All About the Discone Antenna: Antenna of Mysterious Origin and Superb Broadband Performance

Learn about the development, history and some applications of a discone antenna.

Steve Stearns, K6OIK

"The frequency bandwidths demanded by high-definition television have considerable range…" With these prescient words, Philip S. Carter of RCA opened a 1939 paper that compared a variety of antennas for the emerging field of "high-definition" television. Carter showed conclusively that conical antennas held distinct advantages over dipoles and folded dipoles when it comes to broadband performance. Today, conical antennas are making a comeback for broadband applications such as digital television and UWB (ultra-wideband) or impulse radio. Stacked arrays of bowties and biconical dipoles are gradually displacing traditional mainstay antennas such as Yagis and log-periodics for the rooftop reception of digital television (DTV). One conical antenna, long popular among scanner hobbyists, the discone, has been described in previous articles in Amateur Radio magazines and books. The story has never been told fully, however. This article explains the history and theory of the discone, corrects some common misunderstandings, and presents an *EZNEC* model for a 0.6-octave discone that readers may copy and scale to their favorite frequency bands.

Conical antennas, and the discone in particular, have an obscure but fascinating history. Sergei Alexander Schelkunoff, at Bell Labs, was a titan of antenna theory in the early to mid 20th Century. In 1941, Schelkunoff published a major paper in the *Proceedings of the IRE*, which, among other things, analyzed the symmetric biconical dipole and showed that many other antennas can be analyzed as extensions of it.[1] The discone antenna (Figure 1) is one such extension, in which the biconical dipole is asymmetric, one cone's angle being 90°, which gives a flat disk of radius equal to the cone length. Two years later, in 1943, Armig Kandoian at the Federal Telephone and Radio Corporation applied for a patent on the discone antenna. Kandoian's novel or inventive element was apparently that the antenna could be encased in a radome, making it suitable for aircraft, not that it used a cone or disk per se, those ideas being obvious in view of Schelkunoff's prior work. The patent was granted in 1945, whereupon Kandoian and his colleagues, Sichak, Felsenheld, and Nail, at the newly renamed Federal Telecommunica-

[1]Notes appear on page 43.

PO Box 4917
Mountain View, CA 94040-0917
k6oik@arrl.net

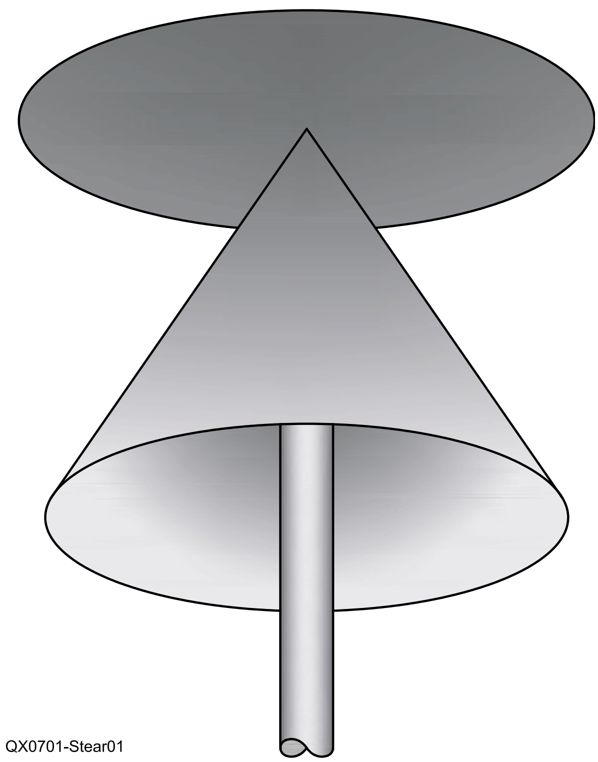

Figure 1 — This illustration shows a home-made discone for 2.4-GHz WiFi use. See www.spaziolink.com/wi-fi.

tion Laboratories, a subsidiary of ITT, began publicizing the antenna in a series of articles in various journals from 1946 to 1953.

In 1952, Schelkunoff published the book *Advanced Antenna Theory*, which gave a comprehensive analysis of the asymmetric biconical dipole in which the angles and lengths of both cones are arbitrary. The discone appeared on page 93 as a special case. Engineering studies of the discone followed shortly thereafter by Nail at the Federal Telecommunication Laboratories and by Crowley and Marsh at Ohio State University. Many variations on the basic discone have appeared since, having such features as multiple cones, multiple disks, meander lines for the cone, and mechanical tuning devices.

