The J-Pole Antenna

R.P. Haviland, W4MB
1035 Green Acres Circle, N.
Daytona Beach, Florida 32119

Editor's Note:

The following article had technical difficulties with the clarity of some of the plots. The softcopy of this article can be expanded so that these plots become clear. Interested parties may contact the author directly for clearer hardcopy plots if necessary.

The J-pole Antenna

R.P. Haviland, W4MB
1035 Green Acres Circle, N.
Daytona Beach, Florida 32119

I. Introduction

This study began as an Amateur Radio project. It is of interest here because it shows the necessity for considering both direct and field coupling of segments, gives some approaches to the drive impedance of end-fed antennas, and demonstrates some inherent limitations of analysis programs.

The J-pole antenna is mechanically simple, and gives good performance for the effort expended on its fabrication. As shown by Fig. 1, it can be constructed from a length of wire with two bends, although the more common VHF designs employ three pieces of tubing plus two $90°$ elbows. A J-pole can be built quickly from a piece of twin-lead or ladder line. In all cases, the standard feed method is to tap the two connections of the feed line part way up on the U-section, adjusting the position for minimum SWR.

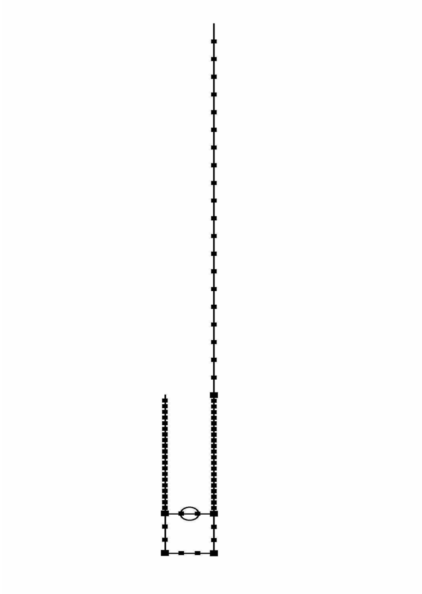


Fig. 1. Typical J-pole antenna, as prepared for Eznec analysis. Segmentation of the lower part of the U and the feed is typical.

II. Standard J-pole Design Practice

The "standard" J-pole design calls for a U section one quarter-wavelength high, with the one extended section being an additional half-wavelength long. The SWR performance of such a design can be excellent, as shown in Fig. 2, which is for a 140 MHz J-pole made from half-inch copper tubing, with the U section spaced 2.0 inches on centers. This chart is for a feed tap at 10% of the height of the U section. It assumes that the feed system is set to the resistance at the feed point, 11.12 Ω in this case. This gives an SWR of 1.05 at 140 MHz, with a 2:1 SWR bandwidth of nearly 6 MHz, more than ample to cover the 2-meter amateur band. Gain is 2.35 dBi, essentially that of a half-wave dipole. Note, however, that the azimuth pattern deviates from uniform (circularity) by just over 1 dB, and maximum gain is tilted upward by $8°$ in this case.

Inspection of Fig. 2 shows that the point of minimum SWR is at 140.2 rather than the design frequency 140.0 MHz. Also, the impedance at the feed point is well below the usual objective of 50Ω. This means the tap point needs to be moved upward. The study reported here had the goal of understanding the J-pole characteristics well enough to achieve minimum SWR precisely at the design frequency and a $50 + j0\ \Omega$ feed point impedance. As will be seen, these objectives have not been completely realized. In this work, some of the limitations of antenna modeling were found to be significant.

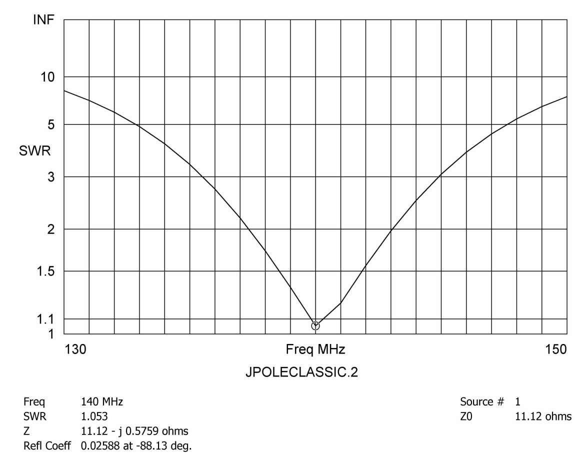


Fig. 2. SWR of a classical J-pole, with feed set to match 140 MHz resonance. The SWR bandwidth varies with mechanical design details, but is usually relatively wide.

