Notes on HF Discone Antennas

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The discone antenna is a broadband basic antenna originally designed for VHF-UHF service. Indeed, it is a staple for upper-range scanning receivers. Developed during WWII by A. G. Kandoian, and brought to the attention of radio amateurs in the later 1940s, the following years saw conversions of the design to HF use. Amateurs have used it from 160 meters up through 10 meters, although the operating passband for any single implementation is limited to about a 2.5:1 frequency range.

Even though the antenna is quite basic in concept, its shape seems to elicit strange reactions from newer amateurs. The reactions run from simple quizzical looks to occasional bizarre explanations of its operation. In these notes we shall look at the antenna with a series of inquiries. We shall start by putting the antenna into its proper class. Then we shall turn to questions of modeling the antenna, sorting out what we can glean from models and what we cannot. Since operating bandwidth is the most pressing question in many minds, we shall next look at that matter, followed by questions of performance. The performance facets of HF versions of the antenna over ground are perhaps the most important, since that is the environment in which we must use the antenna, if we choose to build one. To set a proper framework for judgment by the prospective builder, we shall look at a few other antenna designs that may be relevant.

In order to focus our attention on the properties of the HF discone, we shall confine our attention to creating one to cover the upper HF set of amateur allocations from 14 to 30 MHz. In the main—with a few exceptions—we shall use AWG #12 wires for the structure. AWG #12 wire has a diameter of 0.0808", just larger than the European counterpart common wire that is 2-mm in diameter.

Classifying the Discone

The discone antenna label is a concatenation of "disc" and "cone." The original versions of the antenna consisted of a lower conical section (point upward) topped by a solid disc. Between the center of the disc and the point of the cone we create a small space with a wire to which we attach a feedline, one side to the disc and the other to the cone. The feedpoint impedance of early versions proved to be compatible with the impedance of common coaxial cables (50-75-Ω). By routing the cable down the center of the cone—along a supporting mast—we simplified feeding the antenna in most situations.

To understand what the antenna really is, we should following the progression of antennas sketched in **Fig. 1**. On the left, we have a common center-fed dipole. Except for the widest amateur bands, simple dipoles have operating bandwidths that cover most of the amateur bands. However, for increased bandwidth, we may construct biconical dipoles, shown next to the linear version. A biconical dipole has some interesting properties due to its element shape. The conical half elements tend to yield a broad impedance band that extends well beyond the range of a linear element. In addition, the SWR track of the antenna tends to show two low points, one near each end of the usable passband. These properties of the biconical shape have been known since the earliest days of antenna engineering, but came into prominence with the emergence of special needs for broadband EMI investigations, especially in the VHF-UHF range. Nonetheless, the biconical dipole remains simply a dipole.

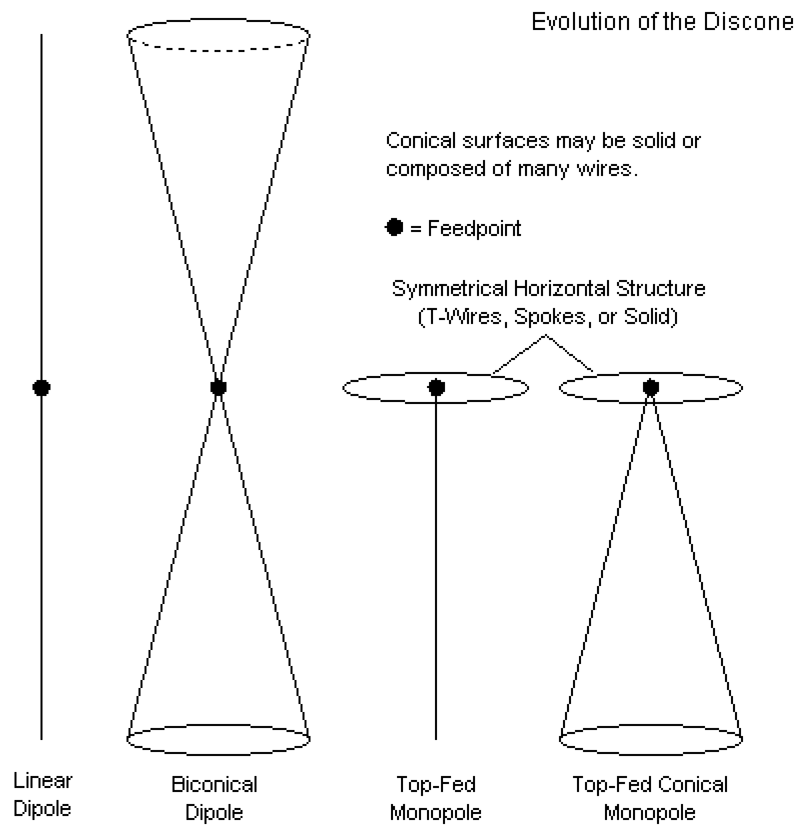


Fig. 1

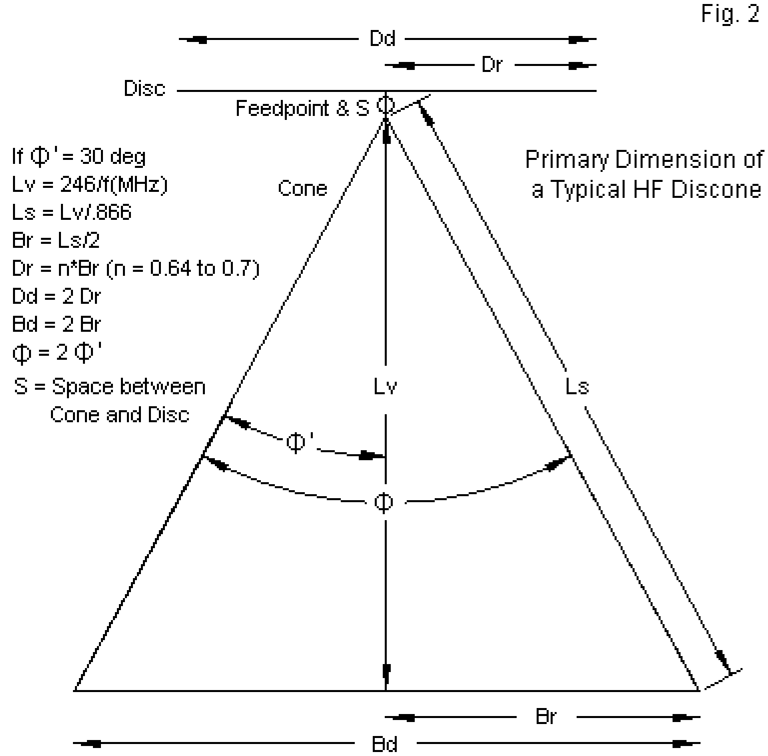
We may remove one leg of a dipole to form a monopole under the condition that we replace the missing leg with a symmetrical or nearly symmetrical structure. The common elevated monopole with 4 radials is a primary example of the technique. The antenna is a monopole to the extent that effective radiation occurs only from the vertical leg of the structure. In principle, however, the antenna becomes an asymmetrical dipole in terms of the current on the various parts of the antenna. If we have a single vertical element and 4 radial legs, then the current next to the feedpoint at the junction on the vertical leg is also present on each of the radial legs at ¼ the value. If the radial legs are truly symmetrical, then the radiation from them is virtually self-canceling. The radial-leg structure can vary from a few linear radials to many such radials to a solid disc. As the number of radials increase, their necessary length to create feedpoint resonance with a given vertical leg decreases. Somewhere in the range of 60 radials, the diameter of the radial structure is the same as for a solid disc.

When elevated above ground, a vertical monopole with radials will operate equally well with the radial set at the top or at the bottom, so long as the feedpoint is at the junction of the vertical and the horizontal portions of the antenna. Top-fed T structures are sometimes used in both amateur and professional service. T-wires are merely a simplified version of the symmetrical radial or disc system.

Finally, to broaden the operating passband of the top-fed monopole, we may replace the linear vertical leg with a conical section, as shown at the right in **Fig. 1**. Essentially, a discone is a top-fed conical monopole, a brother to the standard linear monopole. Like the biconical dipole, the discone will show a broad SWR pattern with its lowest values near the low end and near the high end of the operating range.

Properly classifying the discone antenna removes some of the initial mystery from our understanding of its operating principles. However, it does not tell us how to build a successful HF discone. Most of the dimensional information on the discone derives ultimately from early VHF-UHF studies of the antenna. The most complete set of equations available to amateurs appear in a 1975 *QST* article by Jack Belrose, VE2CV. (See the short reference list at the end for some useful discone articles.) Perhaps the most significant dimension of the discone is the angle Φ between the outer walls of the cone. However, most implementations of the discone use a convenient value for this angle: 60°. Hence, Φ' (1/2 of Φ) is an equally convenient 30°, a value that simplifies calculations, both for construction and for modeling the antenna. If we focus on this value for Φ', we obtain the set of dimensional relationships shown in **Fig. 2** for an HF discone measured in feet. You may adjust the constant in the equation for Lv to obtain the measurements in other units.

