Notes on the Batwing
Part 1: Basic Batwing Properties

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Ever on the lookout for wide-band antennas, I was pleased when John Magliacane, KD2BD, called my attention to the "batwing." Long used in a turnstile and phased-vertical-array configuration, the basic batwing is little understood among amateurs and hence, little used. Perhaps it deserves a better fate.

This series will consist of 3 sessions. The first will examine the basic properties of the batwing as a very broadband dipole antenna. The second will examine two major applications of the batwing. The final section of these notes will deal with a few modeling issues.

The Basic Batwing

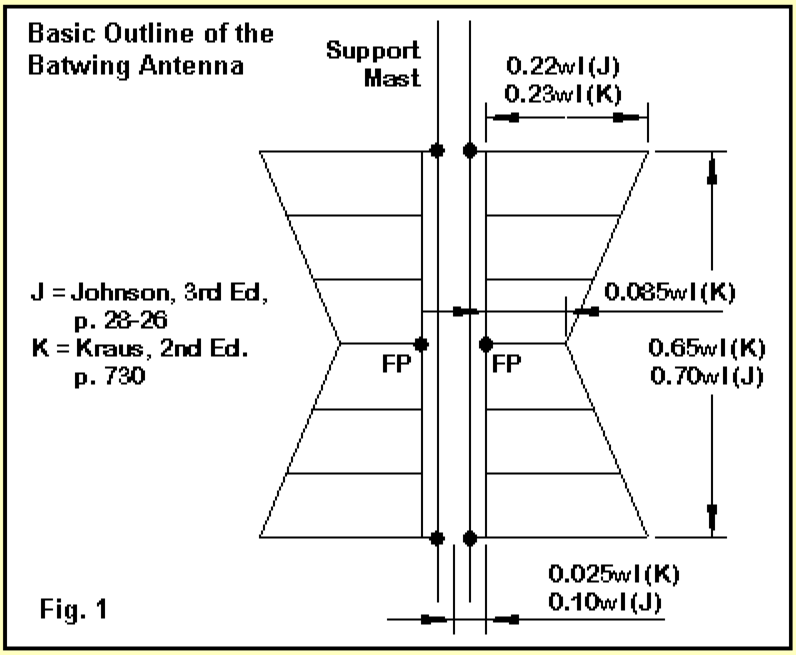
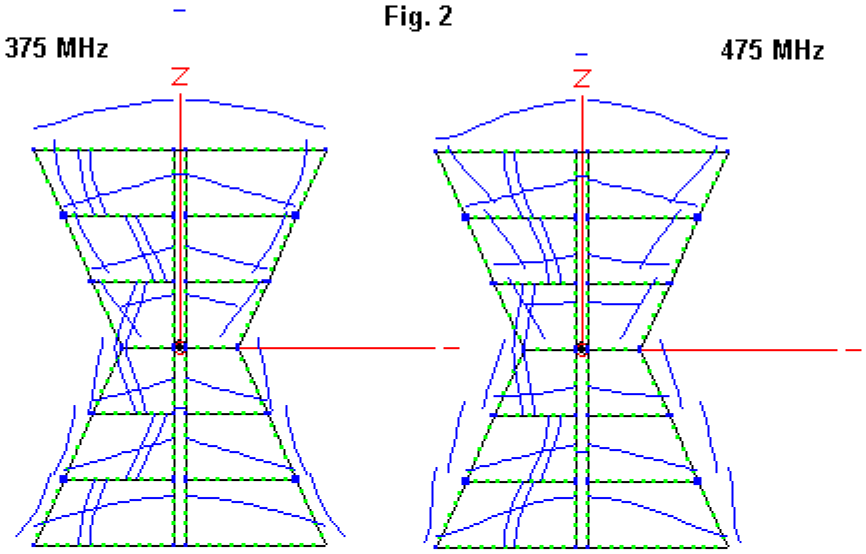


Fig. 1 shows the general layout of the batwing dipole. It consists of dipole elements, each of which is fed from a common feed/phase line. This arrangement has been used at HF, most notably by OptiBeam, as a way of feeding drivers for 3-band Yagis arrays. However, the gain-array lays the elements out on the horizontal plane. The batwing itself places each element on the vertical plane--and has a symmetrical mate for each one. I have seen log-periodic arrays tipped toward ground and used as a wide-band array of dipoles, and the principles are similar--up to a point.

The point of departure is the fact that the batwing doubles the LPDA structure--and connects the element ends. As well, the dipoles appear to be equally spaced, meaning that they do not describe the LPDA taper of both element length and spacing. Instead, the feed system is a combination of mutual element coupling and feedpoint drive, with the termination of the most active elements at any frequency being somewhere between elements.

Fig. 2



Current Magnitude Distribution on a Batwing Antenna
at 375 and 475 MHz

Fig. 2 shows the distribution of current--in magnitude terms only--along the elements of a batwing at widely diverse frequencies: 375 and 475 MHz. The batwing is a very broadband antenna. There are slight differences in the current magnitude curves at these extremes, especially along the longest horizontal elements. As well, the current magnitude shift at each connection point on the feed/phase line is also apparent.

Fig. 1 has 3 pairs of dots indicating connection points. The most common implementations of the batwing, which we can also build from solid plates rather than from rods, use a central conductive mast. The top and bottom elements and the ends of the feed/phase line connect to the mast--mostly as a form of lightning protection. Antenna current on the mast is negligible. The center pair of dots form the feedpoint connection. Connecting the two terminals of the feeder to these two points connects the two feed/phase lines and the elements in series with the source energy.

