The Fan Dipole as a Wideband and Multiband Antenna Element

It's broadbanded and operates effectively on several HF bands—a nice combination for a ham antenna.

Joel R. Hallas, W1ZR

Multiband HF antennas are certainly an attractive concept, especially as new bands are added to our authorized set of frequencies. Now with 9 bands between 3 and 30 MHz, it is difficult to have separate antennas for each band on a reasonably sized piece of property without significant interaction. Over the years there have been a number of common approaches to multiband antennas:

- *Antennas that take advantage of multiple resonances in a single element structure.* This category includes 40 meter dipoles operated on 15 meters and G5RV dipoles. Although these can be effective, the feed impedances are generally different on different bands, often resulting in potentially significant transmission line losses if coax is used.
- *Antennas using resonant circuits as traps to isolate sections.* These can often be effective as well. The traps may restrict the frequency range on each band and will contribute to system losses, however.
- *Antennas using parallel dipoles resonant on each band.* These have been used successfully by some, although I have not been very successful with this approach. Unless elements are orthogonal (two antennas at right angles), the coupling can restrict the frequency range and make adjustment difficult. Mutually orthogonal dipoles for more than three bands are hard for me to visualize.
- *Antennas using tuned feeders and low-loss line.* The "double zepp" approach has gained in popularity with the common use of "no tune" restricted matching range transmitters and the availability of wide range antenna tuners. The typical antenna is a half wave at the lowest band, center-fed with open wire or ladder line. The impedance on any band is considered irrelevant since the tuner can deal with the resultant impedance at the bottom of the low loss line and transform it to the 50 Ω unbalanced impedance needed by the transmitter. This can be a very effective system. The fact that the pattern changes from broadside to a complex multi-lobe pattern above a full wavelength can provide additional geographic coverage from the single antenna. In addition, the whole antenna is always used, providing gain in some directions at the higher frequencies. The typical configuration is shown in Figure 1.

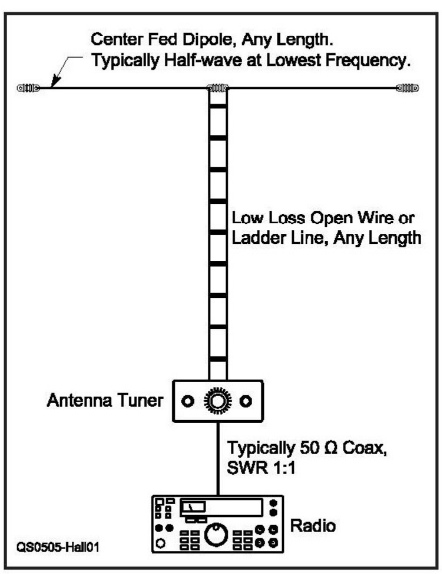

Figure 1—"Double Zepp"—typical configuration.

The loss can be low if connections are made carefully. As shown below, however, the SWR can be above 10:1 on the transmission line on some bands. *The ARRL Antenna Book*[1] indicates that a matched 100 foot length of clean, dry (people used to wax their twin lead!) ladder line has a loss of 0.15 dB or less at HF *if matched*. An SWR of 10:1 adds about 1 dB of loss,[2] still probably less than typical trap antennas.

Another potential area of concern is the impact of the SWR on the voltage and current within the tuner. A high SWR can result in maximum currents and voltages on the line equal to the matched value times the square root of the SWR. These will occur at different spots along the line depending on load, line length and operating frequency. With all the different frequencies involved, it is likely that the maximum of each will be near the tuner on one band or another, however. For a 100 W output and a 10:1 SWR, this results in a maximum of 630 V or 1.6 A. For 1.5 kW it increases to 2.5 kV_{rms}, 3.5 kV_{peak} or 6.1 A, however, which can explain the arcing or smoking observed in some tuners!

Enter the Fat Cylindrical or Biconical Dipole

John Kraus, W8JK, shows the way to solve this problem and simultaneously reduce the frequency sensitivity of such antennas in his classic text *Antennas*.[3] Figure 9-9 indicates that while a cylindrical di-

[1]Notes appear on page 35.

Figure 2—Looking up the tower at the center spreaders of the Cage antenna at W1AW.

Figure 5—W1ZR 20 meter biconical array, hidden in the trees.

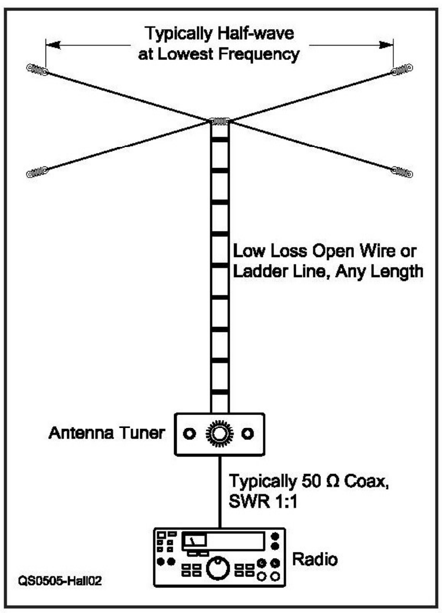

Figure 3—Biconical (fan) dipole configuration.

