Notes on the Batwing
Part 2: Uni-Directional and Omni-Directional Batwings

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In Part 1 of this short series of notes on the batwing antenna, we examined the basic dipole-like properties of the antenna. We found it to have about 3 dB gain over a conventional dipole, along with a very wide bandwidth. The gain is a function of the compression of higher angle radiation due to the antenna's vertically symmetrical structure. The wide bandwidth results essentially from having very closely coupled dipoles of different lengths.

The model that we used--and shall continue using--differs from most commercial implementations of the batwing. It uses no conductive center mast to which the uppermost and lowermost dipoles connect. Hence, the feed/phase lines are closer together than in common versions, but do not have a ground-potential center bus--the mast. The 435-MHz design is 17.66" high by 13.0" wide at the top and bottom and 5.12" wide at the center.

In this part of my notes, we shall explore two typical directions in which one might wish to take the batwing. One direction is the beam antenna. Using a planar reflector, we can obtain a uni-directional horizontally polarized antenna of some promise. The other direction is the application for which the batwing is most famous: as a "super-turnstile" antenna, often stacked for greater gain. The nearly circular omni-directional pattern has proven useful for commercial television transmitting and may prove useful for ATV applications.

The Batwing Beam

Virtually any dipole-like antenna is suitable for use with a planar reflector, that is a solid sheet, screen, or set of closely spaced rods forming a rectangle at a useful distance behind the antenna proper. Almost any size planar reflector that extends at least a bit beyond the boundaries of the driven antenna will provide some gain and front-to-back ratio. However, for many antennas, there is an optimum reflector size in terms of both width and height.

The Double-Diamond

As a sample that we may use for comparative purposes, we may review the double-diamond and its reflector that appear in another item at this site: "Modeling the Double-Diamond for UHF." The double-diamond is actually a pair of side-fed quad loops fed at a common point--the inner corner of the diamonds. As a side-fed quad in duplicate, the antenna is vertically polarized. **Fig. 1** shows the outlines of the double-diamond and its reflector.

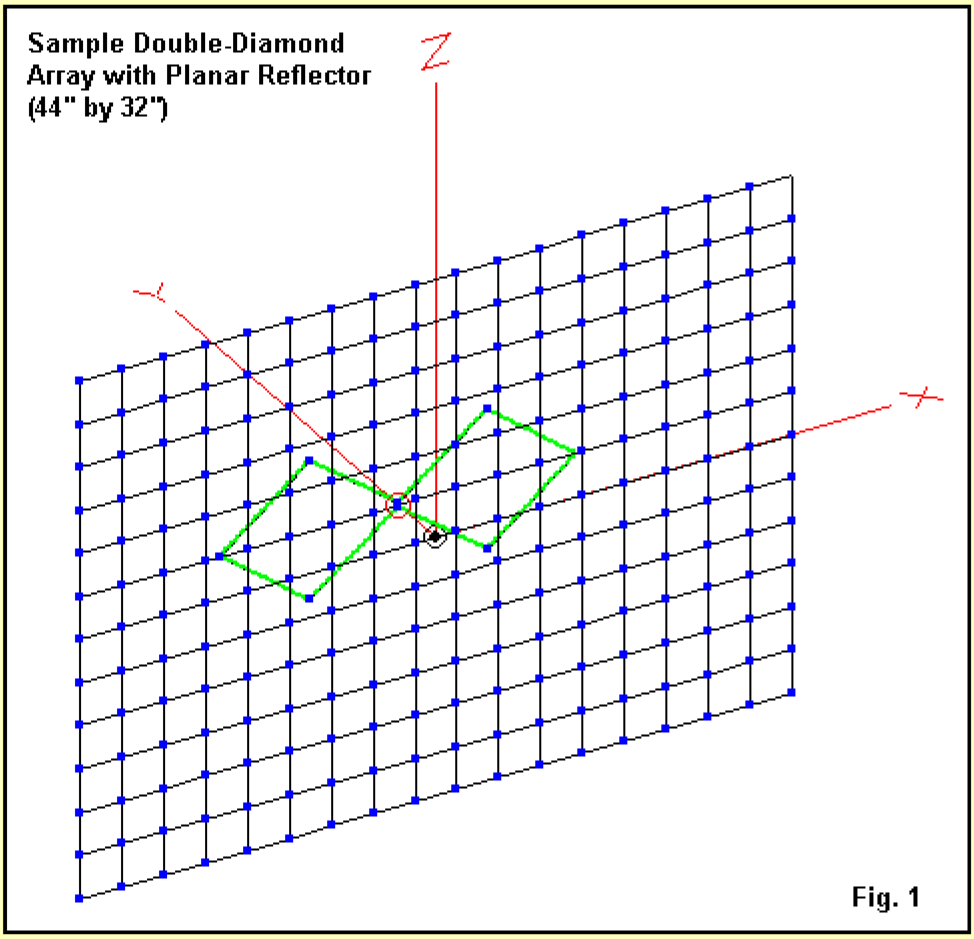

Fig. 1

The reflector is 42" wide by 32" high, the version providing maximum gain with a double-diamond 4" in front of the plane at 435 MHz. The diamond has been shape-adjusted for a combination of maximum gain and a near-resonant feedpoint impedance of 50 Ohms at the design frequency. The reflector model uses 0.1-wavelength spacing between wires whose diameter is sized relative to the spacing. A larger model using 0.05-wavelength spacing was tested and yielded results that are numerically so close to those of the smaller model that it made no sense to wait out the runs of a model 4 times the size.

The results of the runs produced the following free-space performance table.

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Performance of a Double-Diamond and Optimized Planar Reflector

Freq. MHz	**420**	**435**	**450**
Gain dBi	**11.15**	**11.25**	**11.32**
Front-to-Back Ratio dB	**20.96**	**21.28**	**21.64**
-3-dB Beamwidth degrees	**51.2**	**50.6**	**50.2**
Feed Z: R+/-jX Ohms	**38.3 - j30.0**	**45.1 - j 6.4**	**55.6 + j17.0**
50-Ohm SWR	**2.06**	**1.19**	**1.40**

Note: The antenna is vertically polarized.

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Antennas that are capable of covering all of the 70-cm band are not so common that the one may casually bypass the double-diamond with a planar reflector. **Fig. 2** shows the H-plane and E-plane patterns in free-space for the array. When placed well above ground, these patterns translate into well-behaved azimuth and/or elevation patterns, depending on the orientation of the antenna.