KD2BD developed a set of dimensions for a batwing from the two sources noted in **Fig. 1**: Johnson, *Antenna Engineering Handbook*, 3rd Ed., and Kraus, *Antennas*, 2nd Ed. These references provide some background reading sources on the batwing:

- G. H. Brown in *Electronics*, March and April, 1936
- R. W. Masters in *Broadcast News*, January, 1946
- H. E. Gihrig in *RCA Review*, June 1951
- Sato, Kawakami, & Masters, *Trans. IECE* (Japan), May, 1982
- H. Kawakami in *IEEE Trans. Antennas Propagat.*, Dec., 1984

For about 435 MHz, the individual batwing would be 6.25" from feed/phase-line to end, with the shortest dipole 2.31" from its feed/phase-line to its end. The total vertical length is 17.66". KD2BD did not specify the size of the mast or the distance either from its center or its edge to the feed/phase-line.

I used the KD2BD dimensions to construction a model of the batwing for the 70-cm band. For the exercise, I omitted the mast, since one may build a batwing using a non-conductive mast. I separated the feed/phase lines by 0.5", which adds 0.25" to each outer dimension for the longest and shortest dipoles. I segmented the array so that each segment is as close to 0.5" as possible, allowing the use of a 1-segment wire for the connected long dipoles and across the feedpoint so addition of a source. The wire in the model is 0.125" in diameter. My initial models used aluminum, but there is little difference in performance ranging from perfect or lossless wire through copper to aluminum. **Fig. 3** is an outline sketch of the test model, with the dimensions shown as sample sets of coordinates (in inches).

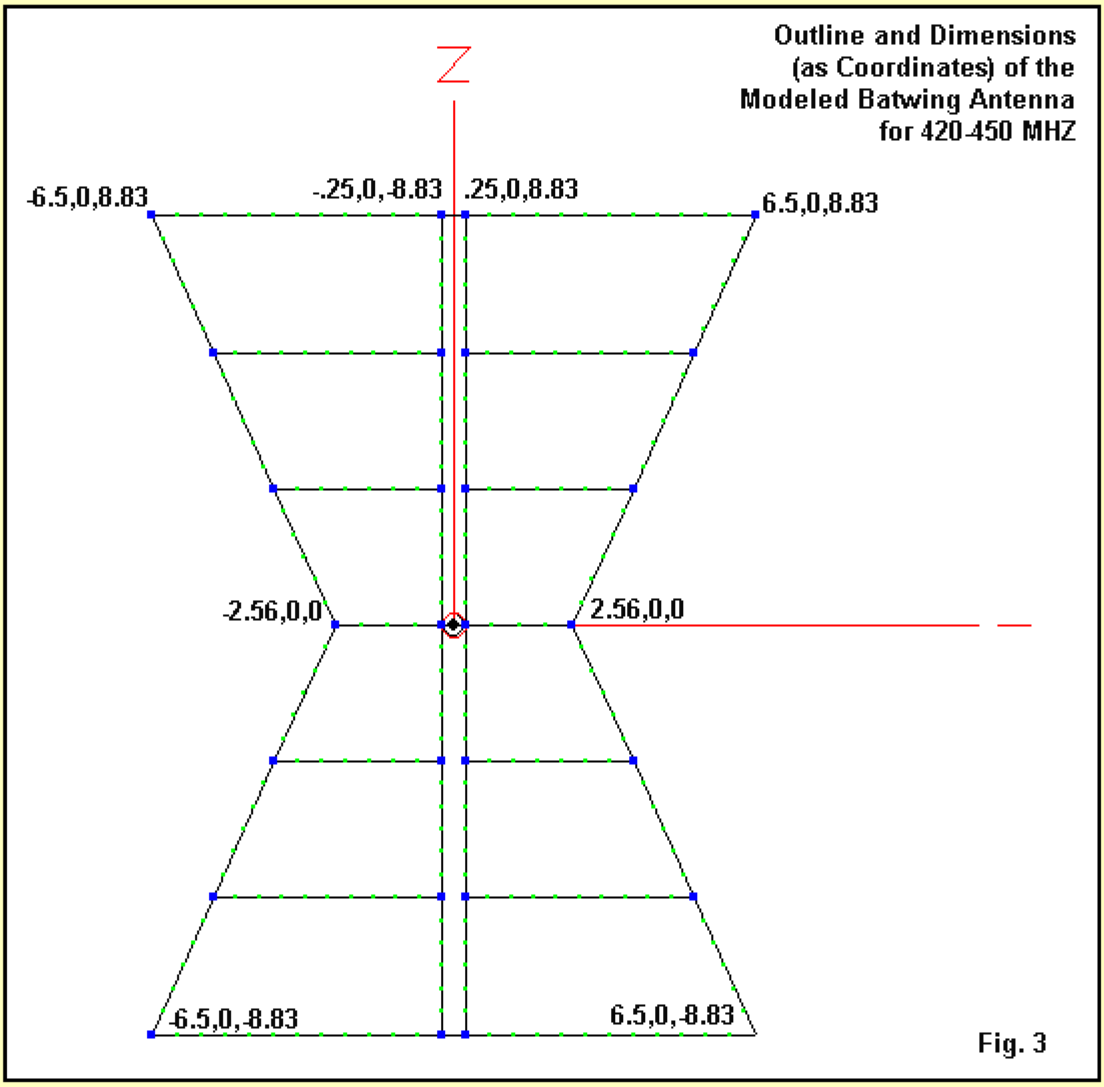


Fig. 3

The segments are all about the same length and each is 4 times the wire diameter. I placed the dipoles equi-spaced from each other, with lengths derived from the need for a straight line from the shortest to the longest. Most photos of the batwing show rounded corners, but the pointed ones do no harm in this proof-of-principle model. As a standard of comparison, I made from 0.125" aluminum a dipole 12.7" long for 435 MHz.

