The Search for a Simple, Broadband 80-Meter Dipole

What amateur has not dreamed of finding a broadband antenna for 80 meters? Feed it with coax and work with a 2:1 SWR across the band!

By Jerry Hall,* K1TD

Like many amateurs who operate in the 3.5-MHz band, you may use a simple, single-wire dipole (or inverted V) antenna fed with either 50- or 75-ohm coaxial line. And like every one of those amateurs, you are inconvenienced when you want to operate from band edge to band edge with that antenna. Since most of today's transmitters require an SWR no greater than 2:1, you probably find yourself restricted to operating within a 200- or 250-kHz segment of the 80/75-meter band.

Common practice with a coax-fed antenna is to cut the length to favor either the cw or the phone end of the band. Amateurs who want to operate both modes often cut the antenna for resonance near the center of the band. In this way they can operate in the upper frequency end of the cw portion of the band and the lower frequency end of the phone portion.

But try to operate with such an antenna over the entire 80/75-meter band. No way! Even if the antenna is cut for the center of the band, the SWR will be greater than 4 to 1 at the band edges, as curve A in Fig. 1 shows. Oh, yes, you can always use a Transmatch or other arrangement to transform the line input impedance to something near 50 ohms, but this invariably requires additional controls to tune when you shift from one end of the band to the other. Wouldn't it be fabulous if you could cover the entire band without the inconvenience of adjusting controls outside the transmitter? Curve B of Fig. 1 shows the SWR response of just such an antenna.

The Search for the Ultimate Antenna

Over my years as an amateur I have done considerable experimenting with wire antennas. I tried one kind, then another, then yet another, always looking for that ultimate 80/75-meter radiator. For years I used a center-fed length of wire with an open-wire feeder. At the input end of the line I used a Transmatch. This arrangement gives quite respectable operation over the 80/75-meter band (and our mf band and other hf bands as well!). I've used lengths from 60 ft total to 170 ft total,[1] and each length gave very good results. (Of course, the longer wires excelled somewhat on the lower frequency bands.) I also tried the double bazooka antenna,[2,3] the miscalled Windom antenna,[4] and several others that as far as I know have no names. Uncounted hours upon hours were spent in assembling and installing these antennas, measuring and plotting SWR values across the band, lowering the antennas to make slight changes, and raising the antennas again, only to repeat the whole process.

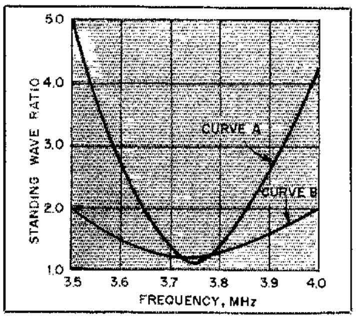

Fig. 1 — Curve A shows the SWR vs. frequency as derived from computer calculations for a no.-12-wire, center-fed, dipole antenna with 75-ohm feeder. The antenna is 125 ft long and is assumed to be in free space with the feed line totally decoupled. This curve correlates very well with that from measured performance of an antenna of this type at a modest height. Curve B shows the SWR response of a broadband dipole discovered in the computerized search described in the text. This antenna has yet to be constructed and tested. See text for details.

Not long ago I realized that rather than devoting so much time to constructing and testing, there was a much better way to continue my search for the ultimate antenna. Why not use a personal computer to perform a preliminary analysis of my ideas? If the computer results looked promising, *then* I could construct and try that type of antenna. In this way I could "test" an antenna in a few minutes, rather than taking a week or more of spare time to check out one or two ideas.

The computerized search proved to be a very worthwhile approach. Over the period of a few weeks I checked out more than 200 different antenna and feed-line combinations. Of all the time spent, a good portion was used in researching the appropriate equations. And of course after that it was necessary to program the computer. But from there things went very quickly. Did I discover anything promising for that ultimate antenna? Well, perhaps. The SWR plot of one of my ideas is that shown in Fig. 1, curve B. But I'm not sure you would classify the antenna as being a "simple" one. More on that later. First, let me tell you how I proceeded with the study.

There are various theories described in the literature for calculating the resistance and reactance of a cylindrical antenna. A wire dipole is a long but, to be sure, a very thin cylindrical antenna. Once the resistance and reactance are known, it is a simple matter to calculate the standing-wave ratio for whatever impedance of transmission line is chosen as the feeder. Thus, with specific physical information to start from, the computer will produce results in terms of resistance (R), reactance (X) and SWR. Details on the math are given in the appendix to this article.

To check the accuracy of the computer program that evolved, I calculated data for several commonly used antennas. Correlation between the computer results and test data I had taken, sometimes years earlier, was excellent. I was more than pleased with the procedure and the results. Changing from 50- to 75-ohm line, for example, was as simple as

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[1] Notes appear on page 27.

entering a different number at the keyboard. And it was just as simple to change the antenna length, or its diameter. The computer could print out results faster than I could develop new ideas.