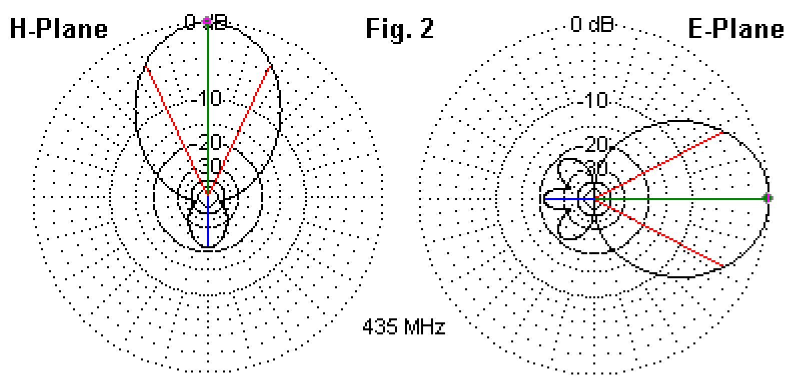


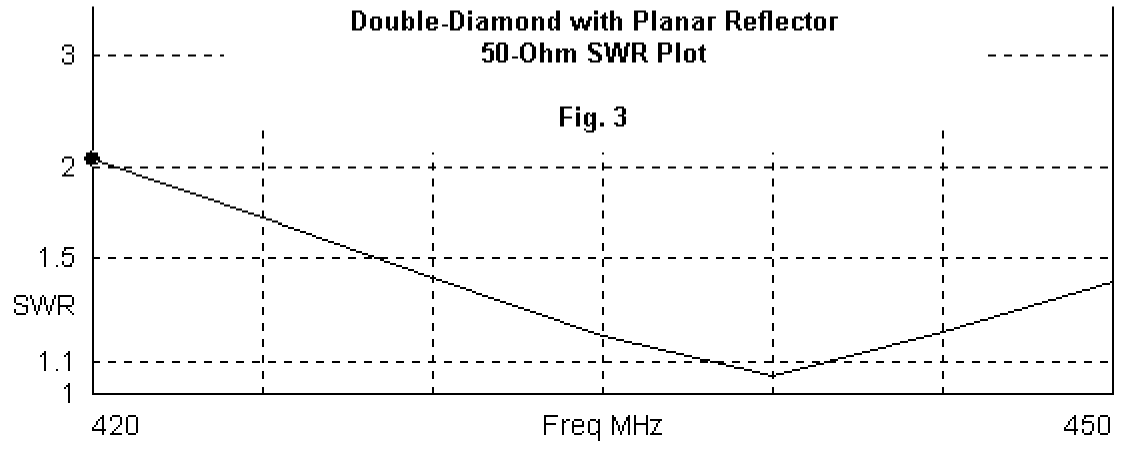
Fig. 2

Double-Diamond with 44" by 32" Planar Reflector
Free-Space Patterns

The SWR curve for the antenna is easily adjusted to better center the 50-Ohm minimum. As **Fig. 3** shows, it is a bit off center in the proof-of-principle design used for the antenna. Obtaining a desired impedance and resonance at the design frequency is a matter of adjusting both the driver size and the distance from the reflector. At 5 inches, there is a shape to the double diamond that yields a 50-Ohm impedance.

Double-Diamond with Planar Reflector
50-Ohm SWR Plot

Fig. 3



The Batwing Array

The batwing is a more complex structure. Therefore, for the exercise at hand, I decided not to attempt to re-size the antenna. Instead, I sought a distance from the reflector that yielded resonance at whatever impedance emerged. At 5" from the planar reflector, the 435-MHz batwing is resonant at 170 Ohms. A 4:1 impedance transformation yields 42.5 Ohms, which might be satisfactory for 50-Ohm cable.

Finding the optimum size reflector is often a matter of trial and error. In this exercise, some of the sizes tried include those in **Fig. 4**. In each case, the first size figure is the width and the second is the height.

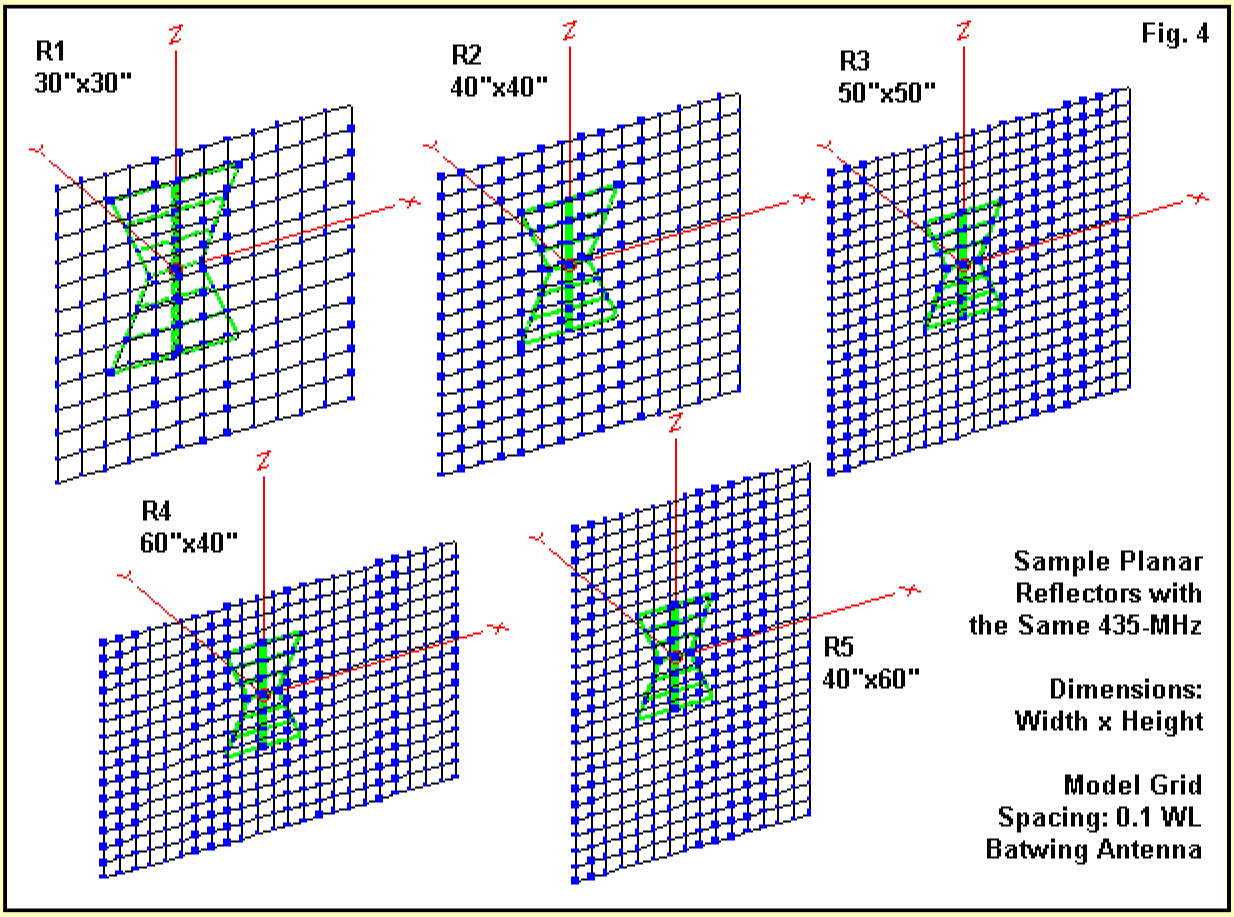


Fig. 4

Sample Planar Reflectors with the Same 435-MHz Dimensions: Width x Height

Model Grid Spacing: 0.1 WL Batwing Antenna

The results on which I based a final selection for a reflector plane appear in the following table.