The following table summarizes the results of a free-space comparison between the two antennas.

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Comparison Between 70-cm Dipole and Batwing

Dipole

Freq. MHz	**420**	**435**	**450**
Gain dBi	**2.09**	**2.12**	**2.15**
-3-dB Beamwidth degrees	**79.2**	**78.5**	**77.6**
Feed Z: R+/-jX Ohms	**64.5 - j25.0**	**72.1 + j 0.3**	**80.7 + j25.5**
75-Ohm SWR	**1.47**	**1.04**	**1.40**

Batwing

Freq. MHz	**420**	**435**	**450**
Gain dBi	**5.09**	**5.22**	**5.36**
-3-dB Beamwidth degrees	**80.0**	**79.2**	**78.4**
Feed Z: R+/-jX Ohms	**76.9 - j15.6**	**80.2 - j 8.8**	**83.9 - j 4.3**
75-Ohm SWR	**1.23**	**1.14**	**1.13**

Note: Antennas as described in text using 0.125"-diameter elements.

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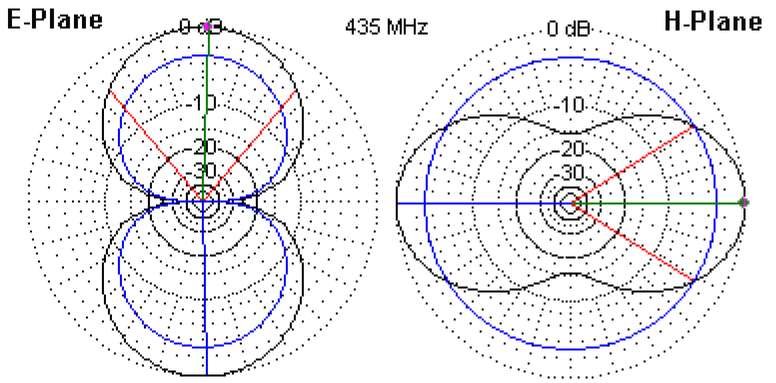
The batwing manages about 3-dB greater gain than the simple dipole at all frequencies, but maintains a very similar -3-dB bandwidth across the 70-cm band. How the batwing accomplishes this feat becomes evident from **Fig. 4**, a set of comparative E-plane and H-plane patterns for the antennas in free space.

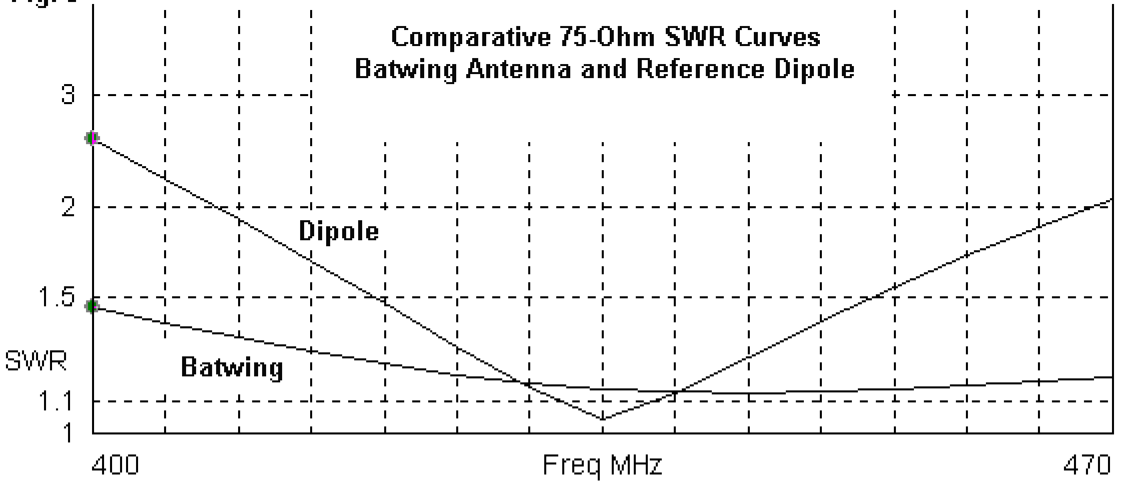


Comparative E-Plane and H-Plane Patterns
Black = Batwing; Blue = Dipole

Fig. 4

The vertical arrangement of matching dipoles in the batwing places the most active elements in the vicinity of 1/2-wavelength from each other. A wavelength at 435 MHz is 27.133", and the overall height of the array is 17.66" or somewhat over 1/2-wavelength. The effective distance between in-phase-fed dipoles is somewhat under 1/2 wavelength, as evidenced by the fact that there are not deep nulls in the H-plane pattern along the Z-axis. However, the spacing is close enough to 1/2-wavelength to significantly compress the radiation along the Z-axis, and this energy shows up as higher gain in the E-plane pattern.