Fig. 2



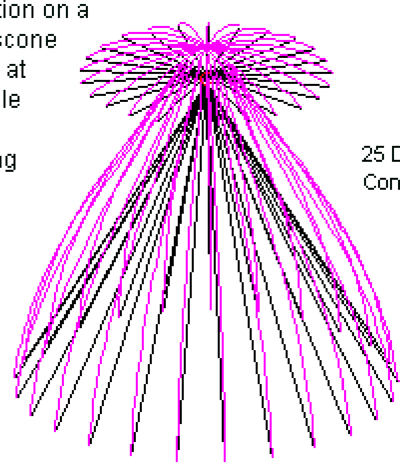
Because we are not working with a linear dipole or monopole, we are not looking for a set of equations that yields a self-resonant antenna at one frequency. Belrose likened the antenna to a high-pass filter with a low-frequency cut off. The analogy is apt and defines the reason for using the vertical length, Lv, as the dimension that should be about an electrical quarter wavelength at the lowest operating frequency. As well, the original equations for the discone presumed a solid-surface conical section (and disc). The use of a wire framework to simulate the surface is imperfect and the lower limit of the passband decreases as we add more wires.

Note that the disc diameter is only about 0.64 to 0.7 the diameter of the open end of the cone. Because we may roughly calculate the disc size based on the largest diameter of the cone misleads newcomers into believing that there is an intrinsic relationship between the two values. However, the relationship is more circuitous. Suppose that we construct a simple monopole with 4 radials such that the current in each radial is ¼ the current in the vertical element. The resonant feedpoint impedance of such a quasi-perfect monopole antenna will be in the 20-25-Ω range. To obtain a 50-Ω impedance without altering the angle of the radials with respect to the vertical leg, we must rearrange the element lengths. Either we may lengthen the radials and shorten the vertical, or we may lengthen the vertical and shorten the radials. In effect, we are creating an off-center-fed dipole structure with the lengths determined by the feedpoint impedance goal. The same reasoning applies to the discone. The disc radius is shorter than the value of Lv or of Ls (the sloping length of the cone) due to wishing for a certain feedpoint impedance. Because the disc interacts with the sides of the cone, the actual behavior of the discone differs from the simple monopole situation.

Modeling Issues

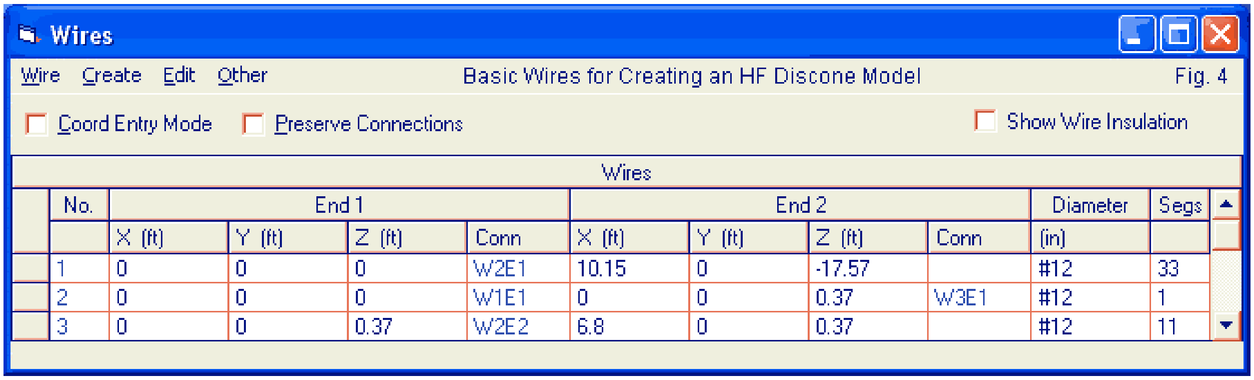
For a discone designed to operate from 14 to 30 MHz, we shall use the following dimensions in models. Lv = 17.57'. Ls = 20.29'. Br = 10.15'. Dr normally will be 6.8' (0.67 of Br). We shall use mainly 25 wires in the cone and in the disc, although we shall look at the effect of increasing the wire count to 45 wires in each part of the structure. Most of the models will not employ a perimeter wire for either the disc or the cone, although builders vary in their construction practices in this regard.

Fig. 3 shows the current distribution along the wires of a typical discone model at 21 MHz, about the middle of the operating range. Although the complexity of the structure may obscure some of the fine detail, we can see that the discone current magnitude distribution follows the basic pattern that we would find in a simple monopole with a minimum number of radials.



NEC models of discones are subject to some limitations. Many models of VHF-UHF discones tend to fail because the structures use relatively fat wires (as a fraction of a wavelength) coming together at angles that result in wire interpenetrations at the cone's point. At HF, the use of relatively thin wire obviates that problem. However, the spacing (S) between the cone's point and the center of the disc remains a problem. In practice, this distance may range from a very small measure to perhaps 2', depending on the frequency of operation.

The segment length in the primary models falls between 0.5' and 0.6' per segment. At this segment length, models may range from 1100 to 2000 segments, depending on the number of wires used in the cone and the disc. Shorter segments would tend to increase the segment count per model to yield unwieldy model run times, especially in performance sweeps. The segment length in the main wires allows only 1 segment for the wire connecting the cone to the disk. NEC recommends that the segments on either side of the source segment be equal in length to each other and to the source segment. However, the complex structure does not yield the most ideal average gain test (AGT) score if we make the source wire (and hence the disc-to-cone separation) equal in length to the wire segments. Hence, I have simply adjusted the source wire length and the disc-to-cone separation to yield the best AGT score and therefore the most reliable model values as measured internally to the model. A value of about 0.37' turns out to be very close to optimal for the models. In fact, **Fig. 4** shows a simplified wire table for a discone model. Only one wire appears for the disc and for the cone, but you may assume an additional 24 or 44 wires for each structure, depending on the model used.

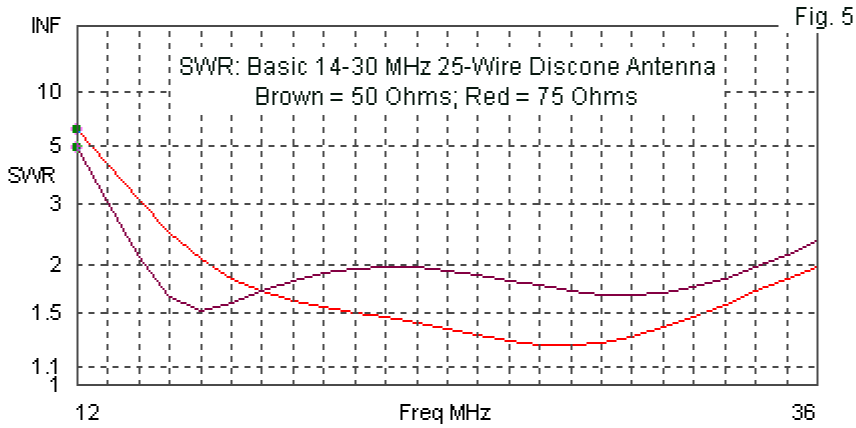


No.	End 1 X (ft)	End 1 Y (ft)	End 1 Z (ft)	End 1 Conn	End 2 X (ft)	End 2 Y (ft)	End 2 Z (ft)	End 2 Conn	Diameter (in)	Segs
1	0	0	0	W2E1	10.15	0	-17.57		#12	33
2	0	0	0	W1E1	0	0	0.37	W3E1	#12	1
3	0	0	0.37	W2E2	6.8	0	0.37		#12	11

Because the source wire length and hence the separation of the disc and the cone result from modeling considerations, the physical distance between the two antenna sections may not correspond with the model. Therefore, the model will have some limitations relative to any physical implementation of a discone. The primary limitation will involve the exact values of the reported impedances. Although the values will be reliable relative to the model, they may not be fully reliable relative to a physical implementation of the design. For the model shown, the main antenna segments are about 0.615' long, compared to the source segment's 0.37' length. For the range of models used, AGT values fall between 0.990 and 1.010. The range allows a comparison of impedance values among variations on a design, but the absolute values of the impedances may not be perfectly accurate. Since our general goal is to show trends in performance among variations, the possible lack of model-to-implementation correlation should create no significant difficulties.

The Operating Passband

Amateur radio operators define an operating passband for basic antennas in terms of the 2:1 SWR ratio. For the discone, we may use a reference impedance of 50 Ω, on the presumption of wishing to operate the antenna with a direct connection between the antenna source point and a coaxial cable feedline. We shall look at a number of variations on the basic model, described earlier as a 25-wire AWG #12 version of the antenna. Sweeps will cover from 12 to 36 MHz in 1-MHz increments to show both the relatively sharp cut-off at the lower end of the operating passband and the shallower rise of impedance at the high end. For this basic model, with a disc diameter that is 0.67 the diameter of the open end of the cone, **Fig. 5** shows the 50-Ω and 75-Ω SWR curves. The 14-MHz 50-Ω SWR is slightly above the 2:1 usual amateur limit, suggesting that for this particular model, one might like to increase dimensions proportionately by a small amount.