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Performance of a Batwing and Various Planar Reflectors

R1: 30" wide by 30" high

Freq. MHz	**420**	**435**	**450**
Gain dBi	**10.27**	**10.44**	**10.62**
Front-to-Back Ratio dB	**19.11**	**19.30**	**19.46**
-3-dB Beamwidth degrees	**56.2**	**55.0**	**54.0**
Feed Z: R+/-jX Ohms	**157.4 + j24.2**	**170.2 + j 1.9**	**169.3 - j25.6**
170-Ohm SWR	**1.18**	**1.01**	**1.16**

R2: 40" wide by 40" high

Freq. MHz	**420**	**435**	**450**
Gain dBi	**10.51**	**10.49**	**10.49**
Front-to-Back Ratio dB	**23.60**	**24.64**	**25.64**
-3-dB Beamwidth degrees	**56.2**	**57.8**	**59.2**
Feed Z: R+/-jX Ohms	**155.9 + j25.7**	**170.1 + j 3.7**	**170.4 - j24.5**
170-Ohm SWR	**1.20**	**1.02**	**1.16**

R3: 50" wide by 50" high

Freq. MHz	**420**	**435**	**450**
Gain dBi	**10.00**	**10.00**	**10.02**
Front-to-Back Ratio dB	**28.38**	**28.81**	**29.24**
-3-dB Beamwidth degrees	**65.5**	**66.6**	**67.6**
Feed Z: R+/-jX Ohms	**156.9 + j25.9**	**170.9 + j 3.4**	**170.8 - j25.1**
170-Ohm SWR	**1.20**	**1.02**	**1.16**

R4: 60" wide by 40" high

Freq. MHz	420	435	450
Gain dBi	9.73	9.76	9.83
Front-to-Back Ratio dB	32.93	34.21	30.15
-3-dB Beamwidth degrees	70.0	70.6	70.6
Feed Z: R+/-jX Ohms	156.5 + j24.9	170.0 + j 2.8	169.9 - j25.0
170-Ohm SWR	1.19	1.02	1.16

R5: 40" wide by 60" high

Freq. MHz	420	435	450
Gain dBi	10.39	10.38	10.39
Front-to-Back Ratio dB	25.09	25.89	26.57
-3-dB Beamwidth degrees	56.7	57.9	58.9
Feed Z: R+/-jX Ohms	155.2 + j26.1	169.8 + j 4.6	170.8 - j23.9
170-Ohm SWR	1.20	1.03	1.15

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There are trends evident in this series of trial reflector sizes. Below a certain size (and the 30" by 30" reflector is below that size), neither the gain nor the front-to-back ratio reach maximum obtainable values. Above a certain size (which the 40" by 40" sample may mark provisionally), an increase in the width of the reflector results in an increase in both the front-to-back ratio and the -3-dB beamwidth. However, gain tends to decrease, as shown in reflectors R3 and R4. Below a certain height (which the 40" by 40" sample may mark provisionally), the beamwidth and the front-to-back ratio decrease, but if too high, the gain goes down.

Although the final size is provisional, it likely falls into the range around 40" by 40" unless a particular application requires that we place more emphasis upon the front-to-back ratio than upon the forward gain. With a larger reflector, we may sacrifice half to three quarters of a dB for the sake of an added 4 to 10 dB front-to-back ratio.

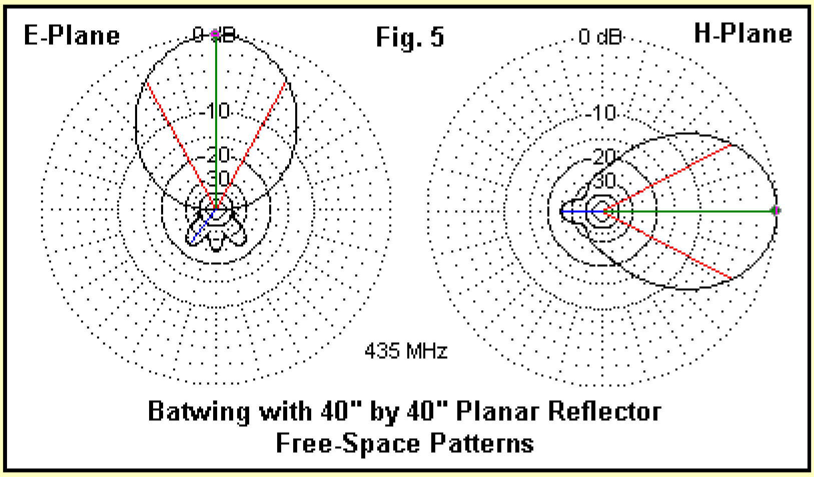
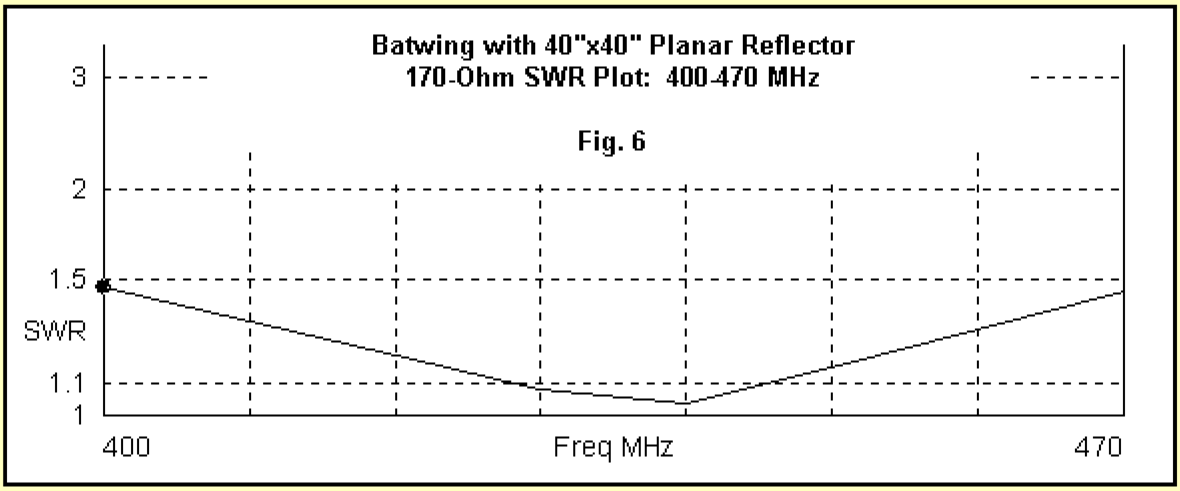


Fig. 5

Batwing with 40" by 40" Planar Reflector
Free-Space Patterns

Fig. 5 shows the E-plane and H-plane patterns for the free-space model using the 40" by 40" reflector. With slightly less gain but higher front-to-back ratios, these patterns are quite similar to those of the double diamond, our standard of comparison. Indeed, in terms of these performance figures, there is little to choose between the two designs. Both not only show balanced performance, but as well sustain that performance across the 70-cm band.