Looking again at Fig. 1, it is evident that the antenna is composed of three coupled circuits. The first is the antenna radiating section, which has a natural frequency and a characteristic impedance, both functions of conductor diameter and length. This antenna is intentionally end-fed, directly voltage-coupled to one arm of the U impedance matching section (the second circuit) which theoretically transforms and infinite resistance at the open end to zero at the short. The third circuit, the feed, is then set to the value of desired feed resistance, usually $50\ \Omega$.

The actual situation is far more complex than this simplistic view. Fig. 3 shows some of the reason for the complexity. First, the NEC calculated current on the half-wave radiator does not follow the nearly free-space cosine curve of an antenna loosely coupled to the stub, shown in Fig. 3a, but when physically connected departs from this in magnitude near the junction to the U section, as shown in Fig. 3b. Also, not shown here, the phase along the antenna varies by some 120°, mostly close to the U section while phase variation is small on the upper half. Second, the currents on the two arms of the U section are not equal in magnitude. Further (also not shown in Fig. 3), the phase of the two currents is not the theoretical 180° as found on the stub alone, but varies along the U from 176° to 143°. Finally, there is a marked discontinuity in current at the feed point as the tap position is raised. There is a minor difference in amplitude and phase at the two ends of the feed.

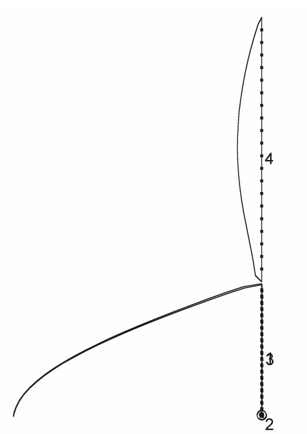


Fig. 3a

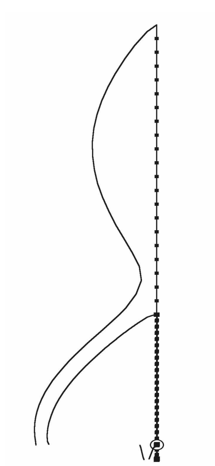


Fig. 3b

Fig. 3. Current distributions. (a) Antenna coupled to U section only by em fields, (b) Coupling by fields and direct connection. The position of minimum current in (b) varies as feed frequency varies.

Fig. 4 shows some explanation of these differences. This is a plot of the total near field at the level of the U-antenna junction, and a short distance away. Even with an excitation of only 12 Watts, the E-field intensity reaches 6000 V/m. The antenna, at zero on the y-axis, decreases the field intensity to 1000 V/m. The unconnected arm of the stub at 2 inches has a high intensity, but the maximum intensity is between the stub arms. Much greater resolution would be needed to define the precise location, but this has not seemed to be important.

It is evident that, in addition to the marked effect of the direct connection, there is a coupling between the U stud and the radiator through the field intensities of the stub and antenna. Also, while the stub arms form a transmission line, the coupling between them is affected by the presence of the antenna, and further by the feed connection. Net radiation from the unbalanced line causes the pattern distortion in the horizontal plane, and the non-symmetric current on the radiator causes the vertical plane pattern shift.

These effects appear to be inherent: they are relatively small, and have previously been ignored. It has not seemed worthwhile to correct them. However, there is the matter of locating the proper tap point for the drive feed and, in some installations, the need to secure unity SWR at the design frequency. The following is a report on the examination of attempting to develop a "cut and it's perfect" design approach. This turned out to be surprisingly difficult, and is not fully realized (see the recommendations at the end).