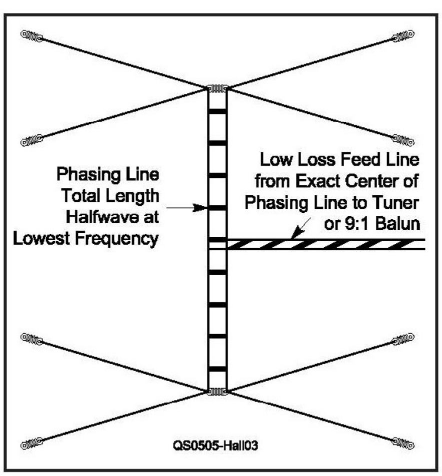

Figure 4—Biconical lazy-H antenna configuration.

pole with a length to diameter ratio of 2000 (about #4 AWG wire at 20 meters) will have an impedance variation between its half wave and full wave resonances of 70 Ω to about 3300 Ω, with corresponding variation in reactance, the 2 λ resonance is at about 2300 Ω and the average is 873 Ω. In contrast, the figure shows that for a length to diameter ratio of 60 (a 6.6 inch cylinder at 20 meters) the half wave impedance is about the same while the full wave is reduced to around 900 Ω, with the average a convenient 454 Ω.

This approach has been used frequently to broaden the bandwidth of a half wave antenna, for example, to allow better coverage of both 80 and 75 meters with a single dipole, but has even more impact on harmonic operation where the concept has not often been employed in amateur service.

The straightforward approach to this is to use larger diameter wire or tubing for the elements. This can work for VHF, but supporting an 80 meter dipole made with 2 foot diameter tubing is hard to imagine! Fortunately, the same effect can be accomplished with a skeleton structure, and a "cage" antenna has been popular in various applications (it was used for the first transatlantic ham QSO and one is now in use at W1AW; see Figure 2). The cage typically uses a crossed spreader and four wires for the elements (six were used for the T/A tests). W1AW Station Manager Joe Carcia, NJ1Q, designed the one at the ARRL HQ station to operate well on all W1AW 80 and 75 meter frequencies. Joe used 3 foot PVC spreaders (reinforced with dowels and sealed using PVC caps and tees) at right angles with #14 stranded wire to construct this highly effective antenna.

An alternate is to use a skeleton biconical dipole as shown in Figure 3. This has the advantages that only two wires are used per side, and that the spreader structure is much simpler. I use a single 6 foot spacer on each end of the elements of a 20 meter array as described below. An 80 meter antenna might require some intermediate spacers to avoid tangles during raising. Note that while the upper wire must support the antenna weight, the lower wire needs only to provide conductivity. Although the amount of wire required is comparable to a parallel dipole antenna, the performance is better.

Fortunately, Kraus provides the capability to transform between the cylinder structure, the thin rectangle (equivalent radius is $^1/_4$ of the width) and the biconical. The impedance of a biconical, or fan, with an end radius of 2.8 times the cylinder radius (in this range) has the same impedance characteristics, yielding a half angle of 2.7°. Extrapolating to the flat biconical (triangle), we would expect to need a triangle base of 4×2.8 = 10.2 times the cylinder diameter. For a 20 meter fundamental antenna this is a manageable 5 foot 7 inches. I also considered a "mini-cage" made of 400 Ω ladder line (typically sold as "450 Ω " ladder line, but really measuring closer to 400 Ω) with the wires connected together at the feed point.

Why Bother?

What does it buy us? I have run *EZNEC*[4] simulations of 80 meter fundamental and 20 meter fundamental skeleton biconical dipoles and compared the results

Table 1

Comparison of SWR of 80/75 Meter Dipoles of Various Cross Section

SWR at 50 Ω, *EZNEC* prediction. Single band coax fed.

Antenna Type	*3.5*	*3.6*	*3.7*	*3.8*	*3.9*	*4.0 MHz*
Thin, #14 wire dipole	5.9	2.8	1.6	2.1	3.6	5.8
Ladder line "cage"	3.8	1.9	1.2	1.7	2.7	3.9
3 foot fan	3.2	1.9	1.1	1.5	2.3	3.2
6 foot fan	3.0	1.8	1.1	1.5	2.3	3.1
22 foot fan	3.3	1.9	1.3	1.7	2.4	3.4
NJ1Q cage	2.5	1.6	1.1	1.4	1.9	2.5

SWR at 400 Ω, *EZNEC* prediction. Multiband ladder line fed.