Before getting into the results, I should emphasize that the main equation on which these calculations are based applies to an antenna in free space. In the presence of the earth, that impedance will be modified. In general, the impedance will be lower when the antenna is less than 1/4 wavelength above ground. Translated to practical terms, this means that most of my calculations showed a better overall match to 75-ohm line than to 50, and these results are what I'll be presenting primarily. However, a 50-ohm line will likely provide lower SWR values in practice at the usual heights for an 80/75-meter antenna, i.e., below 65 feet. But remember, I wanted only a preliminary evaluation on a comparative basis from the computer. I did not feel it necessary to include earth effects in my calculations.

And here's another important point. The calculations take no feed-line currents into account. It is assumed that the feeder, whether it be balanced or coaxial, does no radiating.

A Simple Dipole

We've already looked into a simple dipole antenna of no. 12 wire. Curve A of Fig. 1 shows the SWR response of this antenna, and Table 1 shows R and X values as well as SWR values. The bandwidth between the frequencies exhibiting a 2-to-1 SWR is 208 kHz. With 50-ohm feed line the computed 2:1-SWR bandwidth is only 152 kHz, but keep in mind the remarks of the paragraphs above.

In Table 1, R represents the radiation resistance. This value goes higher with increased electrical antenna length (or higher with increased frequency for an antenna of fixed physical length). Note that the antenna is being fed with 75-ohm line. Note also that the radiation resistance is 75 ohms at about 3.875 MHz, yet the SWR value is still greater than 2:1. How come? The inductive reactance that is part of the feed-point impedance is to blame. (Positive values in the table indicate inductive reactance; negative values indicate capacitive.) While the reactance does not accept any power, it does prevent some of the power from being transferred to the resistance, creating the mismatch. The higher the reactance, the greater the mismatch, and therefore the higher the SWR.

Antenna resonance exists when the reactance goes through zero. Interpolating from Table 1, we see that this occurs at approximately 3746 kHz. Antenna resonance may not always coincide exactly with the frequency of lowest SWR, although with dipole-type antennas and coaxial feeders the two frequencies would never be more than 1, perhaps 2 kHz apart. It would be impossible to detect the difference with practical measuring equipment.

Table 1

Impedance of a Single-Wire Antenna

Antenna length = 125 ft
Antenna diameter = 0.08 inch
Feed-line impedance = 75 ohms

Freq.	*R, Ohms*	*X, Ohms*	*SWR*
3.500	57.2	−118.6	5.16
3.525	58.2	−106.5	4.43
3.550	59.4	−94.3	3.79
3.575	60.5	−82.2	3.23
3.600	61.6	−70.2	2.74
3.625	62.7	−58.1	2.32
3.650	63.9	−46.1	1.96
3.675	65.1	−34.0	1.65
3.700	66.3	−22.0	1.40
3.725	67.5	−10.0	1.19
3.750	68.7	2.0	1.10
3.775	69.9	14.0	1.23
3.800	71.1	26.0	1.43
3.825	72.4	38.0	1.67
3.850	73.7	50.1	1.94
3.875	74.9	62.1	2.24
3.900	76.2	74.1	2.57
3.925	77.5	86.1	2.94
3.950	78.9	98.2	3.33
3.975	80.2	110.3	3.76
4.000	81.6	122.3	4.22

The 2:1-SWR frequencies are 3.647 and 3.855 MHz and the bandwidth is 208 kHz.
Resonance occurs at 3.746 MHz.

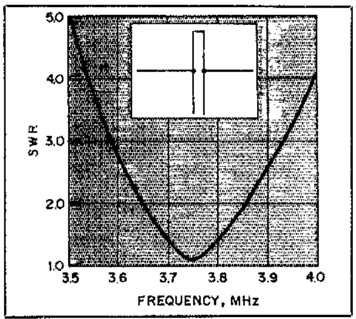


Fig. 2 — SWR curve for antenna with 1/4-wavelength hairpin, as shown in the inset. The antenna is of no. 12 wire, 125 ft long, and fed with 75-ohm line. The hairpin is 52.5 ft of 300-ohm TV ribbon with a 0.8 velocity factor.

Thicker conductors for a single-wire dipole will broaden the SWR response. For example, a dipole made of half-inch-dia wire (such as using the shield of RG-8/U as the radiator) with a 75-ohm feeder exhibits a 2:1-SWR bandwidth of 252 kHz, 44 kHz broader than the antenna of no. 12 wire. In order to maintain resonance at the same frequency as the no.-12-wire antenna, however, its total length must be shortened by about 8 inches.

A Hairpin Match

Now look at the antenna system illustrated in Fig. 2. This antenna is identical to the dipole for curve A, Fig. 1, except that a hairpin of an electrical quarter wavelength at 3.75 MHz has been added. The hairpin will introduce reactance at the antenna feed point as we move away from its quarter-wave-resonant frequency. Below 3.75 MHz this reactance is inductive; above, it is capacitive.