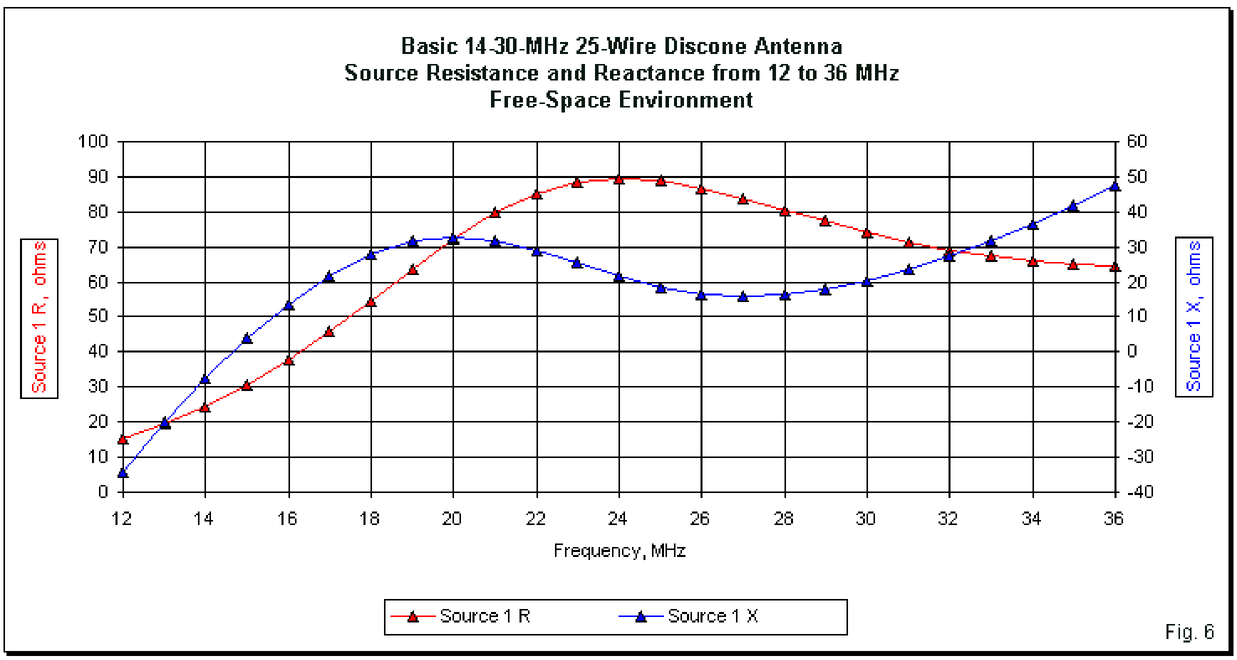
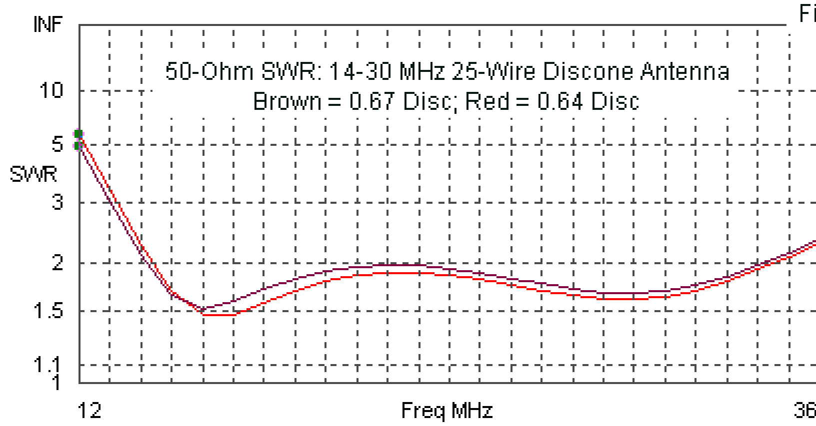


Fig. 6 provides curves for the resistance and reactance across the passband. Note that the reactance is always inductive for this model. It almost reaches zero at 12 MHz, but the source resistance at this frequency is too low to yield a low SWR. The source resistance peaks about mid-band (about 24 MHz) and then declines. However, the reactance describes a more complex curve. The result is a 50-Ω SWR curve with two minimum-value regions, but a 75-Ω curve with only a single minimum region.

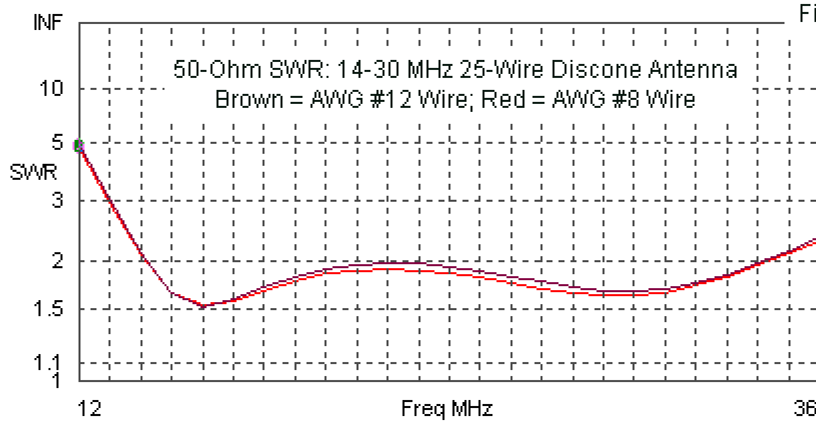
We may reduce the mid-band (21-MHz) resistance and reactance by reducing the disc diameter to about 6.5' (about 0.64 of the open-cone diameter). However, mid-band values can be illusory. **Fig. 7** overlays the 50-Ω SWR curves for the two sizes of disc that we have so far examined, one that is 0.64 time the cone diameter, the other that is 0.67 times the cone diameter. The effect of reducing the disc diameter is essentially to shorten the overall antenna if we were to treat it as a dipole. The shorter overall length results in an SWR curve that moves upward in frequency without changing its essential shape. Therefore, an alternative strategy to increasing the overall dimensions of the array might be to simply increase the disc diameter rather than reducing it. However, to do so would increase the general level of the impedance. As the figure shows, the smaller disc of the two shown results in impedance values slightly closer—overall—to 50 Ω.

Fig. 7

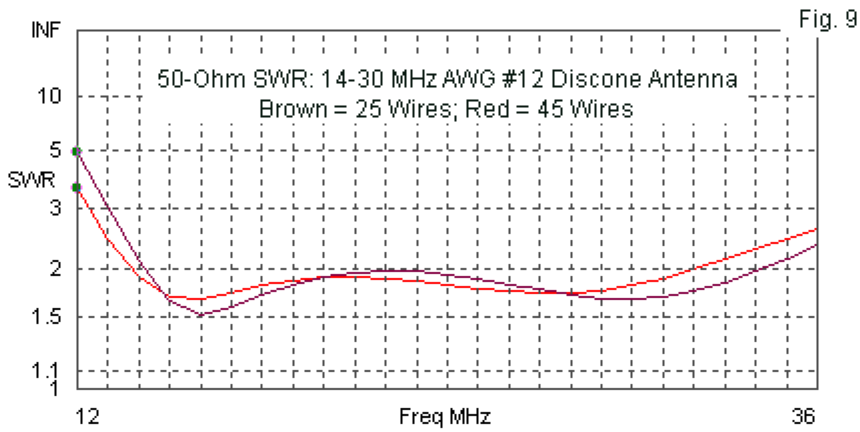


The fundamental equations for creating a discone antenna rested on the use of solid surfaces for both the disc and the cone. The basic model of the discone uses 25 AWG #12 wires. One way to improve the solidity of both surfaces is to increase the wire size. As a sample of the effect, we may replace all of the wires with AWG #8 wire. Its 0.1285" diameter is about 1.6 times fatter than the #12. **Fig. 8** shows what happens to the 50-Ω SWR passband as we use this method of solidifying the surfaces with increasing the wire count. The net effect is to slightly reduce the feedpoint resistance and reactance across the passband, resulting in a curve that is very slightly closer to ideal SWR values across the operating passband. Any shift in the passband limits is visually indistinct. Very likely, this tactic is not worth the extra weight produced by the fatter wires.

