you can check the gain at headings 90 degrees off the maximum gain heading. The two values should be very close. If you prefer to be even fussier, you can take the average of all four gain readings. Rarely will a J-pole that does not involve collinear radiator sections show more than about 2.3-2.4 dBi average gain. These values, of course, are derived from the adjusted values emerging from the AGT test.

With these cautions, you can construct very usable models of J-poles. In fact, in my next effort, I shall be working with some close-spaced, thin wire models, looking for any distinguishing features among the many varieties of twinlead J-poles. Initially, I shall be using bare wire, and the models will not correspond closely to the real ones with their vinyl insulation. That will give us a chance to try out the insulated wire facility of NEC-4 and see what difference insulation can make on J-pole performance and design.

That is ultimately the trouble with J-poles. Once you start working with the design, it adheres to you and will not let go.

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