By happy coincidence this is just the opposite of what the antenna itself does, so the hairpin should cancel some of the reactance at the band edges, right? And because the reactance is primarily responsible for the high SWR, then we would think the bandwidth should be significantly broader. But comparison of the SWR plots reveals that there is negligible bandwidth improvement over the dipole alone. The 2:1-SWR bandwidth is 211 kHz, as opposed to 208 kHz without the hairpin. So what went wrong when we added the hairpin?

Most of us amateurs are not accustomed to thinking in terms of paralleling resistances and reactances, and the results often surprise us. For example, assume we have an antenna impedance of 50 ohms resistance and 100 ohms equivalent series reactance at some particular frequency. A shorthand way of writing this impedance is 50 + j100 ohms, where the j indicates that the number behind it represents a reactance, and the values cannot be added directly. The SWR in 50-ohm feed line for this antenna will be 5.8:1. (See what that nasty reactance does to us!)

Now assume we carefully design a hairpin that presents a pure reactance of −j100 ohms at the feed point for this frequency. The actual feed-point impedance will then be the result of the 50 + j100 ohms in parallel with −j100 ohms. We might think the combination will be near 50 ohms with no reactance, but we would be very wrong. The actual feedpoint impedance turns out to be 200 − j100 ohms. The SWR has dropped only from 5.8:1 to 5.1:1.

If we take the extra trouble to completely cancel the feed-point reactance in this example, we will need a shunt reactance of −j125 ohms. The resulting feed-point impedance then will be 250 + j0. With all this care, we've succeeded in bringing the SWR down only to 5:1.

We tend to forget that shunting an impedance with a reactance to obtain a pure resistance gives us an accompanying transformation of the resistance value. As a matter of fact, this is the very principle involved in matching with an L network. So in this example, the very best we can hope to obtain with hairpin matching is a 5:1 SWR.

Different hairpin lengths of 300-ohm line did not yield significant change in the 2:1-SWR bandwidth. The frequency of resonance for the radiator *system* (no reactance at the feed point) changed slightly, however. Making the hairpin length 26 ft instead of 52.5 ft lowered system resonance from 3.746 to 3.712 MHz. With the hairpin lengthened to 75 ft, system resonance occurred at 3.775 MHz. The length of the radiator wire was held at 125 feet for each case here.

The broadest practical system discovered with a hairpin was 254 kHz in bandwidth, as opposed to 208 kHz without the hairpin. This result was obtained with a hairpin of 25 ohms characteristic impedance, 43.5 ft long. The antenna was 125 ft of no. 12 wire, fed with 75-ohm line. A 25-ohm hairpin can be constructed with two lengths of 50-ohm line connected in parallel (i.e., shield connected to shield and center conductor to center conductor). The velocity factor for the hairpin line was taken as 0.66.

Folded Dipoles

It is commonly stated that a folded dipole has improved SWR-bandwidth performance over a single-wire dipole. (Of course, neither has gain over the other.) Computer calculations verified this statement. I "tested" a folded dipole made of 300-ohm TV ribbon. For these calculations I took the antenna as having a 0.5-inch dia, ignoring the fact that it was not truly cylindrical. The antenna was 125 ft long, and a velocity factor of 0.8 was used to determine the shorted-transmission-line effect of the two halves. (This effect is explained in the appendix.) The 2:1-SWR bandwidth in the 300-ohm feeder came out to be 265 kHz, compared with 208 kHz for the single wire with 75-ohm feeder. System resonance occurred at 3.752 MHz.

But wait a minute! We overlooked something that may be important. With a folded dipole the approximate antenna length for resonance can be determined by the old familiar equation, $\ell = 468/f$. But half of this length is *not* an electrical quarter wavelength as far as the shorted-transmission-line effect goes. To obtain quarter-wave resonance, we must take the velocity factor into account and place the shorting terminations 80% of a free-space half wavelength apart. This is shown in the inset in Fig. 3, and works out to be a distance of 105 ft for 3.75 MHz. The resulting SWR plot is also shown in Fig. 3. The bandwidth is 262 kHz, 3 kHz less than with the shorting terminations at the antenna ends. In addition, system resonance moved from 3.752 to 3.725 MHz (although 3.726 is the natural resonant frequency of a 125-ft single-wire dipole that is 1/2 inch in dia). Thus, it appears to make little difference in bandwidth whether or not the velocity factor is taken into account when placing the shorting terminations.

Some years ago the use of capacitors at the ends of a 300-ohm-ribbon folded dipole was advocated to compensate for the velocity factor. This idea is shown in the inset of Fig. 4. A capacitor value of 5.9 pF per meter of frequency-band operation is used at each end of the antenna. This suggestion seems to have gone unheeded by amateurs, however; I am unaware of any current publications that carry the information. With the computer, I tried this idea with various values of capacitance. The optimum practical value for 3.75 MHz, determined from the Smith Chart, was 470 pF. This was confirmed by the computer, although values as low as 390 pF or as high as 1000 pF provided the same bandwidth results — 266 kHz. Placing the capacitors at the ends essentially does not improve the bandwidth over that with the shorts at the ends, but the results are slightly better than when taking the velocity factor into account for the shorts. Changing capacitor values did change the system resonant frequency slightly, from 3.721 MHz with 390 pF to 3.726 with 470 pF to 3.738 with 1000 pF. The length was held at 125 ft all the while.