Radio Amateurs, meanwhile, had noticed this interesting antenna. A construction article appeared in *CQ* in 1949. More construction articles appeared since then, and are noted at the end of this article. Given such interest, it is surprising that amateur antenna modelers have largely overlooked this antenna. This article corrects that oversight by presenting an *EZNEC* model for a discone that readers may copy, modify, or scale to their favorite bands.

Conical antennas consisting of a single cone fed at its apex against an infinite ground plane are often called "monocones" or less often "unipoles." If the infinite ground plane is replaced by one that is finite and circular, the antenna is called a "discone." A discone can also be thought of as an asymmetric biconical dipole in which one cone's angle is 90° (measured from its axis), so it opens to become a flat disk. The impedance of a discone depends on frequency and three geometric variables: the cone's angle, slant length (measured along the side of the cone), and the radius of the ground plane disk. Feed line SWR depends additionally on the line's characteristic impedance. A discone is not a frequency independent antenna, although this is a common misconception. Rather, a discone behaves more like a fat dipole. Its feed point resistance and reactance vary with frequency, although not through the extremes of a dipole.

Discones are used for broadband operation at frequencies above their first resonance. Manufacturer's data for two popular VHF/UHF discones, the AOR DA3000 and RadioShack 20-043 are shown in Figures 2 and 3 as graphs of return loss versus frequency. The vertical scale of the AOR curve is 10 dB/division; the scale of the RadioShack curve is unspecified. The key feature is that the curves are scalloped. The SWR cycles between high and low as frequency is varied. Receiving is possible on any frequency, but transmitting is best done in the SWR valleys. A good design will keep the SWR peaks below a design limit and position the valleys to coincide with desired transmit frequencies.

There are, broadly speaking, two methods for analyzing antennas that don't require construction and measurement. The first method is mathematical analysis, and the second is numerical antenna modeling. The former was the only method available before computers were invented. Antennas were analyzed mathematically by "normal mode theory" or by solving integral equations. In this article, we'll use a formula developed by Schelkunoff for the feed point impedance of a finite cone over an infinite ground plane, derived from spherical mode theory. The formula allows us to quickly determine the best length and angle for a cone depending on design impedance and bandwidth. More exact formulas for when the disk radius is finite are in the engineering literature. We'll use an *EZNEC* model when analyzing such cases.

In his 1941 paper, Schelkunoff showed that the feed point impedance of many antennas, including the conical monopole over a ground plane, can be represented as terminated transmission lines one-quarter wave shorter than the length of the antenna:

$$Z_{in} = Z_0 \frac{Z_m + jZ_0 \tan\left(k\ell - \dfrac{\pi}{2}\right)}{Z_0 + jZ_m \tan\left(k\ell - \dfrac{\pi}{2}\right)} \qquad \text{(Eq 1)}$$

For a conical monopole of angle θ, measured from axis, the characteristic impedance Z_0 is given by:

$$Z_0 = \frac{\eta}{2\pi} \ln \cot\left(\frac{\theta}{2}\right) \qquad \text{(Eq 2)}$$

The terminating impedance $Z_m = R_m + jX_m$ is the radiation impedance referenced to the current maximum on the antenna. Schelkunoff gave general formulas for the real and imaginary parts of Z_m for all cone angles, but he also gave the formulas for small cone angles in Equation 3 below, where k is the wavenumber $2\pi/\lambda$ and η is the characteristic impedance of free space equal to $\mu_o c$, the speed of light times the magnetic permeability of free space, or 376.73 Ω. (It would be exactly 120π Ω if light would cooperate and travel at exactly 300 million meters per second.) Other symbols in the formulas are Euler's constant, C = 0.5772156649… and

$$\begin{aligned} R_m &= \frac{\eta}{4\pi}\left\{C + \ln(2k\ell) - \mathrm{Ci}(2k\ell) + \frac{1}{2}\sin(2k\ell)\left[\mathrm{Si}(4k\ell) - 2\mathrm{Si}(2k\ell)\right] + \frac{1}{2}\cos(2k\ell)\left[C + \ln(k\ell) + \mathrm{Ci}(4k\ell) - 2\mathrm{Ci}(2k\ell)\right]\right\} \\ X_m &= \frac{\eta}{4\pi}\left\{\mathrm{Si}(2k\ell) - \frac{1}{2}\sin(2k\ell)\left[C + \ln(k\ell) - \mathrm{Ci}(4k\ell)\right] - \frac{1}{2}\cos(2k\ell)\mathrm{Si}(4k\ell)\right\} \end{aligned} \qquad \text{(Eq 3)}$$