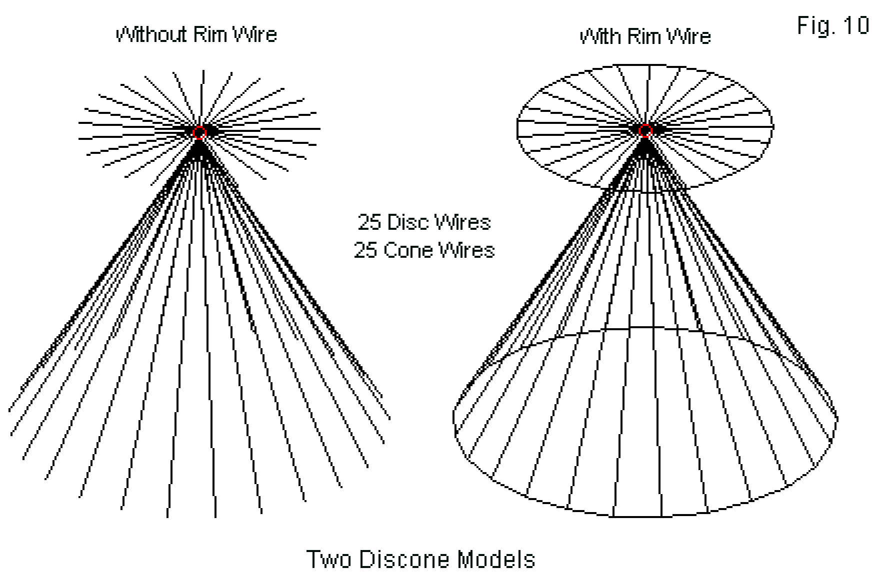
Fig. 8



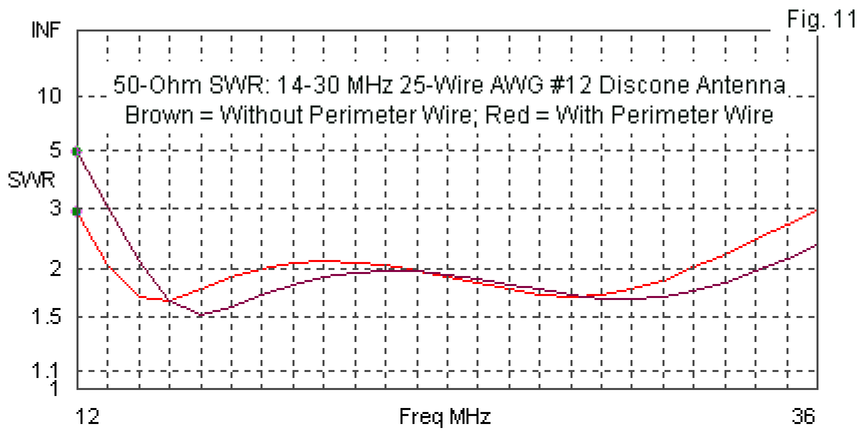
If we are going to increase the weight of the array, we might have more luck simply increasing the number of AWG #12 wires. Let's increase the count in both the disc and the cone to 45. **Fig. 9** shows what happens. Nearly doubling the number of wires closes the surfaces to a higher degree than fattening the wires. As a result, the overall passband reduces the frequency of both the upper and lower limits. The upper limits is now about 32 MHz, while the lower limit is below 14 MHz, with a shallower upswing in the SWR blow that frequency. With 45 AWG #12 wires, the total structure is actually lighter than the 25-wire AWG #8 version.



A final tactic, short of altering the fundamental antenna dimensions, is to add perimeter wires to the open end of the cone and to the disc. **Fig. 10** shows the outline of the models without and with perimeter wires, using the 25- AWG #12 structure as a basis. Besides creating optical conundrums, as one's eyes shift from one possible perspective to the other, the outlines show an important fact about the antenna dimensions. The effective length of the individual wires in both the disc and the cone increase by approximately half the length of any perimeter wire connecting adjacent radial wires.



Of all the tactical moves that we have made, adding a rim or perimeter wire to both the disk and the cone have the most extreme effect. As shown in **Fig. 11**, the perimeter wire is equivalent to increasing the dimensions of both parts of the antenna. The lower minimum region for the 50-Ω SWR values drops by over a full MHz, with a proportional drop to the upper limit of the passband. In addition, just as we saw when increasing the wire count to 45, the overall level of the source resistance increases, although the reactance values tend to remain stable. The net effect is to push the middle operating range to SWR values slightly higher than the desired 2:1 limit. Adding the rim wires does change the interactions between antenna sections. However, the models do not clearly identify which interactions occasion the rise in the feedpoint resistance.



These sample comparative SWR curves provide insight into the general trends in the passband properties of HF discone antennas with sundry variations on the structure. Due to limitations in the modeling of the discone antenna, the curves do not provide necessarily precise values, but the general trends are inherent in the structures. Perhaps the one lesson of the exercise is that it may be better to error in dimensional calculations on the side of a frequency lower than the lowest operating frequency, since the upper end of the operating curve has ample margin for shrinkage above the highest frequency in a 2:1 operating frequency range.

Other Performance Data

Although small variations in structure make a difference to the operating passband with respect to the feedpoint impedance, they have virtually no effect upon the pattern shape or gain of the antenna. The differences amount to those we might encounter by changing the length of a 20-meter dipole a few inches; that is, they are negligible. The comparison is apt when we consider that the discone is as basic antenna as a dipole or an elevated monopole with symmetrical radials.

The SWR curves employed a free-space environment (as well as lossless wire to facilitate accurate AGT values). I shall assume that the 14-30-MHz 25-wire AWG #12 discone is for service on the upper HF amateur bands. **Table 1** lists the modeled performance values for the center of each band.

Table 1. Free-space performance of the AWG #12 25-wire discone

Frequency MHz	Gain dBi	Tilt Angle degrees	Feedpoint Z R +/- jX Ω
14.175	1.71	0	25.5 – j 5.4
18.118	1.70	-6	55.6 + j28.6
21.225	1.72	-10	81.1 + j31.3
24.95	1.84	-17	89.0 + j18.7
28.5	2.14	-26	79.0 + j16.9

The gain values are consistent with those we might obtain from an elevated ¼-λ monopole. The feedpoint impedance values coincide with selected points along the curves in **Fig. 6**. The only values requiring further explanation are the Tilt Angle numbers. **Fig. 12** provides a gallery of free-space H-plane patterns that illustrate the tile angle of the high-gain bearing.

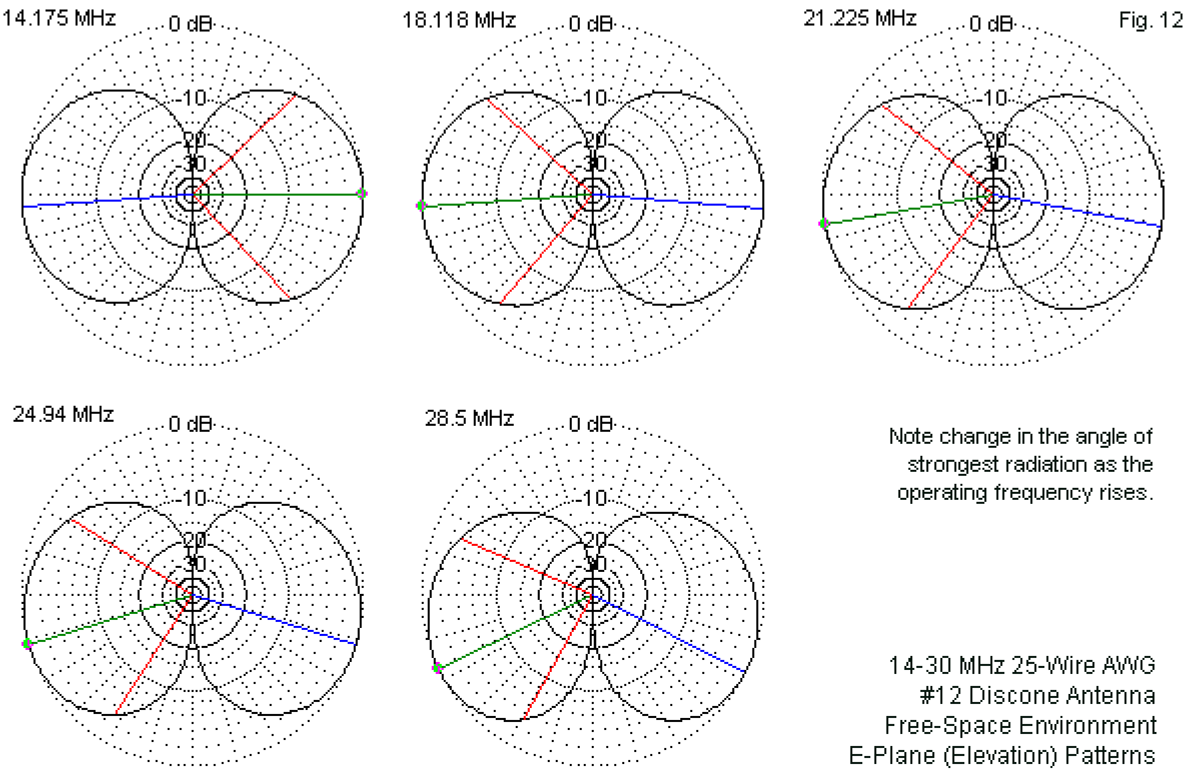


Fig. 12

As the discone's frequency of operation increases, the pattern tilts downward, defined as the direction away from the top disc. As the operating frequency increases, the disk radius become as larger fraction of a wavelength. Its interactive effect upon the overall pattern is reflective in the sense of bending the pattern away from its surface. How much effect it has on the operational patterns of the HF discone over ground will require further work to evaluate.