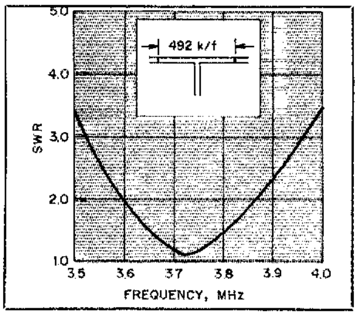


Fig. 3 — SWR curve for a folded dipole as shown in the inset. The antenna and feeder are of 300-ohm TV ribbon. The radiator is 125 ft long, with the shorting connections placed 105 ft apart (k = 0.8). For simplicity in calculations, the radiator was assumed to be cylindrical, with a diameter of 1/2 inch.

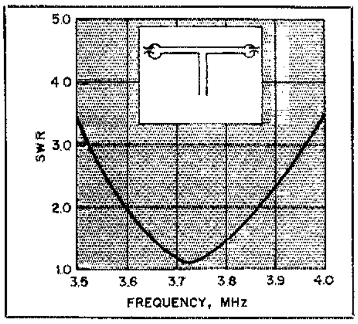


Fig. 4 — A type of folded dipole. The capacitors at the ends compensate for the velocity factor of the 300-ohm TV ribbon for the terminated-transmission-line effect it presents at the feed point. Capacitor values for this plot were 470 pF; the antenna length was 125 feet.

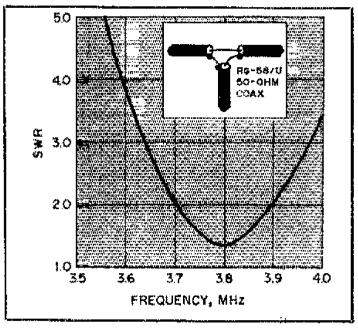


Fig. 5 — The feed-point arrangement of a double bazooka antenna is shown in the inset, and the curve shows the SWR response. The total coax length is 86.67 ft, while the total antenna length is 122.67 ft. The length outside the coax is of 300-ohm open-wire feeder.

The Double Bazooka

The double bazooka antenna is favored by many amateurs because of its "broad bandwidth characteristics." The center portion of this antenna is shown in the inset of Fig. 5. The coaxial line on each side of center is an electrical quarter wavelength of 50-ohm RG-58/U, and is shorted at the outside ends. Because the total coax line length is only 66% of a free-space half wavelength, the antenna is too short for resonance as a radiator. Resonance is obtained by adding a section of 300-ohm open-wire line at each end. Both conductors of each 300-ohm section are tied together, at the connection to the coaxial sections and at the outside ends of the antenna. The antenna is fed with 50-ohm line. The SWR plot of this antenna is shown in Fig. 5. Even though the antenna was "cut" for 3.75 MHz from the double bazooka equations, resonance occurred at 3.803.

Based on computer calculations, the bandwidth of the double bazooka was 190 kHz, compared with 152 kHz for a simple, single-wire antenna fed with 50-ohm line. The improvement is 38 kHz. These computer results agree closely with tests that I conducted in the ARRL lab in 1974, using a General Radio 1606-A rf impedance bridge. From the measured impedances, the 2:1-SWR bandwidth of a double bazooka was 184 kHz, and that measured for a single-wire dipole at the same height and fed with 50-ohm line was 153 kHz. The measured improvement was 31 kHz.

Several variations on the design of the double bazooka yielded some differences in bandwidth. These variations included using 50-ohm line for the radiator and 75-ohm line for the feeder, reversing these arrangements, 75-ohm line for both, and so on. The greatest bandwidth obtained was 268 kHz, using RG-8/U line for the radiator (1/2-in. dia) and a 75-ohm feeder. With a 125-ft antenna and a coax-portion length of 86.5 ft, resonance occurred at 3.725 MHz.

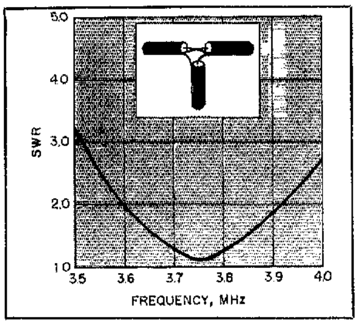


Fig. 6 — SWR plot of an antenna like the double bazooka but with crossed connections at the feed point inset. RG-8/U is used for the coax portion of the antenna (1/2 inch dia), and the feeder is 75-ohm line. The antenna is 124.2 ft long, with 86.5 ft of this length in coax.

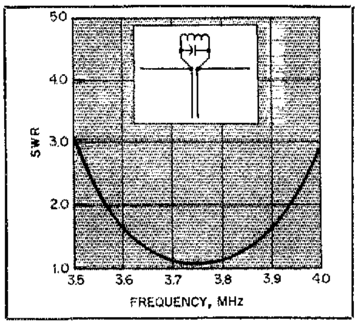


Fig. 7 — A 125-ft 1/2-in.-dia dipole with fixed components at the feed point. The inductor value is 0.5305 μH and the capacitor is 3395 pF. The system is fed with 75-ohm coax. This 124.2-ft antenna has the broadest response of all the practical antennas investigated during the study.