Fig. 5



Comparative 75-Ohm SWR Curves
Batwing Antenna and Reference Dipole

Although the model used a phase-line separation that prevents a true batwing resonance within the 70-cm band, the 75-Ohm SWR curve is much flatter than that of a comparable dipole. **Fig. 5** shows the 75-Ohm SWR curves for both antennas from 400 to 470 MHz.

It is important to remember that the model under test here has no center conductive mast. With the same dimensions, a center mast to which the inner ends of the longest elements connect might change the equivalent uniform-diameter elements lengths by a small degree. As well, the essentially ground potential center mast might also alter the inherent characteristic impedance of the feed/phase line and would require considerable remodeling to effect the impedance shown in the modeled results. We shall do a preliminary exploration of issues surrounding a conductive mast in Part 3 of these notes. However, the model that we are using here should play true to a physical batwing using a non-conductive mast.

Changing Element Diameter

For many would-be batwing builders, the 1/8" diameter elements used in the test model would not be satisfactory. Since the array requires soldering or brazing elements together, some with end to mid-wire junctions, one might prefer to use larger-diameter elements. So I ran a free-space comparison of the batwing--without any dimensional changes--using 1/8", 3/16", and 1/4" elements. Of course, all connected wires in a NEC model should be the same diameter to prevent errors emerging from angular junctions of wires having dissimilar diameters. Hence, the diameter of the wires forming the feed/phase line also increased in diameter. The consequence of this move was to alter the resistive component of the feedpoint impedance, as the fatter wire increased the capacitive reactance of the array. As well, the fatter wire in the feed/phase lines with no change in the center-to-center spacing of those lines decreased the characteristic impedance of the line. (We shall explore some issues related to feed/phase line characteristic impedance in Part 3.)

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Comparison Among 70-cm Batwing Using Various Wire Diameters

0.125" diameter elements

Freq. MHz	**420**	**435**	**450**
Gain dBi	**5.09**	**5.22**	**5.36**
-3-dB Beamwidth degrees	**80.0**	**79.2**	**78.4**
Feed Z: R+/-jX Ohms	**76.9 - j15.6**	**80.2 - j 8.8**	**83.9 - j 4.3**
75-Ohm SWR	**1.23**	**1.14**	**1.13**

0.1875" diameter elements

Freq. MHz	**420**	**435**	**450**
Gain dBi	**5.13**	**5.26**	**5.39**
-3-dB Beamwidth degrees	**80.2**	**79.4**	**78.5**
Feed Z: R+/-jX Ohms	**70.5 - j28.6**	**71.9 - j22.5**	**73.4 - j18.4**
75-Ohm SWR	**1.49**	**1.36**	**1.28**

0.25" diameter elements

Freq. MHz	**420**	**435**	**450**
Gain dBi	**5.15**	**5.28**	**5.41**
-3-dB Beamwidth degrees	**80.4**	**79.6**	**78.6**
Feed Z: R+/-jX Ohms	**66.2 - j37.1**	**66.3 - j31.3**	**66.6 - j27.3**
75-Ohm SWR	**1.49**	**1.36**	**1.28**

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The lower resistive components of the feedpoint impedances suggest that the increased diameter of the feed/phase line with no change of spacing is resulting in a lower characteristic impedance for the line. Hence, before scaling the antenna dimensions, it would be wise to alter the spacing of the feed/phase line to bring the resistance back up and to determine the consequences on the reactance. The reactance seems to show a regular shift of about 30 MHz for each 0.0625" increase in element diameter, but some of that effect is a consequence of the altered characteristic line impedance. Revised spacing between the lines to adjust the feedpoint resistance may well change the accompanying reactance.

The 70-cm band has a 6.9% bandwidth relative to the center frequency of 435 MHz. The batwing's gain across the band varies by just over 0.25 dB, with less than a 2-degree change in beamwidth.

The Batwing Above Ground

For a horizontal antenna high above ground, the gain increases be close to 6 dB relative to the free-space gain as a result of ground reflections. Although this fact is seemingly very well known, it may be useful to take the trouble to run both our reference dipole and the batwing an exercise of placing each--at its center--10 wavelengths above average ground. The results appear in the following table.

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Comparison Between 70-cm Dipole and Batwing 10 WL Above Ground

Dipole

Freq. MHz	**420**	**435**	**450**
Gain dBi	**8.08**	**8.08**	**8.08**
Take-Off Angle degrees	**1.5**	**1.4**	**1.4**
-3-dB Beamwidth degrees	**79.2**	**78.4**	**77.6**
Feed Z: R+/-jX Ohms	**64.0 - j24.7**	**72.0 - j 0.2**	**81.2 + j25.6**
75-Ohm SWR	**1.47**	**1.04**	**1.40**

Batwing

Freq. MHz	**420**	**435**	**450**
Gain dBi	**11.04**	**11.17**	**11.32**
Take-Off Angle degrees	**1.5**	**1.4**	**1.4**
-3-dB Beamwidth degrees	**80.0**	**79.2**	**78.2**
Feed Z: R+/-jX Ohms	**76.8 - j15.5**	**80.2 - j 8.8**	**83.9 - j 4.3**
75-Ohm SWR	**1.23**	**1.14**	**1.13**