However, in a wide-band antenna, the SWR curve may be for some applications as important as the general level of performance. **Fig. 6** shows the 170-Ohm SWR plot for the batwing planar array from 400-470 MHz.



Over this extended range, the 170-Ohm SWR never reaches 1.5:1. It is likely that ice, snow, and whatever chemicals the atmosphere may deposit upon the antenna surface will not be noticed in operation as detuning source with the batwing planar array.

A 2-Stack Batwing Array

The batwing array is a natural for a vertical stack of at least two arrays. A 1-wavelength center-to-center spacing yielded the best results for a batwing stack without the reflector, so I modeled the new array using this separation. One structural simplification that this arrangement produces is an overlapping reflector, using the 40" by 40" version as our starting point. The final vertical dimension was 67", which yields an extension of the reflector above the top array and below the bottom array that is equal to the extension in a single-bay array. **Fig. 7** shows front and side outline views of the model.

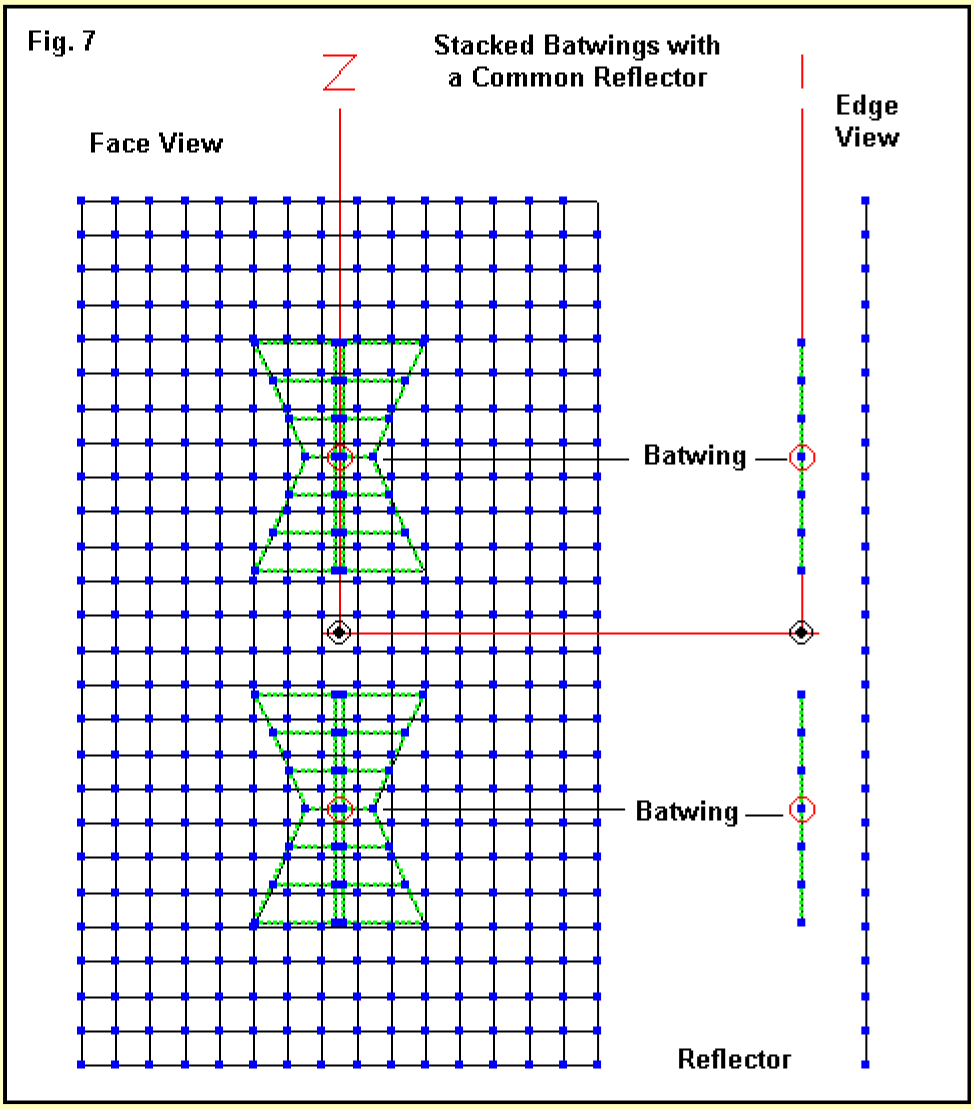


Fig. 7 Stacked Batwings with a Common Reflector

The individual batwings in the 2-stack are identical to those used throughout this exercise. As well, the 2-stack array maintains the same distance from the reflector as in the single-bay model: 5". One consequence of these moves is a centering of the feedpoint impedance in the vicinity of 160 Ohms, which becomes the new standard for SWR reports. The following table summarizes the performance data.

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Performance of a Batwing and Planar Reflector 2-Stack

40" wide by 67" high

Freq. MHz	**420**	**435**	**450**
Gain dBi	**13.46**	**13.48**	**13.50**
Front-to-Back Ratio dB	**23.73**	**24.66**	**25.59**
-3-dB Beamwidth degrees	**56.0**	**57.6**	**59.1**
Feed Z: R+/-jX Ohms	**146.9 + j23.8**	**160.6 + j 6.9**	**163.8 - j17.0**
160-Ohm SWR	**1.19**	**1.04**	**1.11**

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The stack adds about 3 dB to the array gain, but preserves the front-to-back ratio and beamwidth of the single-bat R2 reflector version. Although 160 Ohms may not be convenience as a feedpoint impedance, judicious re-design of the feed/phase line might easily establish a better impedance for transformation to a convenient coaxial cable value. However, using 125-Ohm coax for a phasing line will yield about 100 Ohms for the individual impedances at their parallel junction with a 50-Ohm main feedline. (For the performance over ground at a 10-wavelength height, add about 6 dB to the free-space gain used in this exercise.)