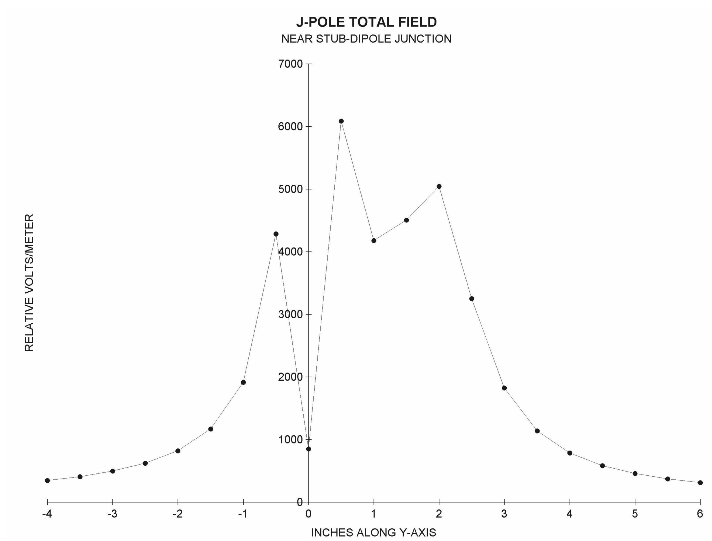


Fig. 4. E-field component of the near field close to the antenna and at the level of the antenna-U junction. The plane of the U is on the Y-axis. Maximum intensity is between the U arms, close to the side connected to the antenna. At approximately twice the U spacing from the arms, the field is nearly symmetical.

III. Characteristics of the Stub

Fig. 5 shows the major characteristics of the stub, considered separately. Fig. 5a shows the resonant frequency, measured by the point of zero reactance at the feed, as a function of conductor size, for a stub $\frac{\lambda}{4}$ at 150 MHz. Over this range it varies by less than $\pm 1\%$, negligible in most situations. The effect of mounting and nearby objects is probably greater. Note the slope changes in the curve. These do repeat in the

NEC calculations. However, they may be due to limits on the program. Warnings of segments being improper do occur in this analysis.

Fig. 5b shows the effect of varying the stub spacing, for a stub $\frac{\lambda}{4}$ high at 144 MHz. Over this range, the resonant frequency does vary linearly with spacing. However, if the total length of conductor is considered, the length of the two sides plus the length of the bottom connection, the resonant frequency is nearly a constant with total conductor length, to within just over $\pm 0.5\%$. The small departure ($<0.003\lambda$) from $\frac{\lambda}{2}$ appears to arise from field fringing at the open stub ends. If stub correction is needed, the height can be set to give 0.4975 λ as the total conductor length.

IV. Characteristics of the Antenna

Information on end-fed antennas is almost non-existent. All I have seen use the approximation that the characteristics are that of half of a center-fed dipole. This neglects the effects of coupling between the two halves. Method-of-moments techniques such as implemented in NEC can approximate the end resistance by using a large number of segments, and deriving the drive resistance as the feed segment approaches the wire end, then extrapolating to total length. This is possibly adequate for thin wires, but with large diameter wires there will be an appreciable field from the wire (or tubing) end, which is neglected by all programs I have seen. The effect can be determined for very large conductors by simulating these as a grid of wires, closed at the ends by a radial grid. A conclusion to draw is that end-feed drive resistance is really not known. Further, the departure from a cosine current distribution in the J-pole case has an appreciable effect.