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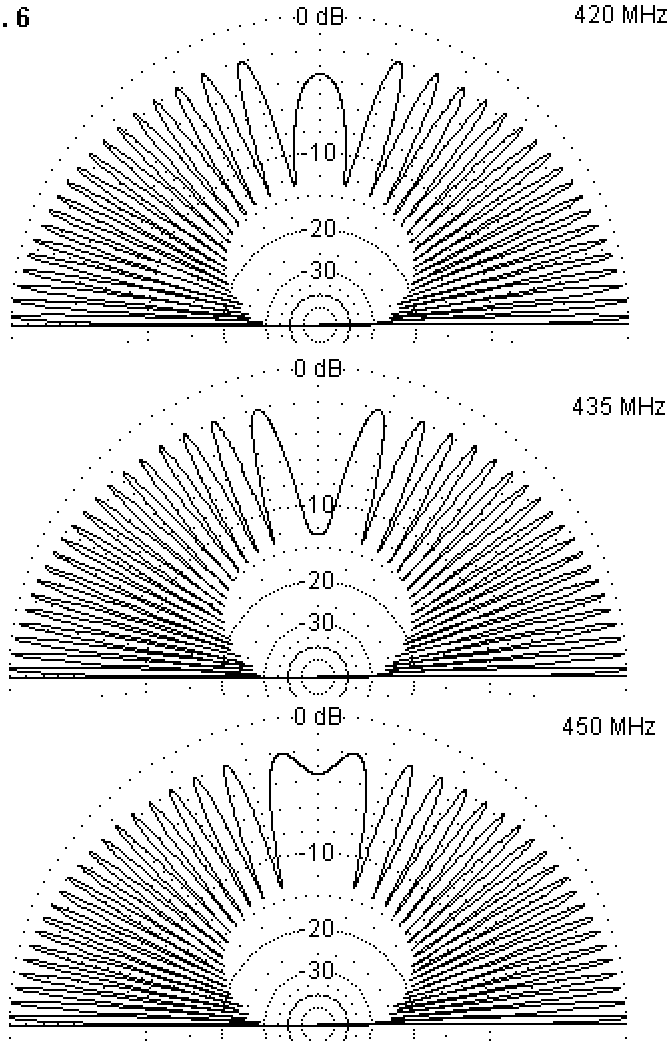
The exercise has changed the numbers virtually not at all, except for the gain and for adding the elevation angle of the lowest and strongest lobe of the pattern over ground. A 10-wavelength height is 271.33" (22.61') at 435 MHz.

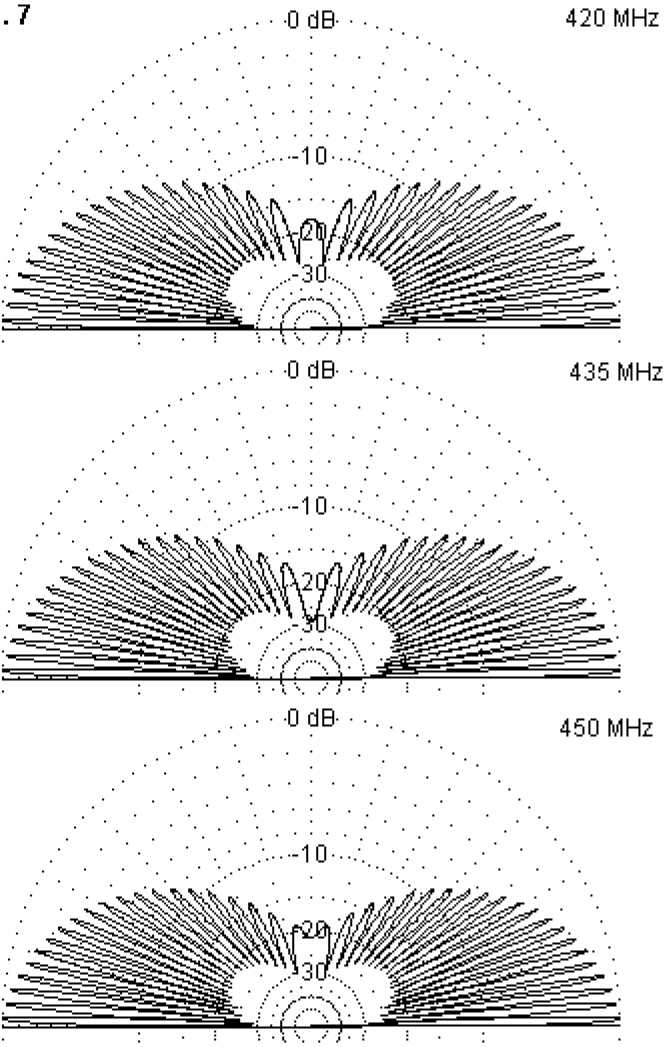
Fig. 6



Elevation Patterns: 70-cm Dipole
10-Wavelengths Above Average Ground

There are significant differences between the elevation patterns of the dipole and the batwing that do not show up in the tabulated numbers. **Fig. 6** shows the elevation patterns of the dipole. For each of the 3 test frequencies, the total lobe pattern would fit inside (with allowance for a difference in strength) of the upper half of the free-space circular H-plane pattern. Essentially, the dipole provides not only a low-angle signal, but very high angle signals of nearly equivalent strength.

Fig. 7



Elevation Patterns: 70-cm Batwing
10-Wavelengths Above Average Ground

The free-space pattern of the batwing showed considerably less energy at high angles relative to the zero-degree angles at which we took the E-plane pattern. That same phenomenon appear over ground in the form of the pattern shown in **Fig. 7**. The high-angle lobes are very much weaker than the low-angle lobes, contributing to the gain advantage of the batwing over the dipole. Like the dipole, the lobe structure of the elevation pattern over ground would fit inside the upper portion of the H-plane pattern in free space, with allowance for the gain differential.