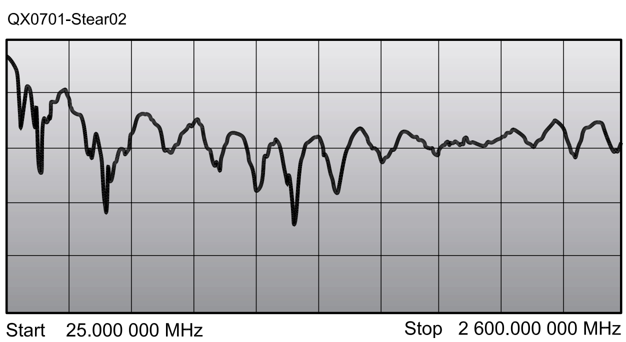

Figure 2 — Return loss of AOR DA3000 discone antenna.

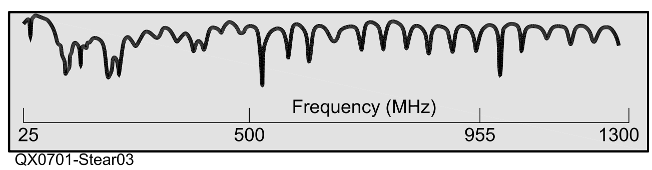

Figure 3 — Return loss of RadioShack 20-043 discone antenna.

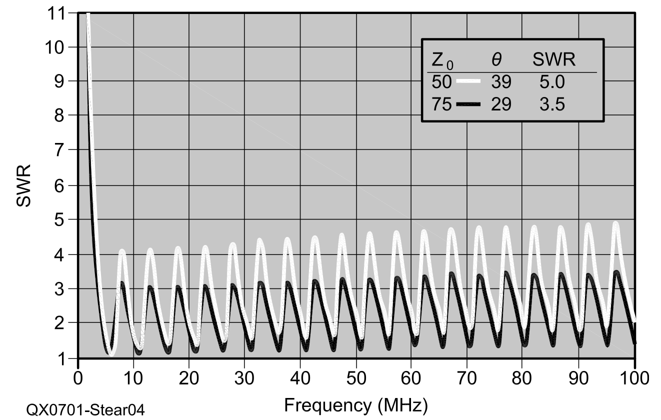

Figure 4 — Computed SWR (at 50 and 75 Ω) of two 100-foot cones.

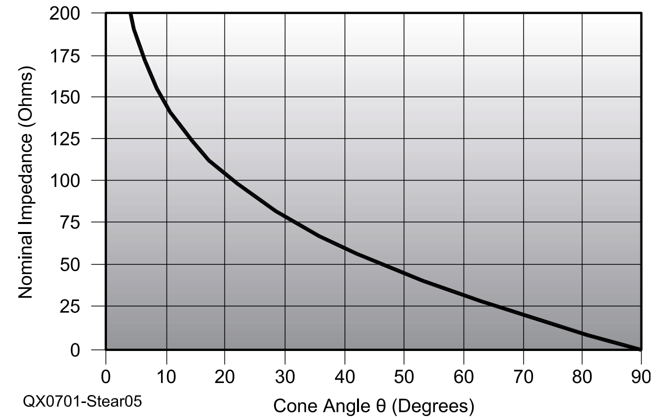

Figure 5 — Nominal monocone and discone impedance versus cone angle.

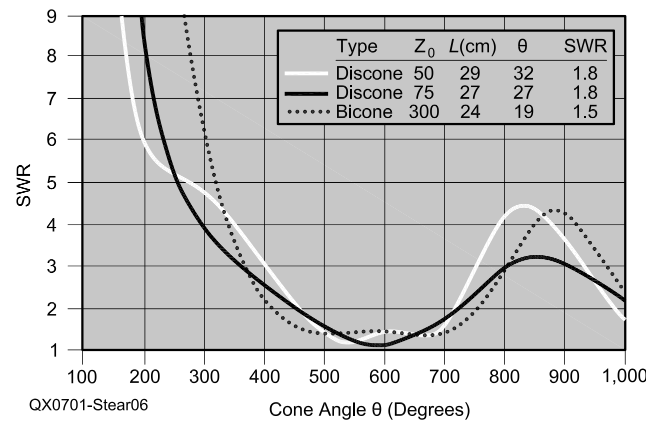

Figure 6 — Predicted SWR of three antennas optimized for UHF TV.

the sine and cosine-integral functions Si(x) and Ci(x), which we won't explain here.