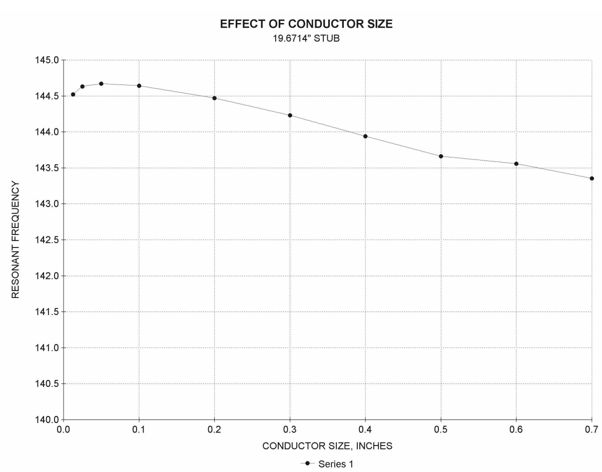
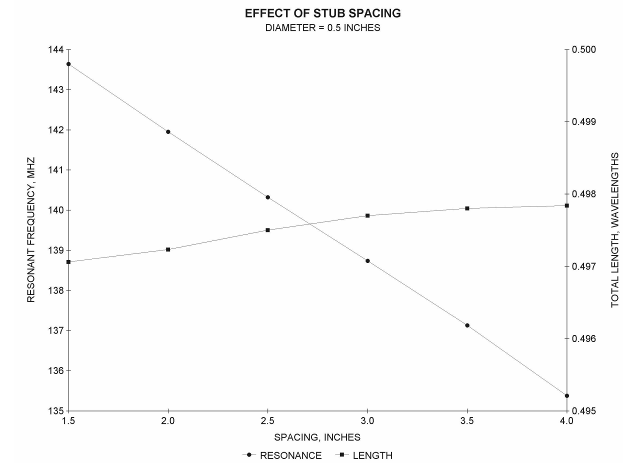


Fig. 5a



. Fig. 5b

Fig. 5. Effect of dimension variation of a $\frac{\lambda}{4}$ stub. (a) Conductor diameter has a small effect on resonance, less than 1% of nominal frequency, (b) Resonant frequency is a linear function of U arm spacing, but is nearly independent of spacing for total length of conductor.

Fig. 6 shows calculated values of the J-pole antenna resistance and reactance. This assumes that the impedance measured for the J-pole assembly is the effect of two impedances in parallel, that of the stub and that of the antenna. The stub impedance was first determined with no antenna and the feed at the top of the stub, then recalculated with the antenna in place. Both resistance and reactance vary almost as the log of diameter over the selected range of sizes.

A number of attempts to visualize the mechanisms involved, and to find a reliable method of going from antenna parts to the complete antenna were made. They led to the further conclusion that it is necessary to work with the complete antenna, rather than attempting to handle it by sections.

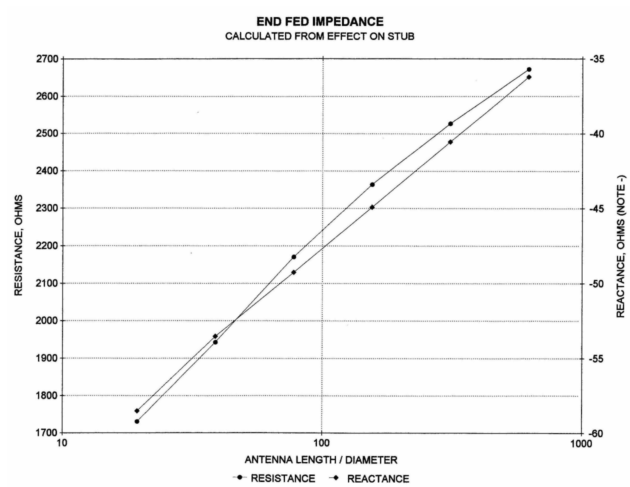


Fig. 6. Calculated end-feed impedance of a half-wave antenna used in the J-pole configuration. See text.

V. The J-pole Assembly

The drive impedance of a 142 MHz J-pole with stub 19.4” high and antenna extending to 58.8” is shown in Fig. 7 for drive positions up to 25% of stub height. Drive resistance varies from essentially zero to over 100Ω, with the variation being nearly linear with tap height. The height for a 50Ω feed is about 12% of stub height.

For tap positions below 10%, the drive reactance change with drive position is small. However, at greater tap heights, the reactance is also increasing, again nearly linearly with height. It appears that this is due to the small inductance inherent in the tap connection: its effect beomes larger as the voltage on the stub increases with height (very nearly a cosine function). This is a complication in matching. It means that there are conditions where increasing tap height to increase drive point resistance is also detuning the system, which requires some further adjustment.