Although incidental to the situation, we may note that the lobe structure in detail is a function of frequency and height above ground. For a fixed height (22.61'), the lobe structure changes as we move across the band. This fact is most evident in the changing structure to the very highest-angle lobes. Note that while the strength of these lobes differs for the two antennas, the lobe structure itself is the same for both antennas in terms of the position of maximums and minimums.

Stacking a Pair of Batwings

A popular use of batwings--especially when turnstiled--is to create vertical stacks of them to increase gain. We may look at some of the basic properties of the batwing stack simply by stacking 2 of them in free space.

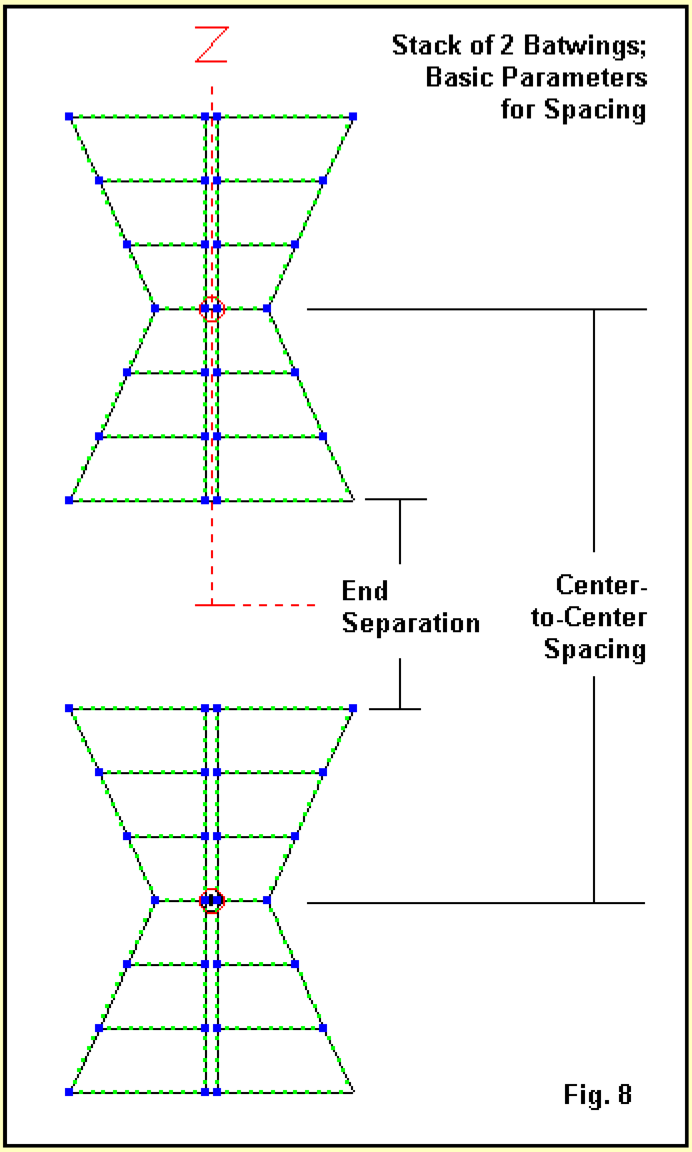


Fig. 8

Fig. 8 shows the outline of such a stack, along with two of the key parameters. The spacing between the centers of each array is limited by the vertical dimension of each antenna. It makes no sense to have them overlap. So we shall be as concerned with the end-spacing as with the center-to-center spacing of the arrays.

The most popular spacing used by most batwing-makers is 1 wavelength center-to-center. At 435 MHz, this amounts to 27.133". The resulting end-to-end spacing is 9.473" or 0.35-wavelength. Under these conditions, we obtain the following free-space performance from a stack of 2 batwings. The feedpoint impedance reports are for each of the two in-phase-fed sources.

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Free-Space Performance of a Stack of 2 70-cm Batwings

Batwing **Freq. MHz**	**420**	**435**	**450**
Gain dBi	**8.43**	**8.62**	**8.80**
-3-dB Beamwidth degrees	**80.2**	**79.4**	**78.4**
Feed Z: R+/-jX Ohms	**71.4 - j12.6**	**75.2 - j 3.7**	**80.5 + j 2.7**
75-Ohm SWR	**1.20**	**1.05**	**1.08**

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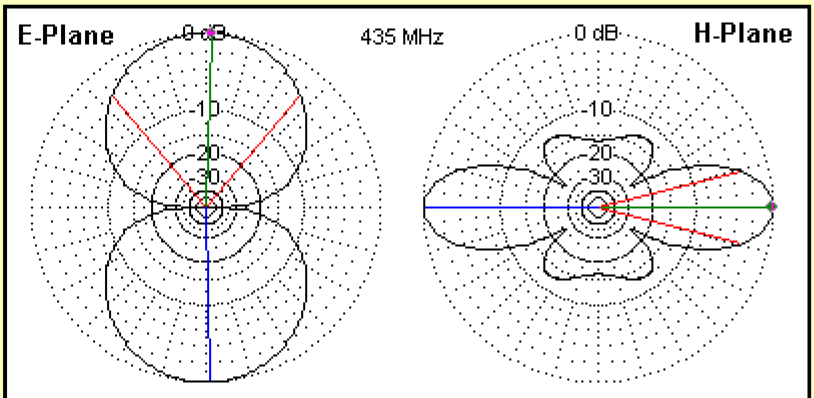
At a center-to-center separation of 1 wavelength, the outer edges of the batwing are vertically about 1.6 wavelengths apart. The net effect is to produce "ear-lobes" on the H-plane pattern. **Fig. 9** shows the H-plane ear lobes clearly.