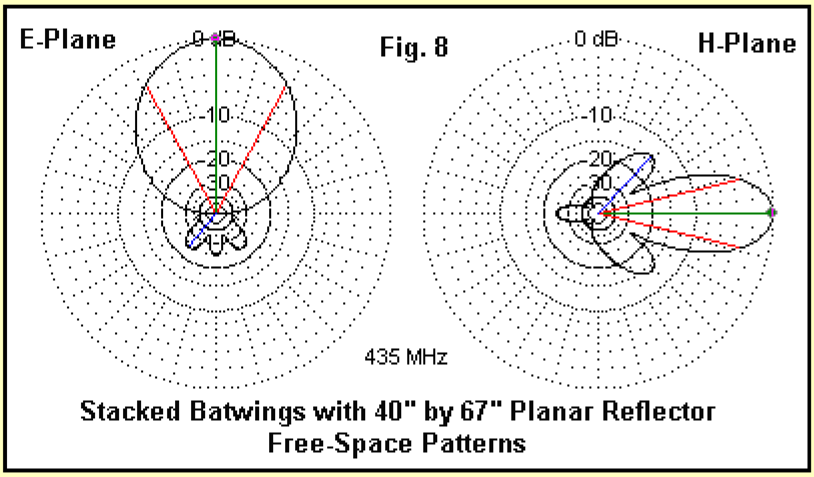
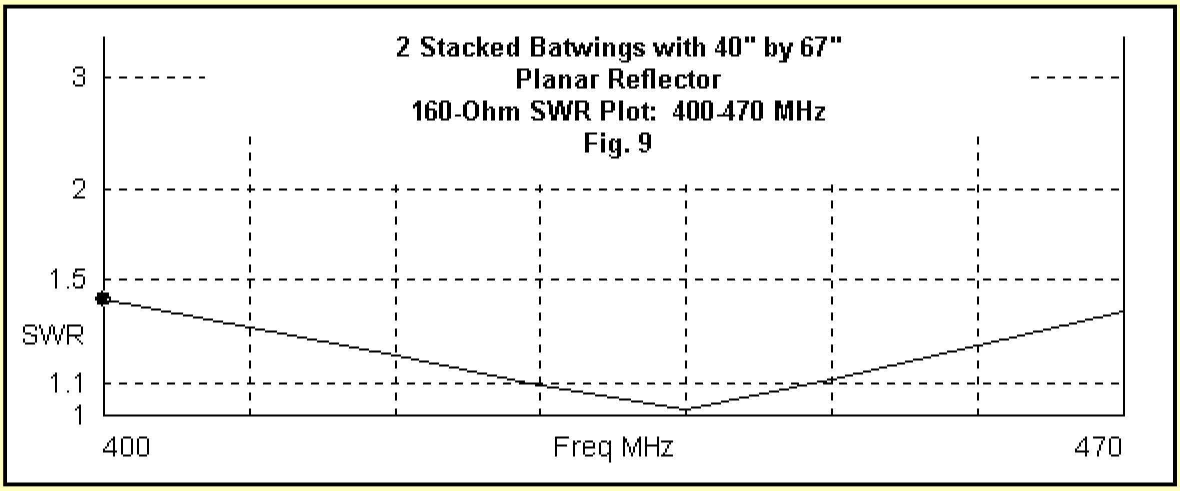


Fig. 8

Stacked Batwings with 40" by 67" Planar Reflector
Free-Space Patterns

Fig. 8 shows the E-plane and H-plane patterns for this free-space model of the directional 2-stack. The E-plane pattern is almost a replica of the single-bay pattern. However, the H-plane pattern shows side lobes at approximately 30 degrees off the main lobe and down by only about 17 dB. These side lobes are the result of the stacking "ears" that we encountered in H-plane patterns derived from batwing stacks without reflectors. With the reflector, the bi-directional ears on each side of the main lobes become single side lobes. These patterns are similar to those that emerge from parasitic extended double Zepp arrays and result from the overall vertical distance between the topmost antenna dipole and the bottommost antenna dipole element. Commensurate with some experimental long-element parasitic beams, it may be possible to tilt each batwing so that the top and bottom project forward of the remainder of the active antennas. There are experimental possibilities for the batwing array that only the future will determine as worthy or not.



2 Stacked Batwings with 40" by 67"
Planar Reflector
160-Ohm SWR Plot: 400-470 MHz
Fig. 9

The final figure (**Fig. 9**) in this portion of the notes is a 160-Ohm SWR plot for the 2-stack from 400 through 470 MHz. The curve shows that for each of the two sources, the feedpoint impedance is as stable as that of the single-bay version of the directional batwing. (However, in terms of a flat SWR curve, the flattest remains to be seen.)

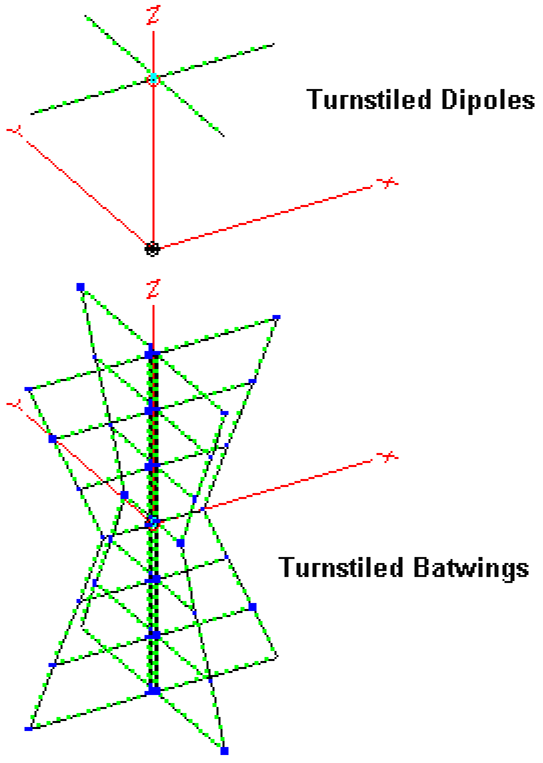
The batwing array with a planar reflector offers a horizontally polarized beam antenna of good performance in a package that is relatively compact in its horizontal dimensions. It is 40" wide by 5" front-to-back. If constructed, the support mast should lie behind the reflector. Indeed, the mast may form a backbone for the reflector. The 67" height of the 2-stack reflector or the 40" height of the single bay may seem large for an essentially utility array. However, lying close to the mast, the reflector and the overall array offer some reduction of snow and ice loading effects that tend to snap many 70-cm Yagis. As well, few Yagis can boast the evenness of the batwing array's performance from one end of the band to the other.

The Batwing Turnstile

The other application for the batwing that appeals to potential users is as an omni-directional horizontally polarized array, possibly suited to ATV and other wide-band uses. Almost any horizontally polarized antenna can be turnstiled, and the batwing is no exception. Of course, the most basic turnstile antenna consists of two simple dipoles at right angles and fed so that the current magnitudes are equal but 90 degrees out of phase. A similar treatment applies to folded dipoles, to quad loops, and to the batwing. Since the turnstiled dipole array is the most basic, let's begin with a comparison between it and what we get when we turnstile a batwing of the 435-MHz dimensions that we have used throughout this exercise.