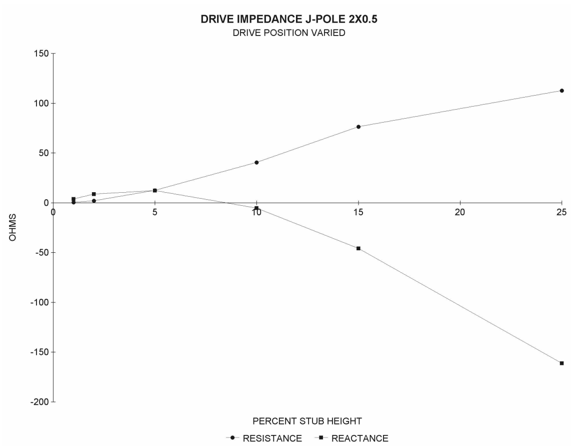


Fig. 7. Drive impedance of a J-pole assembly as the feed position is varied. If the feed is higher than about 10% of the U height, both drive resistance and reactance change. Most designs place the feed in the area of low reactance change.

But there are further complexities. Fig. 8a shows the effect of antenna length on drive impedance. The drive resistance varies much more than the reactance. Again, change to adjust one quantity changes another. Essentially the same situation occurs as the frequency is changed, as shown by Fig. 8b. Finally, as shown in Fig. 8c, changing the conductor size (of both stub and antenna) has a marked effect on drive resistance, but little on reactance. The major reactance change is for small conductors, where the field fringe effects at the top of the stub are relatively large.

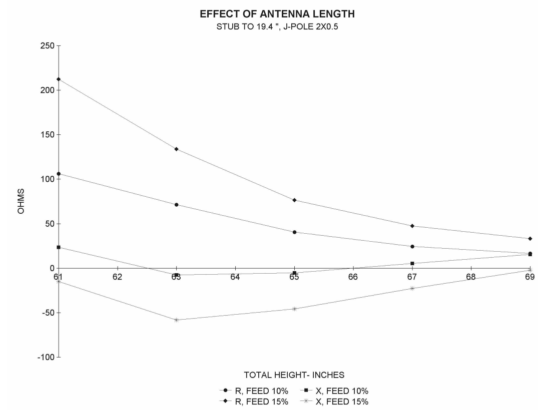


Fig. 8a

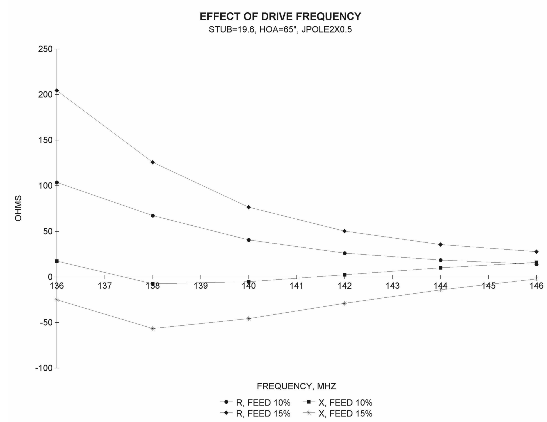
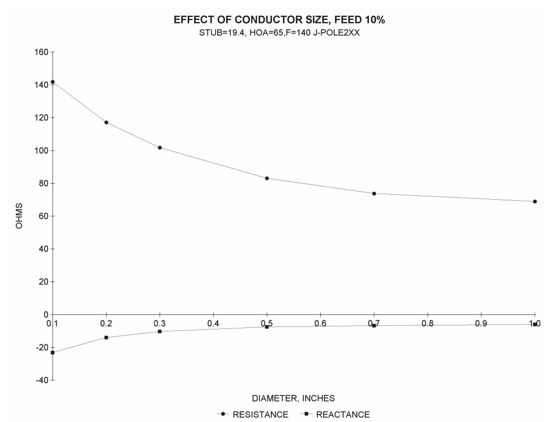


Fig. 8b



. Fig. 8c

Fig. 8. Variational effects on a J-pole assembly. (a) Effect of varying the antenna length on drive resistance, for four feed positions, (b) Effect of varying operating frequency, and (c) Effect of varying diameter of antenna section only. The effects of changing antenna length and drive frequency are very nearly the same. Antenna diameter has little effect on drive point reactance.