Batwing Stack, 1-WL Separation, Free-Space
E-Plane and H-Plane Patterns

Fig. 9

The side lobes give the pattern a similarity to the normal E-plane pattern of an extended double Zepp (a 1.25-wavelength center-fed wire). With the Zepp, we know that shortening the wire to 1 wavelength or less will yield a pattern free of these lobes. Therefore, it may be useful to examine trends in lobe development as we select a closer and a more distance spacing for the two batwings in the stack. Throughout, we shall assume in-phase feeding of the arrays. As well, for this test, we may use 435 MHz as the test frequency.

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Batwing Stack of 2: Varying Separation

	Closer	**Standard**	**Farther**
Center-to-Center (WL)	**0.816**	**1.0**	**1.184**
End-Separation (WL)	**0.165**	**0.349**	**0.533**
Gain dBi	**8.20**	**8.62**	**8.41**
Front-to-Sidelobe (dB)	**-13.83**	**-12.65**	**-7.65**
-3-dB Beamwidth degrees	**79.5**	**79.4**	**79.0**
Feed Z: R+/-jX Ohms	**72.9 - j 9.7**	**75.2 - j 3.7**	**84.1 - j 4.9**
75-Ohm SWR	**1.14**	**1.05**	**1.14**

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With respect to array gain, the 1-wavelength center-to-center spacing appears close to optimum. As we decrease spacing, we find an increase in the front-to-sidelobe ratio, but by only a small amount. As we increase spacing, the ear lobes increase, as indicated by the decrease in the front-to-sidelobe ratio. For this particular model, with all of the physical features described at the beginning of these notes, the 1-wavelength center-to-center spacing also yields the most convenient feedpoint impedance.

Over ground, the stack shows a very usable gain increase over a single batwing. The following performance table tells the entire story. The lower batwing has its center 10 wavelengths above average ground. The feedpoint impedance reports are for each of the 2 arrays, fed in phase.

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Performance over Ground of a Stack of 2 70-cm Batwings

Batwing			
Freq. MHz	**420**	**435**	**450**
Gain dBi	**14.36**	**14.50**	**14.73**
Take-Off Angle degrees	**1.4**	**1.4**	**1.3**
-3-dB Beamwidth degrees	**80.2**	**79.2**	**78.4**

Feed Z: R+/-jX Ohms	**71.4 - j12.6**	**75.2 - j 3.8**	**80.6 + j 2.7**
75-Ohm SWR	**1.20**	**1.05**	**1.08**

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The stack over ground shows the anticipated 6 dB gain over its free-space counterpart. The gain over a single batwing at 10 wavelength center height is slightly more than 3 dB, due partly to the second antenna being 11 wavelengths above ground. Otherwise, there are no significant changes in the remaining reported values.

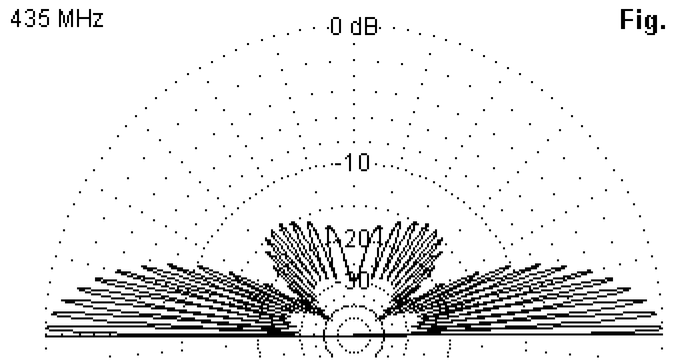

Fig. 10

Elevation Pattern: Stack of 2 Batwings
Centers: 10 and 11 Wavelengths Above Average Ground

Fig. 10 shows the elevation pattern of the batwing 2-stack at 435 MHz. The key element in this pattern is the high-angle radiation that is not present with a single batwing. However, the strongest of this high-angle radiation is 15 dB below the strength of the main lobe. For many applications, this level of high-angle radiation presents no problems to successful use of the batwing stack.

Stacking 4 Batwings

To gain an additional 3 dB of gain, it is necessary to double the 2-stack. A stack of 4 batwing antennas spaced 1 wavelength center-to-center would have the general appearance of the outline sketch in **Fig. 11**.