Table 2

Summary of Computer-Study Results for Various Antennas

These calculations assume the antenna is in free space. In actual installations at moderate heights, the bandwidth for 50-ohm feeders will likely be greater than that indicated here.

Antenna Type	*Radiator Dia., In.*	*Feeder Imped.*	*Bandwidth*
Single-wire dipole	0.08	50	152
Double bazooka	0.38	50	190
Single-wire dipole	0.08	75	208
Single-wire dipole with 52.5-ft hairpin of 300 ohms	0.08	75	211
Single-wire dipole	0.5	75	252
Single-wire dipole with 43.5-ft hairpin of 25 ohms	0.08	75	254
Folded dipole of 300-ohm ribbon, shorts 100 ft apart†	0.5	300	261
Folded dipole of 300-ohm ribbon, shorts 105 ft apart	0.5	300	262
Folded dipole of 300-ohm ribbon, shorts at ends	0.5	300	265
Folded dipole of 300-ohm ribbon, 470-pF capacitors at ends	0.5	300	266
Double bazooka, 75-ohm feeder	0.5	75	268
Double bazooka type of antenna, crossed wires at feed point	0.5	75	324
Single wire with coil and capacitor at feed point	0.5	75	375
Cage dipole	36	75	500

†Dimensions from Fig. 61, p. 2-29, *The ARRL Antenna Book*, 14th ed., 1982.

Other Antenna Types

Next I tried a double-bazooka style of antenna with crossed connections at the feed point. This arrangement is shown in the inset of Fig. 6. I found that a greater bandwidth could be obtained than with the double bazooka, as the SWR plot of Fig. 6 indicates. The bandwidth of this antenna is 324 kHz.

W1RN, one of my colleagues at ARRL Hq., suggested using a fixed coil and capacitor in parallel at the feed point (Fig. 7 inset). The effect should be somewhat the same as with a simple hairpin, because the reactance of an L-C parallel combination goes capacitive with increasing frequency. This is just the opposite of what the antenna does by itself.

The results with various L/C ratios were both interesting and surprising. They were interesting because a quite large bandwidth could be obtained — 375 kHz. (The 2:1-SWR frequencies are 3564 and 3939 kHz.) And they were surprising because, with the arrangement plotted in Fig. 7, there really is no frequency that can be defined as system resonance. The reactance swings across zero at three different frequencies in the band — 3563, 3750 and 3904 kHz, being inductive at the low end and capacitive at the high end. For this antenna arrangement, various L/C ratios were tested by assigning different reactance values at resonance. The reactance for optimum bandwidth was found to be 12.5 ohms at L-C resonance.

Although the calculations were for a radiator of 1/2-in. dia, 300-ohm flat TV ribbon or open-wire line with the conductors tied together should work as well. This antenna looks promising. If constructed for transmitting, the capacitor should be a transmitting type, and the coil should be of low loss. There will be high circulating currents in the L-C components. I have not constructed the antenna.

The Search Continues

Table 2 is a summary of the results of all the various antenna types discussed in this article. The antennas are listed in order of increasing bandwidth, and the results are revealing. I hope this information will dispel many rumors that persist about the bandwidths of various antenna types, and perhaps encourage experimentation among you readers.

What about that ideal-looking curve in Fig. 1? Well, there *was* one other idea I tried in my computer search for the ultimate — a cage antenna. A cage is made with several parallel conductors in a circular arrangement. The assembly resembles a round bird cage. Various materials — either conducting or insulating — can be used as spreaders for making a cage. A spreader would have to be placed every several feet along the antenna. If the antenna conductor wires are spaced close enough together, these conductors will have the effect of being a solid wire for the rf current.

It is a cage antenna that yielded curve B in Fig. 1. The 2:1-SWR bandwidth is 500 kHz, while the radiator is 121.5 ft long and is center fed with 75-ohm coax. The cage diameter is, would you believe, 36 inches! The only problem is that I'm not sure what the maximum spacing between adjacent conductors is for a cage to act as a solid conductor at 3.75 MHz. (I've found nothing definitive in the references, although 0.2 λ is a rule-of-thumb value for wire spacing for a "solid" reflector.) Assuming 4 wires would be satisfactory, a little arithmetic indicates that you would need 486 feet of wire and probably two dozen spreaders to build this dipole antenna. I'm still searching for a *simple* way to obtain the same results.

APPENDIX

If you're a computer buff or if you'd like to know about a mathematical method of simulating a near-resonant dipole antenna, you'll be interested in this appendix. Even if the math doesn't interest you, you may pick up a bit of antenna theory.