VI. Recommendations for Design

Given these interactions, it has not been possible to develop a "cut, assemble and it works perfectly" approach to securing exact match at a given design frequency. This leads to the following recommendations:

- If 1.0 SWR at a given frequency is not a necessity, use the classical $\frac{\lambda}{4}$ stub and $\frac{\lambda}{2}$ antenna dimensions. The tap position can be set using Fig. 9. Note that this will not be the $50 + j0$ drive point, but the one where the magnitude of Z is 50 Ohms.
- If a better match is a necessity, model the antenna with a NEC program, changing dimensions by trial until the design goal is reached. Figures 7 and 8 can be used to give the direction of change, and the approximate amount.
- If exact match is a goal with an antenna already built, measure the drive impedance with a meter or bridge giving both R and X values. Adjust the tap position to give the goal drive resistance, most often 50 Ohms. Use the curves or equations in the *ARRL Antenna Handbook* to design an open or shorted stub to cancel the reactance.

Probably, the classical design will be entirely adequate.

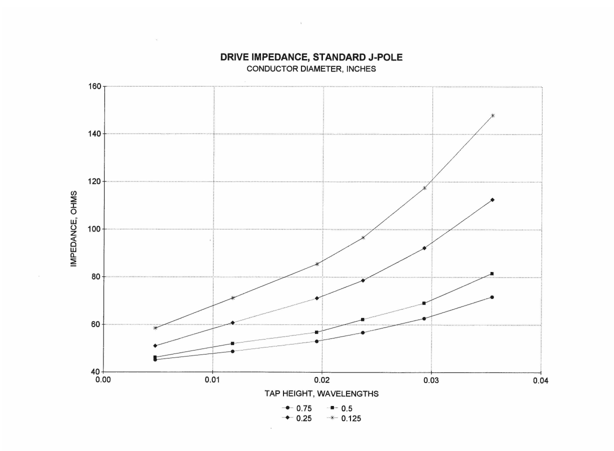


Fig. 9. Drive point impedance of a classical J-pole as a function of tap position, for four system conductor diameters. Interpolate for other diameters. The indicated position should give a good match.

VII. J-POLE VARIATIONS

There are variations of a J-pole, created by adding another half-wave antenna above the main radiator, using either a quarter-wave stub or resonant LC parallel trap as shown in Fig. 10a to give the necessary phase reversal. Be cautious in using this design. For example, Fig. 10b shows the pattern for the antenna of Fig. 10a, using a resonant trap. The gain has increased to 3.5 dB, but the lobe has been tilted upward, so the gain in the horizontal plane has actually decreased. This is partly due to the loss along the wire which happens with all end-fed antennas, but is largely due to the fact that the two half-wave sections are only coupled through the radiation field. Using a quarter-wave stub instead reduces the upward beam tilt. In trials here, the increase in horizontal gain was only on the order of 1 dB, hardly worthwhile.