The first step in this process is to examine the patterns of the discone over ground. For this task, I have selected three top heights: about 25', 35', and 45'. The actual heights are 0.37' higher. The corresponding bottom heights above ground are 7.43', 17.43', and 17.43'. **Fig. 13** outlines the three set-ups to provide perspective on the array size vs. its height above ground. The blue line is a stand-in for a substantial support system.

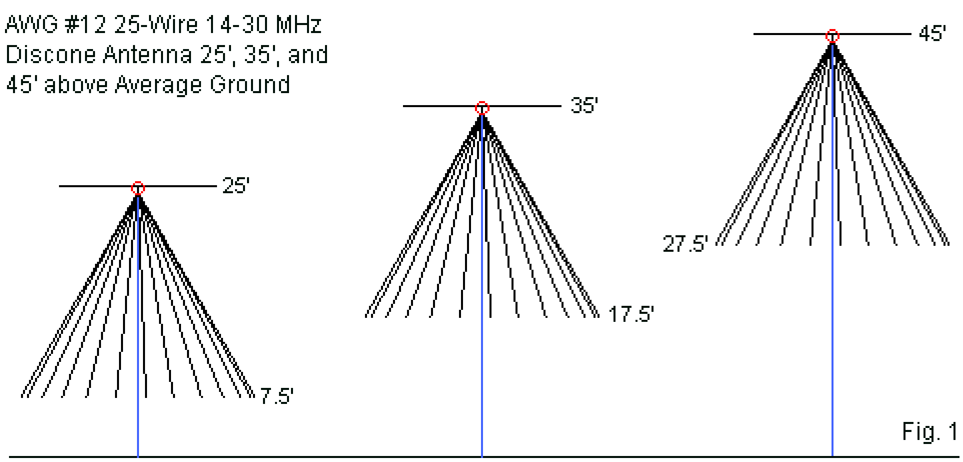


Fig. 13

Table 2 provides the band-by-band data for each height. The gain and take-off (TO) angle data have two entries, one for maximum gain and the other for the gain of the lowest detectable lobe. The second pair of columns only has entries when they differ from the values in the first column pair. The table records the modeled feedpoint impedance data in order to provide for comparisons both with the corresponding information in **Table 1** and among the three heights listed in the table. All values are for average ground (conductivity 0.005 S/m, permittivity 13).

Table 2. Performance of the AWG #12 25-wire discone at three top heights above average ground

Frequency MHz	Max. Gain dBi	TO Angle degrees	Low-Lobe Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ω
A. 25’					
14.175	0.41	19			26.2 – j10.2
18.118	0.64	16			48.8 + j26.1
21.225	0.63	15			75.3 + j38.5
24,94	0.38	14			96.7 + j24.9
28.5	-0.07	13			85.6 + j10.9
B. 35’					
14.175	0.69	15			23.4 – j 5.6
18.118	0.62	13			56.2 + j31.7
21.225	1.24	46	0.54	12	85.0 + j30.1
24,94	1.61	40	0.56	11	86.4 + j15.8
28.5	1.51	36	0.71	10	76.8 + j19.7
C. 45’					
14.175	1.03	48	0.54	13	25.5 – j 4.2
18.118	2.14	40	0.85	12	56.7 + j27.3
21.225	2.42	35	1.32	11	79.1 + j30.8
24,94	2.25	30	1.75	10	90.3 + j20.4
28.5	1.87	9	0.71		79.6 + j15.1

Those unfamiliar with the development of lobes in vertical antennas at various heights above ground may find the table somewhat mystifying. Therefore, **Fig. 14**, **15**, and **16** provide galleries of elevation patterns for the antennas at each height and frequency. The plots allow you to correlate the data to the pattern shapes involved.

The pattern shapes are largely functions of three interactive factors. First is the height of the antenna (normally measured at the feedpoint, that is, the region of highest current) above ground as a fraction of a wavelength. We may raise the antenna height physically or introduce a second factor: raising the operating frequency. As we do either, we find that an initial single elevation lobe develops into a two-lobe structure. Further increases in height eventually yield a condition in which the second elevation lobe is stronger than the lowest lobe. That condition produces the need to supply additional information on the lowest lobe to permit an evaluation of potential performance at low elevation angles that favor HF skip-communications.

The ground is the third factor. As operating frequency increases for a given antenna height (as a fraction of a wavelength), ground losses also increase. Increasing the antenna height goes some distance in counteracting this final condition. Therefore, we shall find differences in the reported gain of the antenna at different heights and frequencies, even though the pattern shapes and TO angles may be similar.

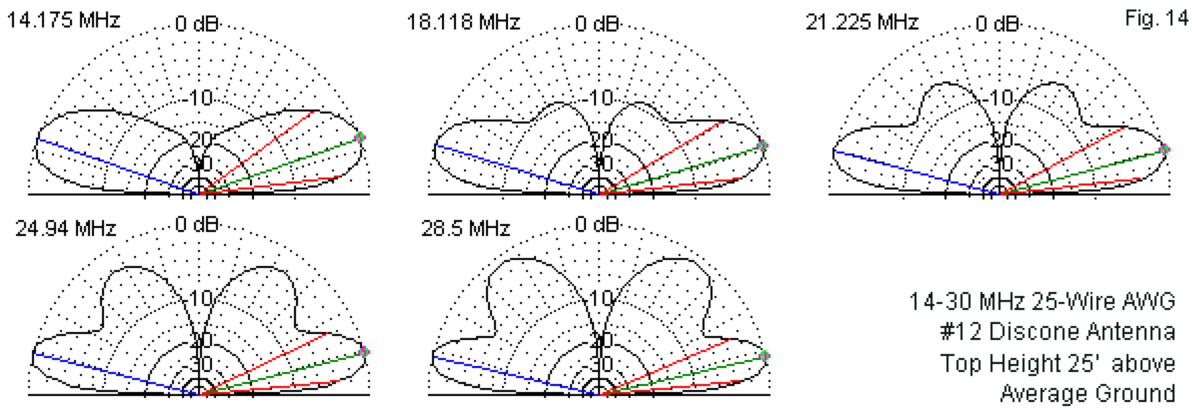


Fig. 14

14-30 MHz 25-Wire AWG
#12 Discone Antenna
Top Height 25' above
Average Ground

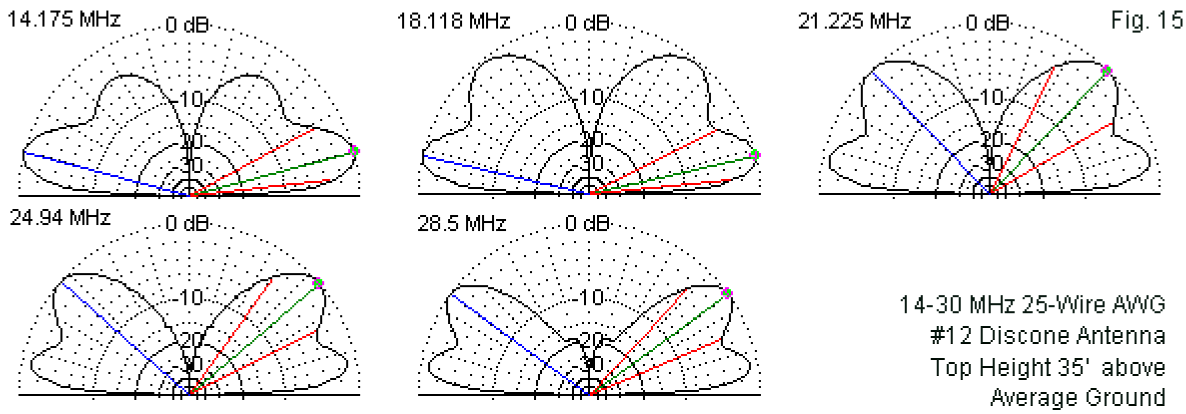


Fig. 15

14-30 MHz 25-Wire AWG
#12 Discone Antenna
Top Height 35' above
Average Ground

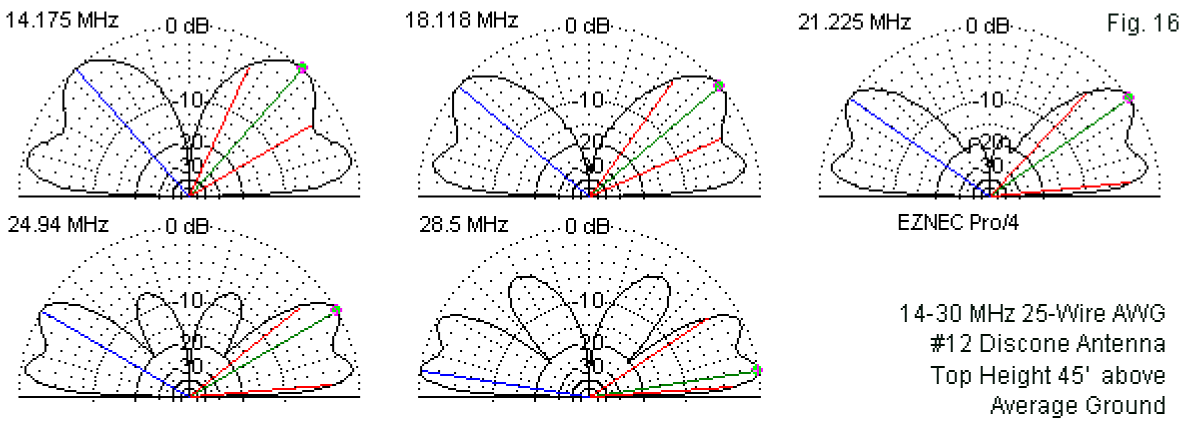


Fig. 16

14-30 MHz 25-Wire AWG
#12 Discone Antenna
Top Height 45' above
Average Ground

The function of the tables and pattern galleries is not to reach judgmental conclusions about the subject HF discone antenna. Rather, the goal is to provide data that may allow a prospective builder to decide in advance whether any of the pattern sets are usable for projected communications objectives and which height may be best among the possibilities.