Of the material researched, a text by Jasik contains information that seemed well suited to use with a personal computer.[3] The technique Jasik presents uses the induced emf method, based upon a sinusoidal distribution. His equation, in simplified form, is

$$Z = R + j\left[Y - 120\left(\ln \frac{24\ell}{d} - 1\right) \cot m\right] \qquad \text{(Eq. 1)}$$

where

Z = feed-point impedance at the center of the antenna, in the form R + jX. R and X are in ohms.
R = radiation resistance, a function of m (see Eq. 2)
j = complex number notation, indicating rectangular coordinates; the entire j term represents the reactance at the feed point
Y = function of length m (see Eq. 3)
ln = natural logarithm
ℓ = total length of antenna, feet
d = diameter of antenna, inches

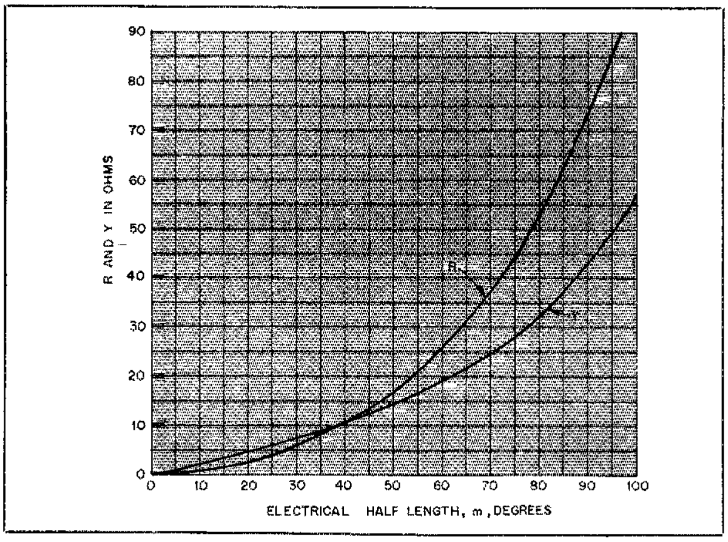


Fig. 8 — Values of R and Y (ohms) vs. m, electrical half length of the antenna, in degrees. (After Jasik; see note 5.)

m = electrical length of half the antenna = 180 (f*l*/984 + 0.013) degrees. (Note that m is not constant across the band.)
f = frequency in megahertz

Jasik states that Eq. 1 is valid only when the half length of the antenna is not much longer than a quarter wavelength, meaning near half-wave antenna resonance. This was no limitation for this study, but be aware that Eq. 1 is invalid for, say, center-fed long wires or harmonic antennas. For short dipoles the equation may be simplified, but Eq. 1 still applies here since we're working near resonance in all cases.

R and Y are complex functions of the electrical half length of the antenna, m. Jasik merely presents a table of values, and also a graph showing the values of R and Y for various values of m in radians. The graph is presented in Fig. 8, with m converted to electrical degrees.

For the computer analysis, it was necessary to arrive at R and Y values from equations, rather than from Jasik's table or graph. Further research indicated that taking sine and cosine integrals was required to compute R and Y.[6] Rather than tackle what I felt would be a monumental task in programming such a procedure, I chose to derive more simple equations that approximate the values Jasik shows. These equations are

$$R = \frac{m^{2.736}}{3048} \quad \text{(m is in degrees)} \qquad \text{(Eq. 2)}$$

$$Y = \frac{m^{2.234}}{549.7} \quad \text{(m is in degrees)} \qquad \text{(Eq. 3)}$$

In these equations, R and Y are in ohms.

Although these equations are only approximations for Jasik's data, they were optimized for the range from 80 to 100 degrees. The maximum variance from Jasik across the 80/75-meter band is less than 0.5 ohm, assuming resonance within the band. The variance increases significantly for short dipoles.

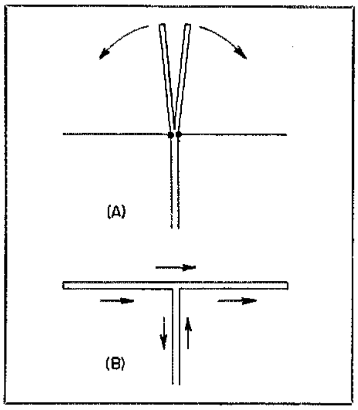


Fig. 9 — At A, a single-wire antenna with two quarter-wave stubs connected in series across the feed point, illustrating the "transmission-line effect" of a folded-dipole antenna. At B, the stubs are brought down to replace the single wire as a radiator, resulting in a folded dipole. Arrows show the direction of current flow in the feeder and the antenna conductors.