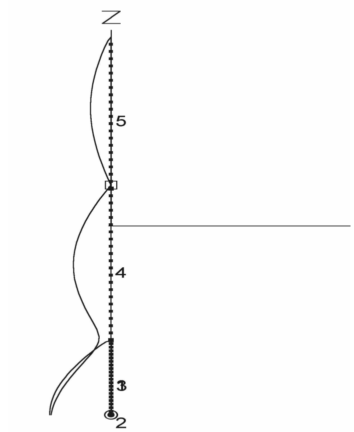


Fig. 10a

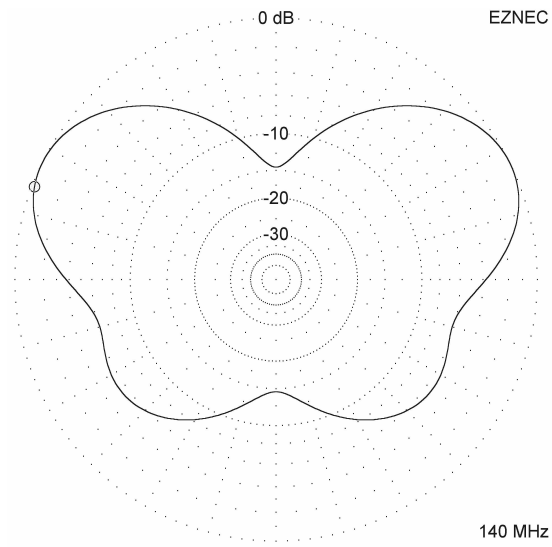


Fig. 10b

Fig. 10. A J-pole version with two colinear antenna elements, in this case separated by a resonant trap. (a) Current distribution, and (b) Pattern in the vertical plane of a vertical assembly. The current in the upper antenna will be greater if the trap is replaced by a quarter-wave stub, and maximum radiation will be at a lower elevation angle.

There is a way to secure both a better pattern and better gain. This, in essence, mounts a second J-pole upside down from the common design, as shown in Fig. 11a. Here, the feed is at the base of the U of either antenna to give pattern symmetry. The antenna is really constructed of two pipe sections one wavelength long, overlapping by a half-wave, and fed at the line of symmetry.

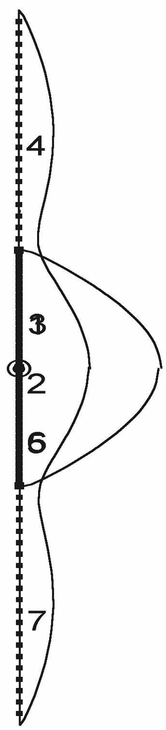


Fig. 1. Fig. 11b

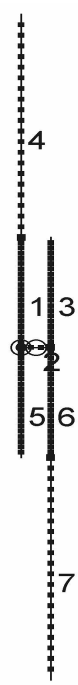
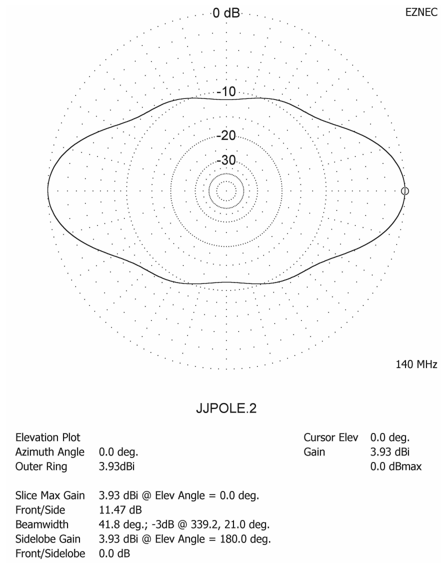


Fig. 11a



. Fig. 11c

Fig. 11. Two J-poles in a back-to-back configuration, formed from two 1λ conductors overlapping a half-wavelength, fed at the center of symmetry. (a) Schematic, (b) Current distribution, and (c) Vertical plane pattern. This is a simple way to increase gain.

The current on the antenna is shown in Fig. 11b. While the currents on the two stub sections are not the same, otherwise the distribution is symmetrical. The result of this shows in the pattern plot of Fig. 11c. Gain has nearly doubled, essentially to 4 dB. The maximum gain is at right angles to the line of the antennas, that is, toward the horizon. Since the feed is to the bottom of two U sections in parallel, the drive resistance is very low, on the order of 7Ω. The point of zero drive reactance is much lower than indicated by the half-wave section length, being very close to 0.44 wavelengths. Design parameters for this variation were not studied further.

Mounting this antenna as an isolated vertical may be a little more of a problem than for the conventional type. However, it is easy to mount from the corner of a tower by the use of one or two plastic tube standoffs plus one or two tee-sections and element spacers. Feed would be at the center of symmetry, with a quarter-wave matching transformer (which could be integrated with the supports) to change the low drive resistance of 6.8Ω to the transmission line impedance. This design merits more attention.

VIII. Concluding Remarks

The mechanically simple J-pole antenna proved to be surprisingly complex, partly due to the presence of three coupled circuits, but also to the fact that common construction requires approaching the computational limits of NEC.

The author found it quite surprising that the "standard design" 0.25λ and 0.5λ J-pole sections (as discussed in Section II) turn out to be so close to best design, after experience with the difference in quads and dipoles.