Comparative Possibilities

Constructing an HF discone antenna requires a considerable amount of material, planning, and care, whatever the final dimensions. Before committing to such a project, the potential user should be aware of how the anticipated performance compares with other candidates for the job of covering 20 through 10 meters. We shall look at only 3 possibilities, and then only generically. Actual implementations—whether homemade or commercial—may vary in performance for a large number of reasons. **Fig. 17** shows the range of our candidates.

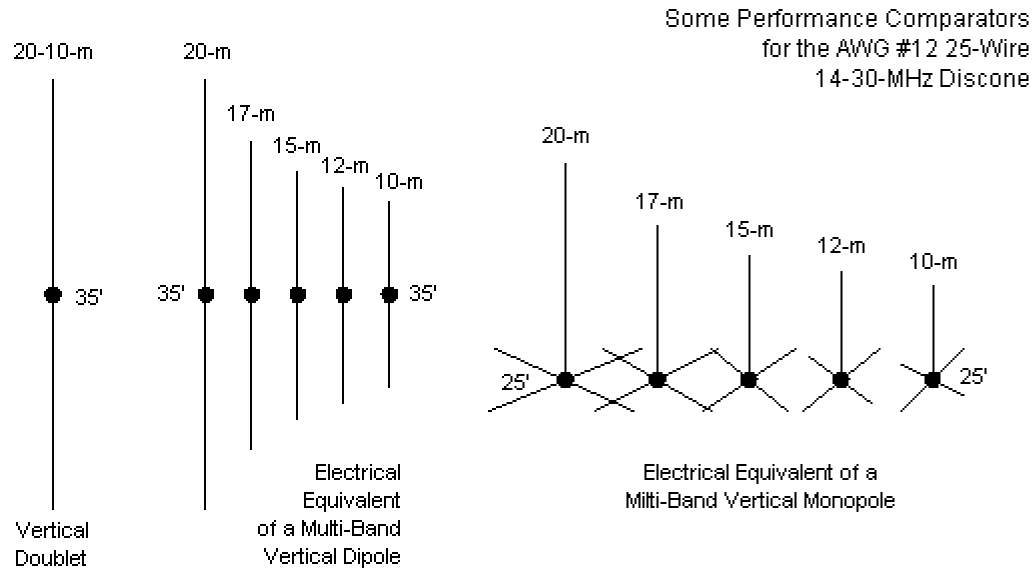


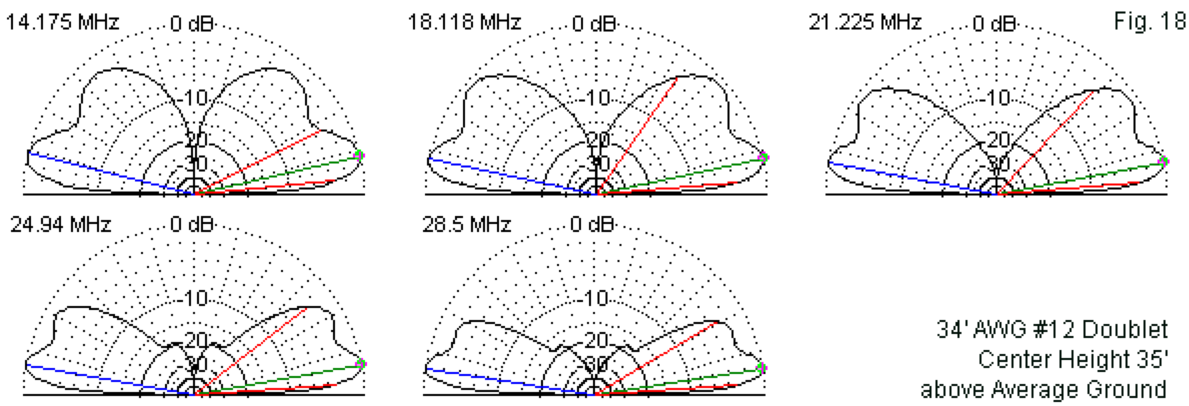
Fig. 17

We shall look at a very simple structure, a center-fed doublet just long enough to be self-resonant in the 20-meter band. Next, we shall explore multi-band ½-λ dipoles, that is, antennas that are self-resonant on each of the upper HF bands by virtue of using stubs and other devices to obtain dipole performance. Finally, we shall look at ¼-λ multi-band monopoles. In practice, these antennas are usually equipped with traps to obtain 1/4-λ performance as measured from the feedpoint upward along the vertical element. In both latter cases, we shall use individual antenna models to estimate the likely performance, ignoring any losses and other aberrations created by the means of obtaining resonant operation on each band. The results will not be the performance obtainable from one or another commercial antenna, but only a ballpark estimate.

The Vertical Doublet: Let's set up a center-fed vertical doublet that is just long enough to count as a ½-λ dipole on 20 meters. 34' of AWG #12 copper wire will do the job. The center feedpoint will be at the 35' level, equal to the level of the feedpoint for the middle-level discone antenna. The antenna wire will therefore extend from 18' above ground to a top height of 52'. **Table 3** provides the modeling data for this antenna.

Table 3. Performance of a vertical doublet fed at 35' above average ground

Frequency MHz	Max. Gain dBi	TO Angle degrees	Low-Lobe Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ω
14.175	0.90	13			73 + j16
18.118	1.48	12			183 + j461
21.225	2.17	11			416 + j935
24,94	3.13	10			1639 + j1804
28.5	4.12	9			3438 – j1746



The gallery of elevation patterns for the doublet shows why the doublet requires no low-lobe entries and why the gain values increase as the frequency increases. As the user increases the operating frequency, the doublet becomes longer as a fraction of a wavelength. At the middle of 10 meters, the antenna is slightly longer than 1-λ. As we increase the length of a center-fed doublet, the beamwidth narrows and the resulting gain in the main lobe increases. These natural actions of the antenna keep the lowest lobe as the strongest lobe, despite the fact that the rising feedpoint shows the emergence of the third elevation lobes at 12 and 10 meters. The discone antenna with a top height of about 35' held the gain in the lowest lobe to a very consistent value—between 0.54 and 0.71 dBi—at comparable elevation angles to those of the vertical doublet.

The doublet is perhaps the mechanically simplest antenna that we might use. Implementations might use tubing amenable to simple rope guys along with a lower non-conductive post. However, the doublet also shows an extreme range of impedances, some with very high reactive components. Hence, the antenna would require parallel feedline used in conjunction with a wide-range antenna tuner. Routing the feedline and adding protections against common-mode currents in the shack are two common problems associated with the vertical doublet. Nevertheless, assuming that one may overcome these difficulties, the antenna would outperform the discone on all bands and save considerable time, energy, and money related to construction.

Resonant ½-λ Dipoles: There are a number of commercially made antennas that claim to have the performance of resonant dipoles on all operating bands. The methods of implementation vary, but some are usable in elevated operating positions. Therefore, as a second comparison, let's create a series of such dipoles and place them so that the feedpoint is at 35'. The models will again use AWG #12 copper wire, although most commercial versions of these antennas use aluminum tubing. The results are idealized, as shown in **Table 4**.