Remember that m is designated in electrical degrees in the above equations. If your computer calculates in radians (and most do), substitute the value of pi for the factor 180 in the definition of m in Eq. 1, and use Eqs. 4 and 5 for finding R and Y.

$$R = 21.17\, m^{2.736} \quad \text{(m is in radians)} \qquad \text{(Eq. 4)}$$

$$Y = 15.39\, m^{2.234} \quad \text{(m is in radians)} \qquad \text{(Eq. 5)}$$

Let's say we wish to determine the SWR plot of a single-wire antenna like that resulting in curve A of Fig. 1. The length is 125 feet and the wire diameter may be taken as 0.08 inch for no. 12 wire. For each frequency of interest in the band we may determine the feed-point impedance, $Z = R + jX$, from the above equations. The resulting SWR value for that impedance is then

$$SWR = \frac{A + B}{A - B} \qquad \text{(Eq. 6)}$$

where
$A = \sqrt{(R + Z_0)^2 + X^2}$
$B = \sqrt{(R - Z_0)^2 + X^2}$
Z_0 = characteristic impedance of feed line

With these equations you now have all the basic information you need to calculate and plot SWR curves for single-wire cylindrical antennas. I'll leave the computer programming details up to you, as the operation involves only entering data, straightforward mathematics and displaying the results.[7] The results of my computer calculations across the 80/75-meter band for this antenna are those appearing in Table 1.

Folded Dipoles, Stubs, Hairpins, and All That

In more complex antennas, or those with some type of matching arrangement incorporated at the antenna feed point, the net impedance result is equivalent in placing an additional impedance in parallel with the $R + jX$ impedance of the antenna alone. Let's add a hairpin in shunt with the 125-ft antenna we've been talking about, as shown in the inset of Fig. 2, in hopes of broadening the SWR response. For simplicity, let's use 300-ohm TV ribbon as the material for the hairpin. The ribbon has a velocity factor of 0.8. So as not to introduce reactance across the entire band, let's make the hairpin length equal to quarter-wave resonance at the center of the band, 3.75 MHz. (At this frequency, the shorted quarter-wave line will represent an "open," or at least a very high impedance at the feed point of the antenna.) The physical length of the hairpin will be 52.5 ft.

As we depart from hairpin resonance and move in frequency toward either band edge, the hairpin will introduce reactance at the antenna feed point. In one frequency direction the reactance will be inductive, and in the other, capacitive, as mentioned earlier. How much and what kind of reactance may be determined from

$$X_H = j\, Z_H \tan h \qquad \text{(Eq. 7)}$$

where
X_H = reactance of hairpin at antenna end
Z_H = characteristic impedance of the transmission line used for the hairpin
h = electrical length of the hairpin

Eq. 7 assumes a lossless hairpin. The resultant impedance at the antenna feed point is $R + jX$ of the antenna in parallel with X_H. Calculations of this nature are simplest when the resistance and reactance terms are converted to either admittance and susceptance or else to polar notation. These procedures have been discussed in detail in earlier *QST* articles.[8,9]

Instead of a hairpin of balanced transmission line, coaxial line might be used. In this case the matching arrangement might be more properly termed a stub. Hairpins or stubs need not be limited to resonant quarter wavelengths.

In the case of a folded dipole, a combination of factors affect the feed-point impedance. One factor is the "shorted-transmission-line" effect of the two halves of the antenna. The result of this factor is the same as placing the reactances of two hairpins in series, and connecting the series combination in parallel with the R + jX of the antenna. This is illustrated in Fig. 9A. With two identical hairpins in series, the total reactance is twice that obtained from Eq. 7.

In Fig. 9B the two hairpins are brought down to become the radiator as well. In so doing, antenna currents are caused to flow in both conductors, as indicated by the arrows. The total antenna current divides equally between the upper and lower conductors, and the direction of current flow will be the same in both, as shown. However, the feed line is connected to only one of the two conductors. With the same amount of power being delivered to the antenna but only half the feeder current flowing when compared with a single-wire antenna, it stands to reason that the feed-point impedance must be four times greater. This comes from the power equation, $P = I^2 Z$, where Z is a complex quantity, R + jX. The impedance of the antenna as a pure radiator is therefore four times that obtained from Eq. 1. Thus, the actual feed-point impedance of the folded dipole is

$$Z = 4\,(R + jX) \text{ in parallel with } 2\,(j\,Z_H \tan h) \qquad \text{(Eq. 8)}$$

In a folded dipole type of antenna, the "transmission-line shorts" need not be placed at the extreme ends of the antenna. They may be placed nearer the antenna center, perhaps for better bandwidth. This idea is that shown in Fig. 3. Neither must the line be made of ribbon. Coaxial sections may be used, as is done in the double bazooka antenna.

The preceding paragraphs give the mathematic equations for computing feed-point impedances and then determining the standing-wave ratios for the feeder of your choice. Whatever type of cylindrical antenna might come to your mind can be simulated by applying the equations and reasoning out the configurations, as was done above, to determine the shunt or modifying impedances. Antenna lengths, feed-line impedances, hairpin-line impedances, hairpin lengths and other factors may each be assigned independently. The results may be calculated in terms of R, X and SWR. You can test a whole farm of antennas without ever having to go outside.

Notes

[1] meters = feet × 0.3048; inches = ft × 12.

[2] C. C. Whysall, "The 'Double Bazooka' Antenna," *QST*, July 1968, pp. 38-39. This antenna also appears in each edition of *The Radio Amateur's Handbook* from 1969 through 1977.