Schelkunoff's asymptotic formula isn't numerically accurate for discones having large cone angles or finite disk radii. The formula, however, does reveal general trends and interesting design trades. More accurate formulas for general discones and biconical dipoles or "bicones" were developed by Hahn and Fikioris, and most recently by Samaddar and Mokole.[2]

For broadband operation, the best cone angle depends on bandwidth. Given a frequency band from f_1 to f_2, the optimum cone angle decreases as the ratio f_2/f_1 increases. For a nominal 50-Ω antenna, as the design bandwidth increases from one to five octaves, the optimum cone angle decreases from 47° to 39°, and the peak SWR creeps up. In addition, as the feed point design impedance increases, the optimum cone angle decreases. An interesting implication pursued in some designs is that the cone should be curved instead of flat sided. Our interest here is flat-sided cones.

Wires

Wire Other

Coord Entry Mode Preserve Connections

Wires

No.	End 1				End 2				Diameter	Segs
	X (mm)	Y (mm)	Z (mm)	Conn	X (mm)	Y (mm)	Z (mm)	Conn	(mm)	
1	0	0	0	W2E1	0	88.2557	0		2.72211	8
2	0	0	0	W3E1	-33.774	81.5376	0		2.72211	8
3	0	0	0	W4E1	-62.4062	62.4062	0		2.72211	8
4	0	0	0	W5E1	-81.5376	33.774	0		2.72211	8
5	0	0	0	W6E1	-88.2557	-7.71556E-06	0		2.72211	8
6	0	0	0	W7E1	-81.5376	-33.774	0		2.72211	8
7	0	0	0	W8E1	-62.4062	-62.4062	0		2.72211	8
8	0	0	0	W9E1	-33.774	-81.5376	0		2.72211	8
9	0	0	0	W10E1	1.05244E-06	-88.2557	0		2.72211	8
10	0	0	0	W11E1	33.774	-81.5376	0		2.72211	8
11	0	0	0	W12E1	62.4062	-62.4062	0		2.72211	8
12	0	0	0	W13E1	81.5376	-33.774	0		2.72211	8
13	0	0	0	W14E1	88.2557	1.54311E-05	0		2.72211	8
14	0	0	0	W15E1	81.5376	33.774	0		2.72211	8
15	0	0	0	W16E1	62.4062	62.4062	0		2.72211	8
16	0	0	0	W33E1	33.774	81.5376	0		2.72211	8
17	0	0	11	W18E1	0	122.577	251.571		2.72211	23
18	0	0	11	W19E1	-46.9082	113.246	251.571		2.72211	23
19	0	0	11	W20E1	-86.675	86.675	251.571		2.72211	23
20	0	0	11	W21E1	-113.246	46.9082	251.571		2.72211	23
21	0	0	11	W22E1	-122.577	-1.0716E-05	251.571		2.72211	23
22	0	0	11	W23E1	-113.246	-46.9082	251.571		2.72211	23
23	0	0	11	W24E1	-86.675	-86.6751	251.571		2.72211	23
24	0	0	11	W25E1	-46.9082	-113.246	251.571		2.72211	23
25	0	0	11	W26E1	1.46172E-06	-122.577	251.571		2.72211	23
26	0	0	11	W27E1	46.9082	-113.246	251.571		2.72211	23
27	0	0	11	W28E1	86.6751	-86.675	251.571		2.72211	23
28	0	0	11	W29E1	113.246	-46.9082	251.571		2.72211	23
29	0	0	11	W30E1	122.577	2.14321E-05	251.571		2.72211	23
30	0	0	11	W31E1	113.246	46.9082	251.571		2.72211	23
31	0	0	11	W32E1	86.675	86.675	251.571		2.72211	23
32	0	0	11	W33E2	46.9082	113.246	251.571		2.72211	23
33	0	0	0	W1E1	0	0	11	W17E1	2.72211	1

Figure 7 — Wire table of an *EZNEC* discone model.