Table 4. Performance of vertical dipoles, each fed at 35' above average ground

Frequency MHz	Max. Gain dBi	TO Angle degrees	Low-Lobe Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ω
14.175	0.89	13			70 - j0
18.118	1.32	42	1.22	12	73 + j0
21.225	2.11	37	1.65	11	74 – j0
24,94	2.62	32	2.27	11	73 – j0
28.5	2.77	10			72 + j2

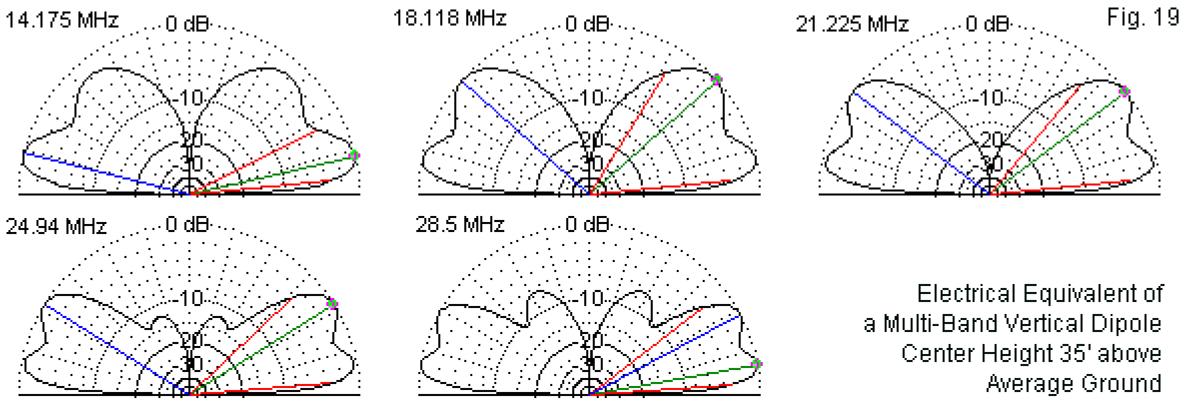


Fig. 19

Electrical Equivalent of
a Multi-Band Vertical Dipole
Center Height 35' above
Average Ground

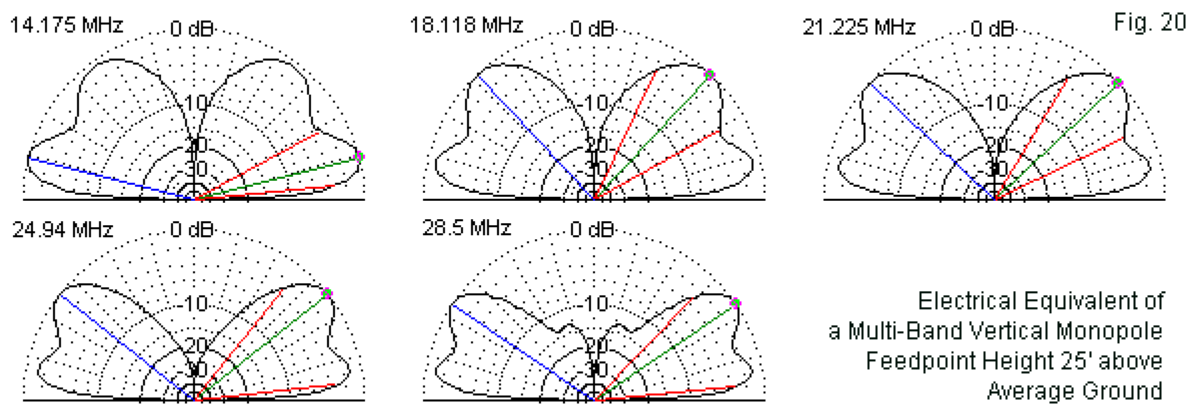
As shown in **Fig. 19**, the patterns for the dipoles with a constant 35' feedpoint do not benefit from the narrowing beamwidth that comes with electrically lengthening the element. Hence, they all exhibit (in free-space) the 80° beamwidth that provides sufficient energy to give the second elevation lobe dominance on the 3 middle bands of the HF set. Still, the lowest lobe of the dipole set manages to provide more gain than the discone on the lowest lobe, the one of highest interest for skip communications.

Structurally, the multi-band dipole is simpler mechanically than the discone, but the required matching systems to achieve resonance on each band may in fact be outside the reach of many antenna builders. As well, the variety of means by which commercial multi-band dipoles achieve resonance may not always produce true dipole patterns. Nevertheless, for the savings in labor and maintenance, a multi-band dipole offers an attractive alternative to the HF discone.

The Trap Multi-Band Monopole: We shall simulate a multi-band ¼-λ monopole and radials with a set of individual ¼-λ monopoles. In each case, the AWG #12 copper wire models will set the radials at 25' above ground, the average height for roof mounting. The top height of the 20-meter monopole is about 43', just above the level of the middle discone, but its feedpoint is 10' lower than the more complex structure. All of the impedance values will be low because each monopole uses equal lengths for the vertical element and the 4 radials in each model. Commercial antennas go to great design lengths to achieve values closer to 50 Ω at the feedpoint on each band. The performance values would not change by very much, and the models will ignore any losses associated with traps or other means of obtaining resonance on each upper HF band. The idealized data appears in **Table 5**.

Table 5. Performance of vertical monopoles, each fed at 25' above average ground

Frequency	Max. Gain	TO Angle	Low-Lobe Gain	TO Angle	Feedpoint Z
MHz	dBi	degrees	dBi	degrees	R +/- jX Ω
14.175	0.39	14			22 + j2
18.118	1.41	47	0.51	13	23 + j3
21.225	2.00	43	0.72	12	24 + j2
24,94	2.51	38	1.21	12	23 + j1
28.5	2.67	34	1.58	11	23 + j2



The elevation plots in **Fig. 20** show the degree to which higher elevation lobes dominate performance on most bands with a rooftop monopole. If we compare the data for the 35' discone and the monopoles, we discover that the values are very similar for the lowest lobe on the lower three bands. On the upper two bands, the lowest monopole lobes show superior performance. Of course, the monopole values do include losses from the means of obtaining resonant performance.

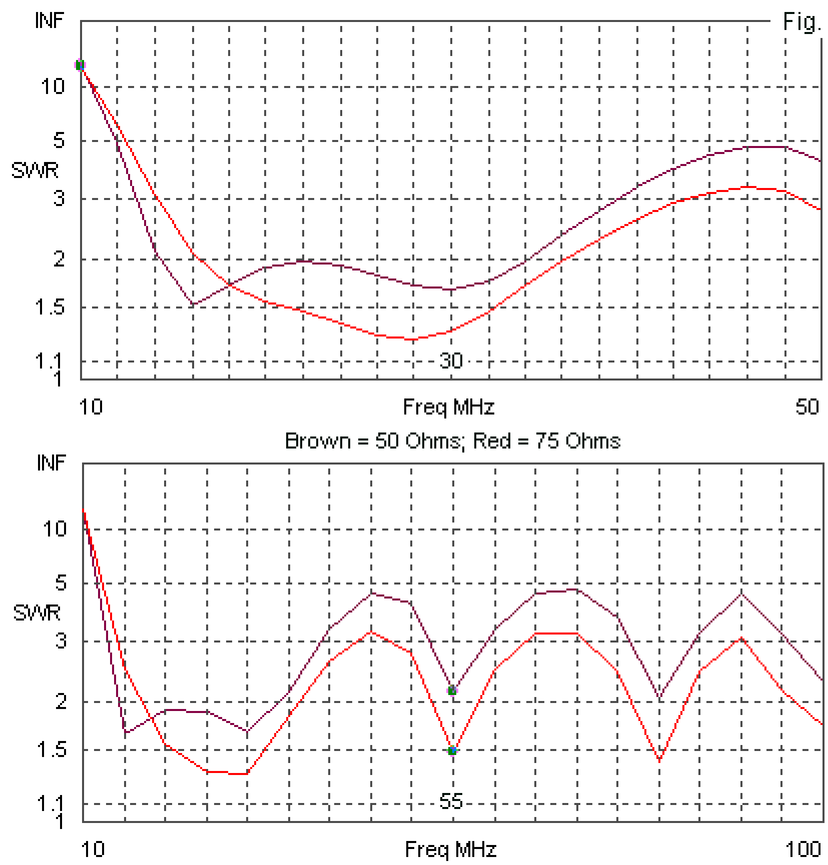
Multi-band vertical monopoles for rooftop mounting, with a requisite small set of radials, are so readily available in commercial form that few amateurs construct their own versions. In general, the structures are relatively simple, easy to support, and require little maintenance (although antenna maintenance should be a regular part of every amateur operator's twice-yearly schedule). Hence, they remain perhaps the most dominant form of vertical antenna used with amateur stations.

The HF discone—at least the version used as the primary focus of these notes—has one major feature that the multi-band dipoles and monopoles lack: the ability to function effectively outside each amateur band over the range for which the design is rated. To achieve the goal of obtaining similar performance across a wide frequency span (2:1 in the model shown) the construction challenges are considerable. One might do well to examine the versions shown in Belrose' 1975 *QST* article or the pair of discones created Daniel Krupp, W8WNF, in his article in Volume 5 of *The ARRL Antenna Compendium*.

Extended Frequency Performance

VHF-UHF discones often carry service frequency ranges considerable larger than the 2:1 range of the subject model shown in these notes. Before we close, we might take a brief look at what happens to the AWG #12 wire discone intended to cover 14 to 30 MHz when we push the range upward. We should keep in mind that the precise numbers associated with the SWR values in **Fig. 21** may not be those of the model, although the model will be accurate enough to indicate the general trends involved. The figure provides two SWR curve sets, one with an upper limit of 100 MHz, the other limited to 50 MHz. In both cases, the graphs provide values for both 50-Ω and 75-Ω reference levels. Except at the lowest end of the range, the 75-Ω curves show the lower values. For extended-frequency service, the 75-Ohm curves may prove to be the more useful, since their peak values rarely exceed 3:1. If we assume that the modeled values are higher than we might obtain with a well-adjusted physical prototype, the peak values would decline even further.