Dipole vs. Batwing

As shown in **Fig. 10**, the turnstiled dipole pair is deceptively simple. We take two dipoles, each of which is resonant at the design frequency. We cross them at their centers, displacing them so that they do not touch each other. We (current) feed one dipole. From that dipole to the other, we run a 90-degree current phase-shift network. The network can be a simple or complex as desired. For our model--since it takes no physical space--we may run a 1/4-wavelength transmission line having an impedance equal to that of a single dipole at resonance. The net impedance of the dipole pair is 1/2 the impedance of a single dipole.



Outlines of Turnstiled Dipoles and Batwings

Fig. 10

The batwing appears more complex, but most of that impression comes from the basic structure of the antenna. The model outline shows (although hardly visible) that we have displaced one structure vertically from the other by enough for the center wires to clear each other. We feed each batwing in the 90-degree pair at its normal feedpoint. Our feedline goes to one feedpoint. From there to the other, we run our 1/4-wavelength phase line. However, the native impedance of a batwing of the modeled design is about 80 Ohms. We used 70-Ohm transmission line, the same characteristic impedance used with the dipole turnstile. The mismatch yields pattern distortions. The simplest way around this problem is to use a length of line that minimizes the pattern distortions. In this case, with a design frequency of 435 MHz, instead of using 6.78" of line (with a velocity factor of 1.0), we used 6.4".

For our free-space models, we obtained the follow results, tabulated in terms of the maximum and minimum gain and the differential. The last figure--in addition to the squaring of dipole turnstile patterns--is a measure of the non-circularity of the pattern--designed to be omni-directional.

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70-cm Dipole and Batwing Turnstiles

Dipole Turnstile

Freq. MHz	**420**	**435**	**450**
Max. Gain dBi	**-0.53**	**-0.76**	**-0.04**
Min. Gain dBi	**-3.45**	**-1.85**	**-3.36**
Gain Difference dB	**2.92**	**1.09**	**3.40**

Batwing Turnstile

Freq. MHz	**420**	**435**	**450**
Max. Gain dBi	**2.41**	**2.57**	**2.83**
Min. Gain dBi	**1.01**	**1.24**	**1.28**
Gain Difference dB	**1.40**	**1.33**	**1.55**

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Although the dipole turnstile shows a more circular pattern at 435 MHz, it degrades toward the band edges to produce about 3 dB differential in the maximum and minimum gain levels. The batwing turnstile has much smoother performance across the band, as we might expect from an antenna design that is inherently broad band. As well, the batwing turnstile averages about 3 dB higher gain across the band than its dipole counterpart, a figure which is consistent with our comparisons in Part 1 between a single dipole and a single batwing.

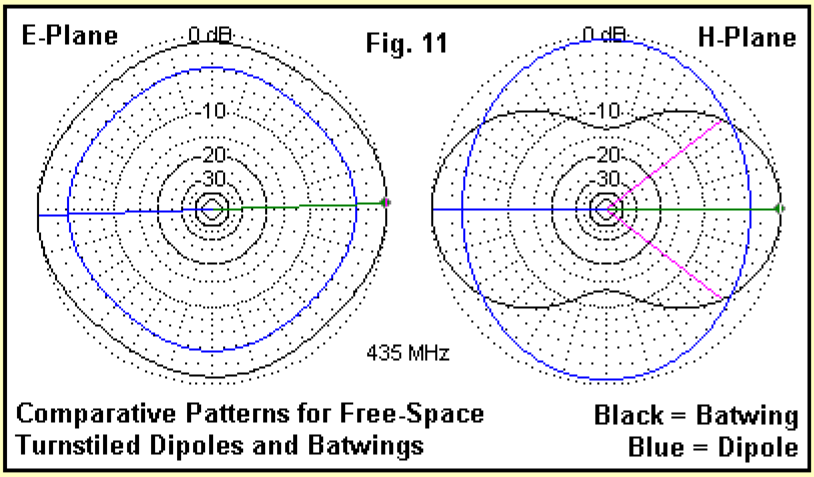

Fig. 11

Comparative Patterns for Free-Space Turnstiled Dipoles and Batwings

Fig. 11 shows comparative E-plane and H-plane patterns at 435 MHz for the two types of turnstile antennas. We can easily see the reason for the higher gain of the batwing version, given the H-plane compression of the high-angle radiation that is typical of the dipole turnstile. However, for a more comprehensive view of pattern distortions, we need to compare E-plane patterns across the band.

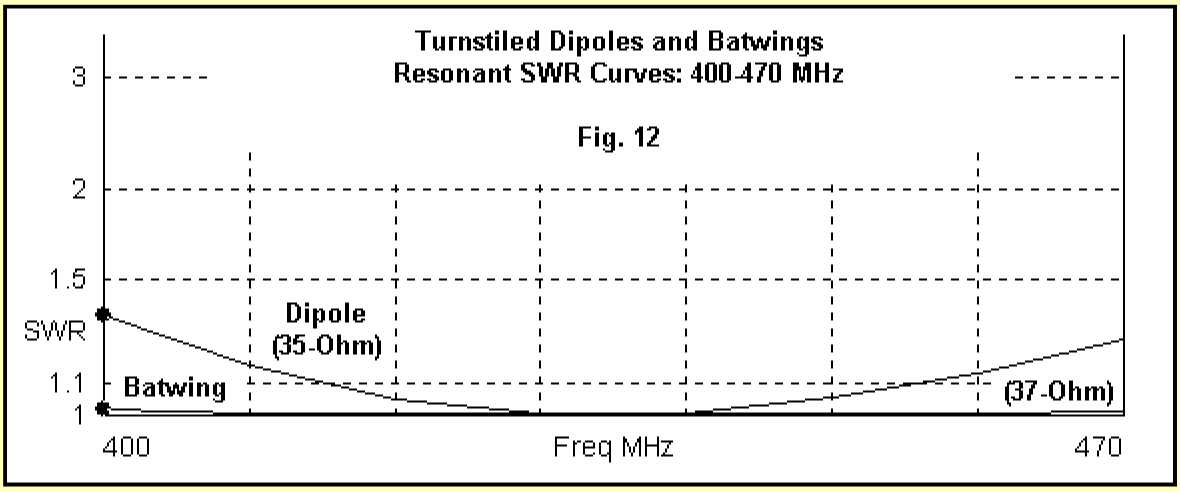
Turnstiled Dipoles and Batwings
Resonant SWR Curves: 400-470 MHz

Fig. 12

Before examining those patterns, let's take a glance at the comparative SWR patterns in **Fig. 12**. A turnstile antenna exhibits a very wide SWR bandwidth. The dipole turnstile shows less than 1.4:1 35-Ohm SWR from 400 to 470 MHz, well beyond the band limits. The turnstiled batwings show a 37-Ohm SWR of under 1.11:1 across the same span, despite the 10-Ohm mismatch between the phase line and the batwing feedpoint impedance.