Antenna Type	*80*	*60*	*40*	*30*	*20*	*17*	*15*	*12*	*10 Meters*
Thin, #14 wire	7.2	6.5	12.9	14.7	8.3	9.0	5.8	9.2	5.0
Ladder line "cage"	8.5	4.1	7.0	10.7	4.7	7.0	3.6	5.2	3.5
6 foot fan	8.2	3.6	4.8	8.0	3.8	4.5	2.8	4.0	2.7
NJ1Q cage	9.1	2.4	2.1	6.6	2.3	2.6	3.6	1.3	4.1
Max gain over $^1/_2$ λ dipole	0.85	1.2	2.2	4.9	2.5	3.5	1.7	2.2	4.7
Azimuth of main lobe (number of significant lobes)	90 (2)	90 (2)	90 (2)	90 (2)	129 (4)	118 (4)	152 (10)	138 (6)	149 (10)

with that of a single wire dipole. To make comparison easy, for each case, I "trimmed" the length to provide best SWR from band edge to band edge. At 80 meters, using Kraus' factors, the predicted end spacing is about 22 feet, so I also ran it at a more reasonable 6 feet to find the difference.

I was glad I did, since *EZNEC* predicts that beyond a few feet the additional spacing doesn't matter. The results are interesting at the fundamental as well as on the harmonics (see Table 1). At 80/75 meters, while a thin wire dipole's SWR across the band may be outside of the range of many in-rig auto tuners, even the easiest to make multiwire configurations are within the usual 4:1 range of such devices on this tough band.

Note that with ladder line feed as a multiband antenna, on the higher bands where losses are highest, the SWR variation is reduced significantly. We still have the SWR at the first resonance to deal with and it is very similar to that with the single wire, typically around 8:1 at resonance. Note that the reduction in impedance variation will generally also mean less retuning as frequency is changed across any band. Tables 1 and 2 tell the story.

Table 2

Comparison of SWR of 20 Meter Dipoles of Various Cross Section

SWR at 50 Ω, *EZNEC* prediction. Single band coax fed.

Antenna Type	*14.0*	*14.1*	*14.2*	*14.3*	*14.35 MHz*
Thin, #14 wire	1.7	1.6	1.6	1.65	1.7
Ladder line "cage"	1.3	1.25	1.3	1.3	1.36
6 foot "fan"	1.2	1.1	1.03	1.16	1.22

SWR at 400 Ω, *EZNEC* prediction. Multiband ladder line fed.

Antenna Type	*30*	*20*	*17*	*15*	*12*	*10 Meters*
Thin, #14 wire	40	5.1	6.0	6.7	10.5	10.6
Ladder line "cage"	32	6.5	5.3	4.5	5.9	5.4
6 foot "fan"	26	7.8	4.6	4.4	4.2	4.2
Max gain over #14 dipole (dB)	0.8	1.1	1.4	1.8	2.3	

All at 90/180°

Table 3

Performance of Biconical Lazy-H at 73 Ft Elevation

Gain and SWR	*30*	*20*	*17*	*15*	*12*	*10 Meters*
Gain dBi	8.5	10.3	12.0	12.7	11.4	12.4
Gain over dipole	1.1	2.5	4.7	5.1	3.9	4.4
Gain over 20 m fan	0.6	2.2	3.8	4.0	2.5	2.8
EZNEC SWR	31	4.2	10.6	13	4.9	2.6
Measured SWR	4.6	1.3	1.4	2.7	2.5	1.7

The Biconical Lazy-H

At my station, I have solved the problem of high SWR at the fundamental (half-wave) on the 20 meter fundamental antenna by making a "stacked biconical" (a popular TV antenna in the '50s) or "biconical lazy-H," if you prefer. This consists of two 20 meter biconical dipole elements, the second a half wavelength below the first and fed in phase with 400 Ω ladder line. By transforming each element's low impedance at 20 meters through the resulting quarter-wave matching section to the center of the phasing line, and feeding them in parallel, I end up with about a 4:1 SWR across 20 meters.

This configuration, shown in a diagram as Figure 4 and a hard-to-see photo in Figure 5, provides broadside gain on 20 meters. It also acts like a well matched 4 element combination broadside and collinear array on 10 meters. The downside of this is that I now have higher SWR on some of the intermediate bands. On the plus side, broadside gain is provided on all bands 14 through 30 MHz. It will tune and operate on 30 meters as well, but watch the SWR!

At W1ZR, this antenna is fed with about 150 feet of ladder line and then a 9:1 balun. The SWR readings were taken with a Bird 43 wattmeter at the balun. I expect that the difference between predicted and measured results is due to some combination of loss in transmission line and balun and measurement error. The antenna does seem to perform well.

Notes

[1]R. D. Straw, N6BV, Ed., *The ARRL Antenna Book*, 20th edition, p 24-20.

[2]*The ARRL Antenna Book*, 20th edition, p 24-10.

[3]J. Kraus, W8JK, *Antennas,* New York: McGraw-Hill Book Co Inc, 1959.

[4]*EZNEC* is a registered trademark of Roy W. Lewallen (**www.eznec.com**).

Joel Hallas, W1ZR, is QST *Assistant Technical Editor and Product Review editor. You can reach him at* **jhallas@arrl.org**.