[3] W. Maxwell, "A Revealing Analysis of the Coaxial Dipole Antenna," *Ham Radio*, Aug. 1976. This excellent reference provides insight into some of the theory underlying the procedure presented in the appendix of this article.

[4] *The ARRL Antenna Book*, 13th (1974) and earlier editions.

[5] H. Jasik, *Antenna Engineering Handbook* (New York: McGraw-Hill Book Company, 1961), pp. 3-1 through 3-3.

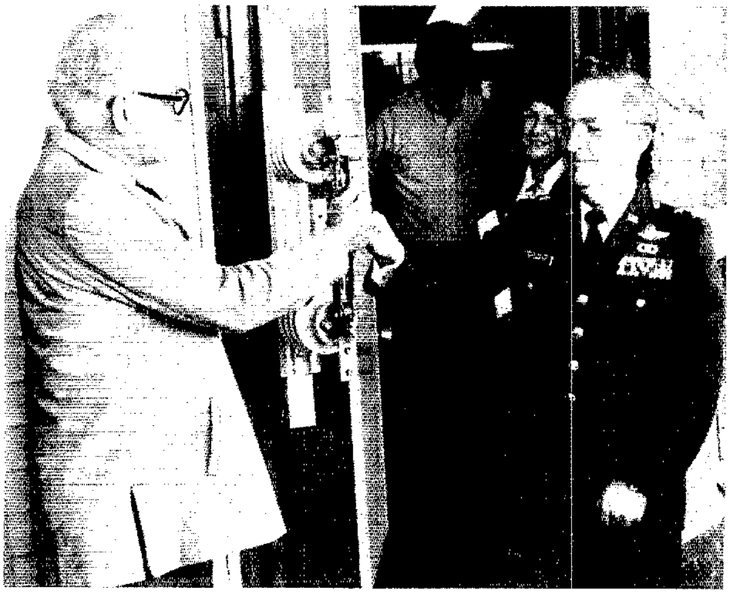
[6] P. S. Carter, "Circuit Relations in Radiating Systems and Applications to Antenna Problems," *Proceedings of the IRE*, Vol. 20, June 1932, pp. 1004-1041.

[7] A photocopy of the program the author used with an IBM personal computer is available upon request, as is the same program written for the TRS-80 model I Level II. Send $2 to cover copy fee, postage and handling to Dept. TD, ARRL Hq., 225 Main St., Newington, CT 06111. Request BASIC program ANTRXSWR/BAS, and be sure to state which computer program listing you desire.

[8] J. Hall, "A Simple Approach to Complex Circuits," *QST*, July 1977, p. 35. Also see Feedback, Aug. 1977 *QST*, p. 41.

[9] J. Bartlett, "Learning to Use Rectangular and Polar Notation," *QST*, November 1979.

Strays



Senator Barry Goldwater, K7UGA (left), and Major General Robert F. McCarthy, commander of Air Force Communications Command, ceremoniously "pull the switch" to terminate operation of MARS station AFC6BG. Since the 1960s, the station has provided a link to home for many armed forces personnel stationed in Southeast Asia and the Pacific.

MARS STATION AFC6BG IS QRT

☐ An amateur station that was a "link with home" for many Vietnam-era military personnel and their families has ceased operations. Military Affiliate Radio System (MARS) station AFC6BG in Paradise Valley, Arizona, went off the air on January 15.

Owned by U.S. Senator Barry Goldwater, K7UGA, AFC6BG served in the 1960s as a phonepatch relay point for those stationed in Southeast Asia to talk to family and friends in the U.S. With the reduction of phonepatch traffic in the 1970s, the station became a radioteletype "gateway" station for the Pacific. The decision to close the station was based on a combination of declining mission activity and the anticipated cost of modernizing the station's aging equipment.

In recognition of the station's years of service, Secretary of the Air Force Verne Orr, WA6IOG, sent the following MARS message to K7UGA: "Operated exclusively by your dedicated volunteers, and at considerable personal expense to you, AFC6BG has provided the Department of Defense and the nation, in times of emergency, a service unparalleled in military communications. We all owe you and your people a tremendous debt of gratitude that can never be adequately repaid." In closing ceremonies at the station, Major General Robert F. McCarthy, commander of Air Force Communications Command, described the volunteers' service as that "which will stand the test of time and will display to others a sense of commitment and dedication." He presented plaques of appreciation to K7UGA, W7FCQ, a long-time station manager, station manager AFA6PU and a dozen volunteers who helped the station in recent years. — *U.S. Air Force News Release*

ATTENTION QRO OPS

☐ The 1983 Dayton (Ohio) Hamvention, scheduled for April 29-May 1, will offer cw operators the opportunity to challenge the world record for copying Morse code. As documented in the *Guiness Book of World Records*, the record of 75.2 wpm was set in 1939 by Ted McElroy. In addition, Cw Proficiency Certificates will again be awarded. For more information, write to Frank J. Schwab, W8OK, Cw Proficiency Chmn., Dayton Hamvention, Box 44, Dayton, OH 45401.