As I had occasion to note in my *QEX* article, "Some Notes on Turnstile-Antenna Properties" (Mar/Apr, 2002, pp. 35-46), it is never safe to use the SWR curve of a turnstile antenna for any purpose. A turnstile antenna reaches the limits of an acceptable pattern long before it reaches unusable SWR values. **Fig. 13** tells us something of that story.

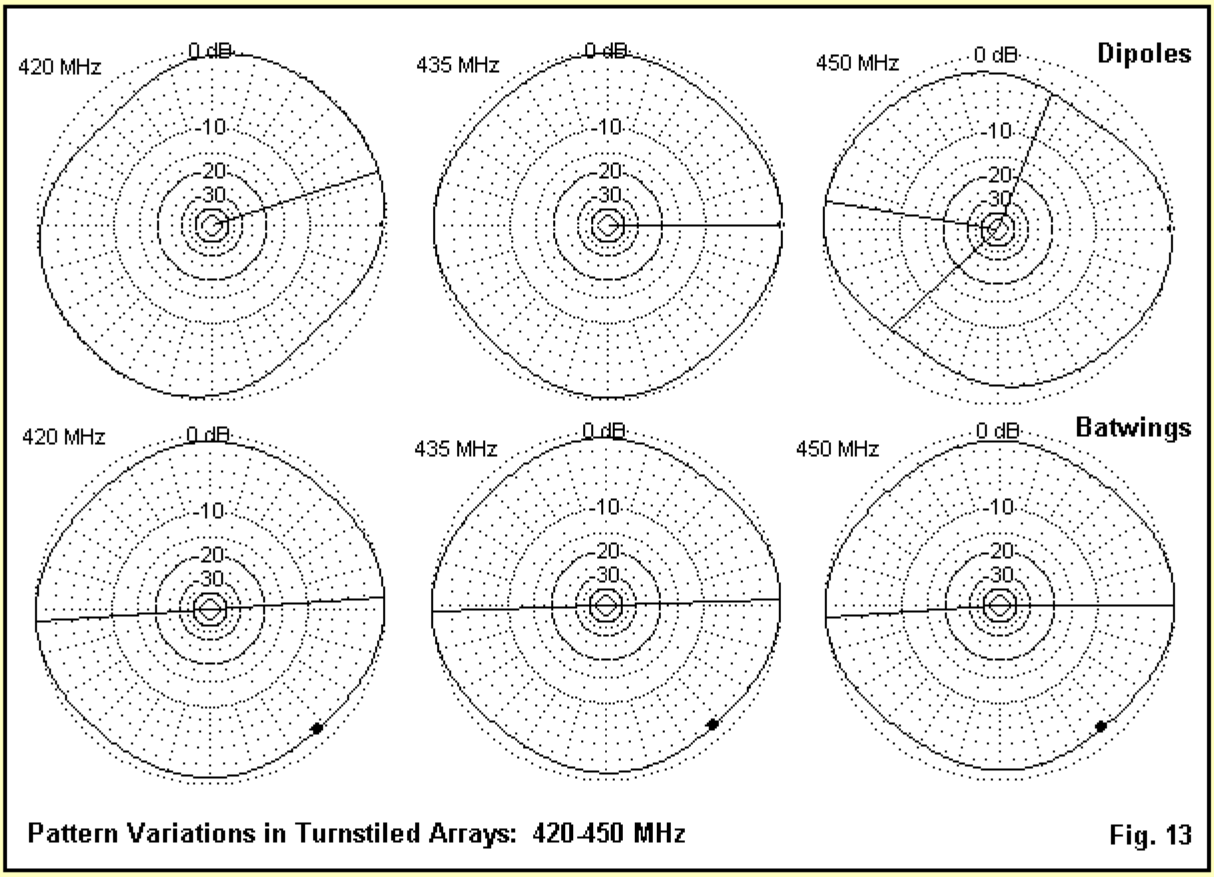
Pattern Variations in Turnstiled Arrays: 420-450 MHz

Fig. 13

Fig. 13 provides the necessary free-space patterns to make a proper evaluation of the adequacy of the two types of turnstiles as omni- directional antennas for all of the 70-cm band. The combined patterns in **Fig. 11** appear as separate patterns in the center column of **Fig. 13**. The effects of the closer line match are evident in the peaks of the dipole pattern. Equally apparent are the pattern degradations at 420 and 450 MHz. No longer are these patterns close to a flatted circle. Instead, they form distorted ovals with high front-to-side differentials. On the other hand, the batwing turnstile maintains its overall pattern shape across the entire band.

How well the batwing turnstile performs over ground appears in the following table. As we have done throughout these notes, we placed the center of the batwing 10 wavelengths (271.33" or 22.61') above average ground.

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Performance of a Batwing Turnstile 10 WL Above Ground

Freq. MHz	**420**	**435**	**450**
Gain dBi	**8.33**	**8.51**	**8.78**
TO Angle degrees	**1.5**	**1.4**	**1.4**
Feed Z: R+/-jX Ohms	**37.1 + j 0.1**	**37.2 + j 0.0**	**37.2 + j 0.0**
37-Ohm SWR	**1.004**	**1.006**	**1.006**

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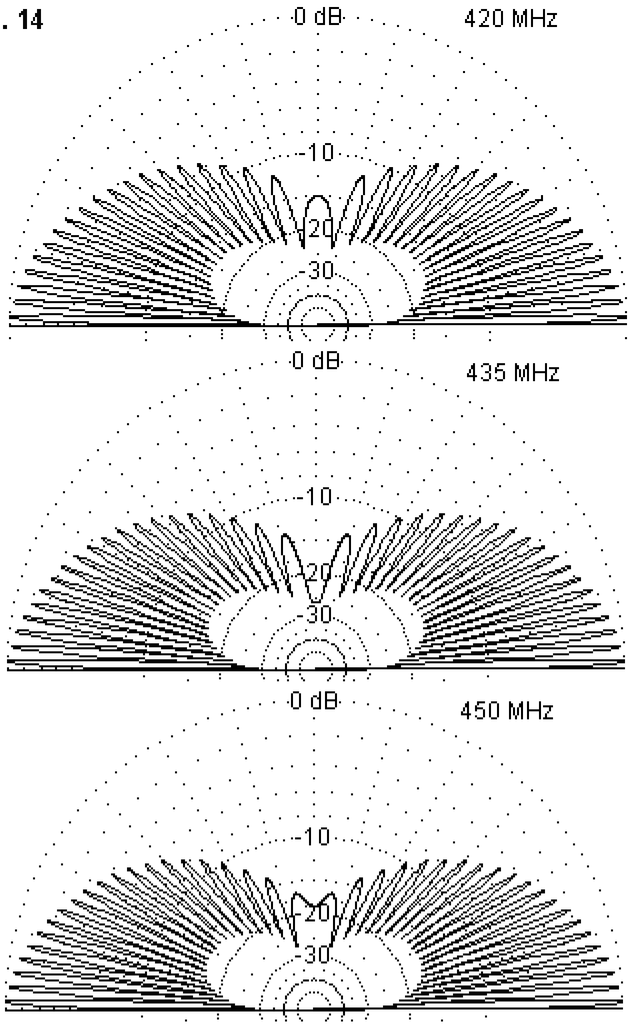
The gain differential across the band is only 0.45 dB, and, of course, the 37-Ohm SWR is negligible. Variables of weather that may affect the antenna tuning have no significant effects on the performance of the antenna.