Fig. 21



Expanded 50- and 75-Ohm SWR Plots: AWG #12 25-Wire Discone Antenna

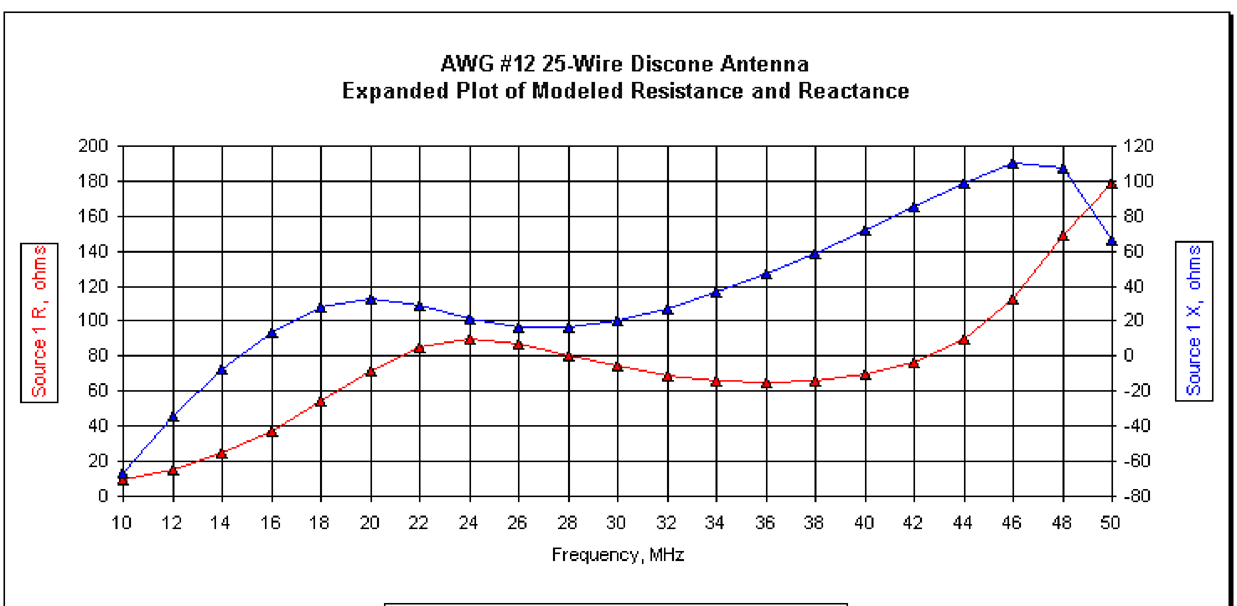
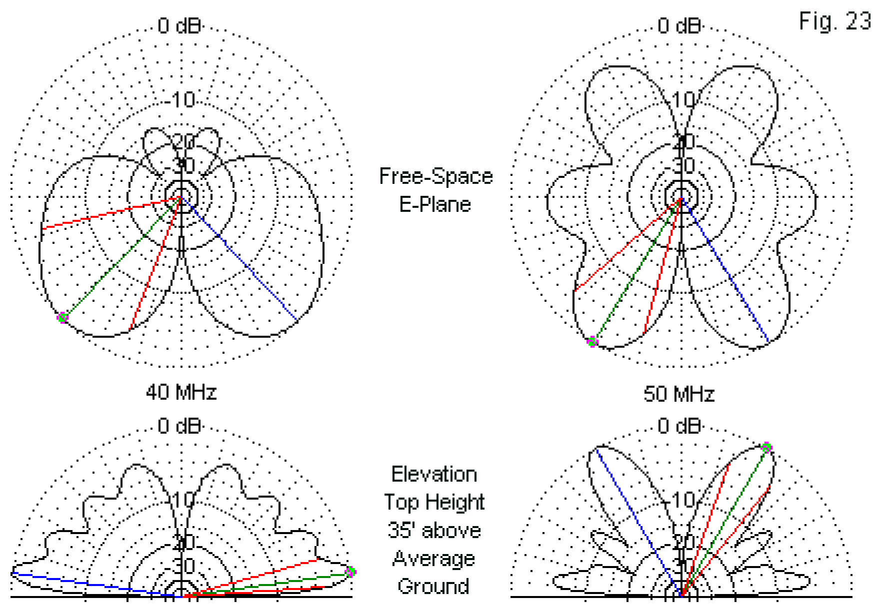


Fig. 22

The curves for 10 through 50 MHz extend the range of earlier curves that stopped at 30 MHz. They suggest that perhaps with judicious design work, we might be able to tame the discone for a 4:1 to 5:1 frequency range. Based on Belrose' measurements for his 40-meter base-line discone, such ranges are entirely feasible. The chart of modeled values of feedpoint resistance and reactance in **Fig. 22** suggest that finding a means of limiting both the resistance an the reactance values at the upper end of the expanded passband might achieve the goal. Changing the spacing between the disc and the cone—a task that modeling does not permit within the range of acceptable AGT scores—might alter the interactions sufficiently to reduce these values.

If we allow that extending the SWR performance is feasible, the remaining question is whether we obtain good antenna performance in the process. **Fig. 23** provides a general idea of what happens as we extend the operating frequency and therefore extend the element length of the cone to more than an electrical 5/8-λ.



AWG #12 25-Wire 14-30-MHz Discone Antenna
Free-Space and Elevation Plots for Higher Frequencies

The upper patterns are free-space E-plane patterns for 40 and 50 MHz for the very same model that we have used throughout these notes. In **Fig. 12**, we noted a pattern tilt angle (away from the disc) that increased as we raised the operating frequency. The process continues with further increases in the operating frequency. At 40 MHz, the angle is 47° below the line marking a true dipole-type bidirectional free-space pattern. At 50 MHz, the angle increases to 59°, with a second set of lobes forming to the disc side of the antenna.

When we place the antenna 35' at its top above average ground, we obtain patterns that combine incident and reflected rays. At 40 MHz, the result is a weak lowest lobe (0.31 dBi) compared to many other antenna types one might use for vertically polarized service in this range. At 50 MHz, high-angle radiation dominates the pattern, although at a 7° elevation angle, the gain is still about 1.3 dBi. These patterns suggest that there is very little reason—and even less good reason—to push the operating span of a wire discone antenna much beyond a 2:1 frequency range.

Conclusion

Summarizing our findings is a difficult task. First, we have looked at wire discones for the upper HF range as perhaps the most promising structural and frequency region for the purposes of obtaining reasonably accurate models. Despite some uncertainties about the precision of the models with respect to correlating model impedance values with those one might obtain from a physical implementation, the primary models revealed the general trends that hold for the discone. Less critical were the constraints on modeling performance, since the antenna is a basic antenna and not a complex array of antenna elements.   In this arena, we were able to develop reasonable performance expectations for the antenna at various heights above ground. In the process, we noted that the discone is subject to the same upper lobe development rules that apply to antennas with more limited frequency ranges.

When we compared the discone to some other types of multi-band antennas, we discovered that the critical performance of the discone's lowest lobe only matched or fell below the levels of performance obtained from the comparators. The chief merit of the discone appears to be its ability to operate consistently across a 2:1 or slightly greater range of frequencies. When we press operations beyond these limits, even if we obtain adequate impedance performance, we obtain less-than-desirable patterns.

In the end, a discone for frequencies below the VHF bands is a project for those with special needs (such as coverage between amateur bands) or for those who simply like to meet a construction challenge of very high proportions. Perhaps the one region that might best benefit from a discone antenna includes the 160-meter and 80/75-meter amateur bands. **Fig. 24** shows the 50-Ω SWR curve for a free-space scaled version of the primary model—still using AWG #12 wire—with the two amateur bands marked.

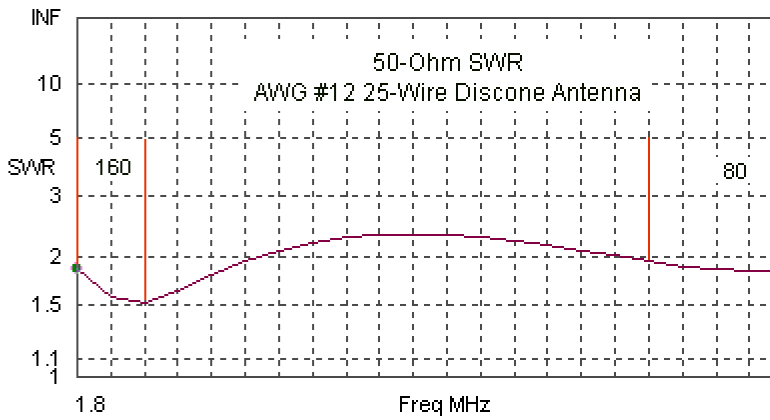


Fig. 24

The antenna would be over 141' tall, plus allowance for ground clearance. The disk has a radius of nearly 55', while the cone opening has a radius of nearly 82'. Such an antenna would indeed cover both bands, but the construction hurdles might challenge the most inveterate wire antenna aficionado.

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