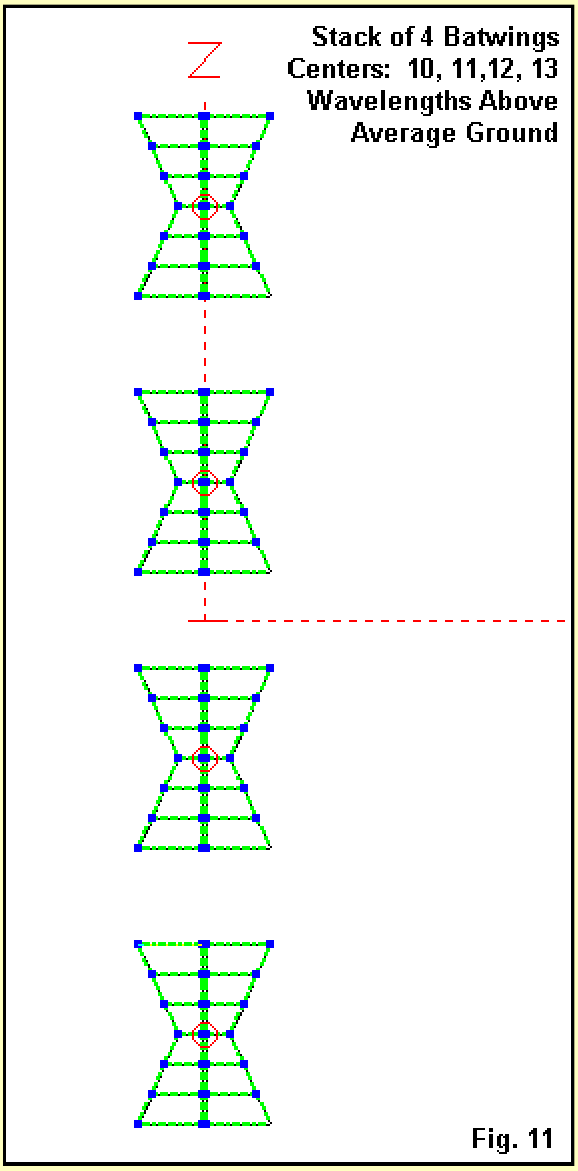
Stack of 4 Batwings
Centers: 10, 11,12, 13
Wavelengths Above
Average Ground

Fig. 11

When building vertical stacks of arrays, there is a common misconception that there is an equality of performance in all categories for each of the arrays. However, that is not quite the case. The inner arrays couple to at least 2 other arrays, while the outer arrays couple only to arrays toward the center of the stack. This yields some slight differences of performance, as indicated in the table below by the feedpoint impedances. The stack has its lowest antenna centered at 10 wavelengths (22.61') above average ground, with the remaining arrays centered at 11, 12, and 13 wavelengths (24,87', 27.13', and 29.39'). Each array is fed in phase with the others.

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Performance over Ground of a Stack of 4 70-cm Batwings

Batwing Freq. MHz	**420**	**435**	**450**
Gain dBi	**17.59**	**17.75**	**17.89**
Take-Off Angle degrees	**1.3**	**1.2**	**1.2**
-3-dB Beamwidth degrees	**80.2**	**79.4**	**78.4**
Outer 2 Antennas			
Feed Z: R+/-jX Ohms	**71.9 - j10.6**	**76.5 - j 2.7**	**82.0 + j 2.9**
75-Ohm SWR	**1.16**	**1.04**	**1.10**
Inner 2 Antennas			
Feed Z: R+/-jX Ohms	**65.3 - j 8.5**	**70.5 + j 2.2**	**77.7 + j 9.9**
75-Ohm SWR	**1.20**	**1.07**	**1.14**

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The resistive component of the impedance across the 70-cm band differs by about 6 Ohms between an outer (top or bottom) or an inner position, a difference of about 8.5%. The modeled performance presumes that each array is fed in phase. A standard phasing harness for a stack of 4 arrays would not provide such perfection of energy distribution, and the results would show up as slightly altered gain figures.

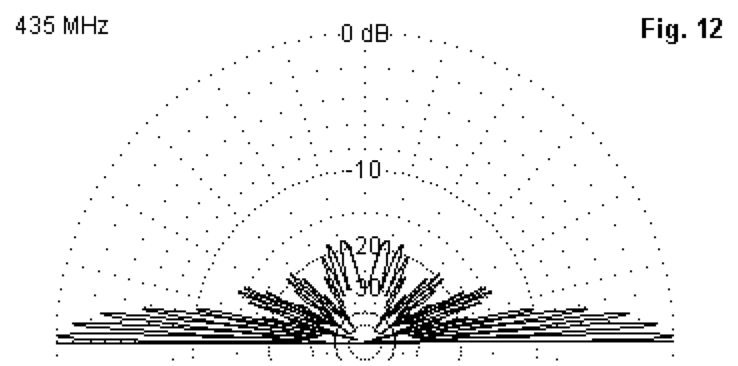

Fig. 12

Elevation Pattern: Stack of 4 Batwings--Centers: 10, 11, 12, 13 Wavelengths Above Average Ground

The differences between a 2-stack and a 4 stack are not confined to gain and power distribution. **Fig. 12** shows the elevation pattern of the 4-stack at the base-antenna center-height of 10 wavelengths above average ground. Although the secondary high-angle lobes remain 15-20 dB below the lowest main lobe far-field strength, they do show a change of distribution, relative to the pattern of high-angle lobes in **Fig. 10** for the 2-stack.

From Basics to Applications

In this portion of my notes on the batwing antenna, we have examined some of its basic properties as a very wide-band dipole antenna. It holds promise of being useful for applications in the UHF range, where we can make good use of constant performance characteristics across a wide area of the spectrum. The models used a 435-MHz design frequency and cover all of the 70-cm band with less than a 1.2:1 75-Ohm SWR in most cases and cover 400-470 MHz (a 16% bandwidth relative to 435 MHz) with about 1.5:1 or less 75-Ohm SWR. Because most batwing applications use horizontal polarization, we have confined ourselves to that orientation.

In the second part of this series we shall examine two principal applications of the batwing. The first is with a planar reflector to obtain uni-directional performance. The second is as a turnstile array to obtain omni-directional performance. In the UHF range, hardly anyone is satisfied with bi-directional performance, the basic property of a single batwing and its stacks.

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