Fig. 14



Elevation Patterns: Turnstiled Batwings
10 WL Above Average Ground

Fig. 14 shows the elevation patterns of the antenna. In shape, these patterns are virtually identical to those shown for a single batwing along its line of maximum bi-directional gain. The slight changes in the radiation lobes near the zenith angle are evident as we move across the band.

A common practice is to stack turnstiles in an effort to achieve more omni-directional gain. Stacking batwing arrays is also common. Therefore, I modeled two vertically stack turnstiled batwings with 1 wavelength center-to-center spacing. One caution derived from the study of single batwings is the fact that the impedance changes slightly for each batwing in a stack relative to the impedance of an isolated batwing. To see if the changes made any difference, I left the 6.4" phase line used with the single batwing turnstile antenna. The free-space pattern results appear in the following table.

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70-cm Batwing Turnstiles: Free-Space 2-Stack

Freq. MHz	**420**	**435**	**450**
Max. Gain dBi	**5.45**	**5.65**	**6.08**
Min. Gain dBi	**4.42**	**4.53**	**4.40**
Gain Difference dB	**1.03**	**1.12**	**1.68**

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The seemingly improve performance derives in part from the direction in which the impedance changes when two batwings are in a 1-wavelength stack. It decreases. Hence, the 70-Ohm phase line is a better match for the array than when used with a single turnstiled batwing. As a result, the pattern distortion is lower for two-thirds of the band. Changing the phase line length would have permitted me to optimize the pattern, or at least center the distortion level.

The desirability of optimizing the phase line appears in the following table of values taken with the stacked batwing turnstiles 10 and 11 wavelengths above average ground.

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Performance of a Batwing Turnstile 2-Stack 10 WL Above Ground

Freq. MHz	**420**	**435**	**450**
Gain dBi	**11.31**	**11.57**	**12.02**
TO Angle degrees	**1.4**	**1.3**	**1.3**
Feed Z: R+/-jX Ohms	**37.2 + j 0.0**	**37.4 + j 0.0**	**37.5 + j 0.2**
37-Ohm SWR	**1.004**	**1.010**	**1.014**

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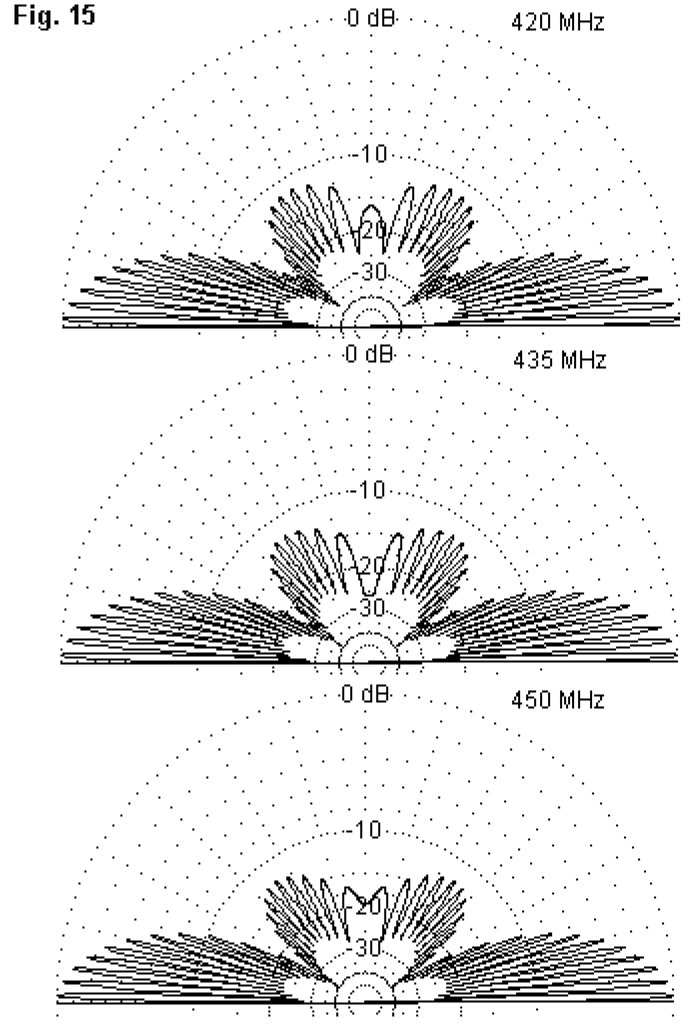
The trend that we saw in the free-space E-plane gain readings re-appears in the performance table for the batwing turnstile stack above ground. Although slight, the degradation of the nearly ideal readings appears in the upper portion of the band. Between 420 and 435 MHz, we see only a 0.26 dB change of gain, but between 435 and 450 MHz, the gain rises 0.45 dB. The 37-Ohm SWR curve shows a comparable set of changes. Even a turnstile design as promising as the batwing array can use careful optimizing.

Fig. 15



Elevation Patterns: 2-Stack of Turnstiled Batwings 10 WL Above Average Ground

Fig. 15 shows the elevation patterns across the 70-cm band for the stack of turnstiled batwings. Once more, the shape of these patterns is almost identical to the shape of the elevation patterns for single batwings stacked above ground, when we take those patterns along the axis of maximum gain. Nonetheless, the overall omni-directional gain of the turnstiled batwings is well under that of the bi-directional single array, as is true whenever we turnstile a horizontal antenna to achieve omni-directional performance.

Given the fact that the single and turnstiled batwing results are comparable at every point, we can repeat a caution mentioned when we stacked 4 single batwings. The impact of mutual coupling will be greater on the inner antennas of the stack than on the outer antennas. Hence, preservation of an omni-directional pattern may require careful attention to the phase line or whatever other means are used to effect phasing in order to avoid pattern distortions. The SWR curve of the composite phased array may not itself give much clue. Hence, careful design analysis, normally via good modeling practices, may be the best pre-construction and pre-measurement procedure to achieve as pure an omni-directional pattern as possible.

Conclusion: Not Quite Yet

Although we have examined the basic properties and the two main applications of the batwing, we are not quite done with the antenna. Our model uses no common mast, a feature of many batwing antennas. That fact leaves a number of unanswered questions. As well, the changes in performance that we observed in Part 1 when we arbitrarily changed the wire diameter raises further questions. It may well be that the batwing is susceptible to some modeling alternatives that may give us a few added insights into the antenna. So, let's spend one more session on our batwing notes.

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