Figure 4 shows SWR curves calculated from Schelkunoff's formula for two 100-foot cones over infinite ground planes. The cone angle and length have been optimized for five-octave operation at both 50 and 75 Ω. Now, we can use an antenna modeling program to get better accuracy with less effort. Nonetheless, I found the best cone angles for each feed point impedance in a five-octave band with a single command to Microsoft *Excel*'s solver tool and 60 seconds of patience. Doing the same optimization in *EZNEC* would have taken days if *EZNEC* had an optimizer — which it doesn't, unfortunately.

An approximate formula for the best cone angle for a given feed point design impedance is obtained from the characteristic impedance formula above.

$$\theta = 2\tan^{-1}\exp\left(\frac{-Z_0}{60}\right) \quad \text{(Eq 4)}$$

Figure 5 illustrates the relation between θ and Z_0 given by this approximation. The predicted angle is good for design bandwidths up to two octaves but should be reduced if the design bandwidth is greater.

There are a lot of different ideas about the proper shape of a discone. Typing "discone" into Google Images reveals a variety of shapes. A common error appears to be making the disk too small and the cone too long. Using a computer, one can jointly optimize a cone's angle, slant length, and disk radius. Increasing the disk radius while simultaneously decreasing the cone's slant length is akin to sliding a feed point along an off-center-fed (OCF) dipole. This interpretation becomes exact if we regard the discone as an OCF biconical dipole with one cone's angle being 90°. Computer modeling reveals the best geometry for a given design impedance and band of operation, as will be shown below.

The procedure for designing a discone for transmitting has one extra step. The slant length is adjusted to put the SWR valleys on the desired transmit frequencies. Alternatively, an SWR valley can be shifted to a transmit frequency by using a mechanical tuning scheme such as those of McNamara or Rappaport.

When constructing a discone, the cone and ground plane can be made from rods or sheet metal as illustrated in Figure 1. When using rods, at least eight should be used. The AOR DA3000 uses 16, while the Diamond D-130J and RadioShack 20-043 use eight. You can adjust the impedance by bending the rods in or out. This is an advantage of rod construction.

Example

As an example, we'll consider a discone for receiving UHF TV channels 14 through 53. The frequency range is 470 MHz to 710 MHz. We set the discone's first resonance at a frequency below 470 MHz because, as shown in Figure 4, the SWR shoots up below the first resonance. Making the antenna too small incurs a big penalty.

A rule of thumb is to set the first resonant frequency at 0.7 times the lowest operating frequency. In this example, that comes out to 329 MHz or a wavelength of 91 cm. The disk radius plus cone slant length should equal half of this number or 46 cm. Now, you could allocate this length equally to the disk radius and cone slant length, making them both 23 cm. This may not be the best way to divide the length, however. Nail suggests that for a 50-Ω design, the ratio of radius to cone length should be:

$$\frac{R}{L} = 0.72 \times \sin\theta \quad \text{(Eq 5)}$$

which gives $R/L = 0.36$ or the ratio $R:L = 26:74$ for a cone angle of $\theta = 30°$. An antenna modeling program can be used to confirm this ratio or to find a better ratio for a different design impedance. You can vary the proportions: 10:90, 20:80, 30:70, 40:60, 50:50 and so on, and compute an SWR sweep for each combination to find what ratio gives the smallest peak SWR over the band of interest.

Let's consider the UHF TV antenna example. To keep things simple, we'll let the disk be an infinite ground plane and use Schelkunoff's asymptotic formula; in practice, we'd use *EZNEC* and include disk

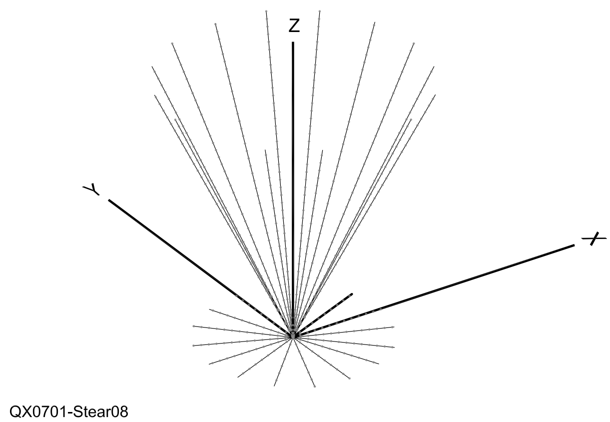

Figure 8 — Geometry of *EZNEC* discone model.

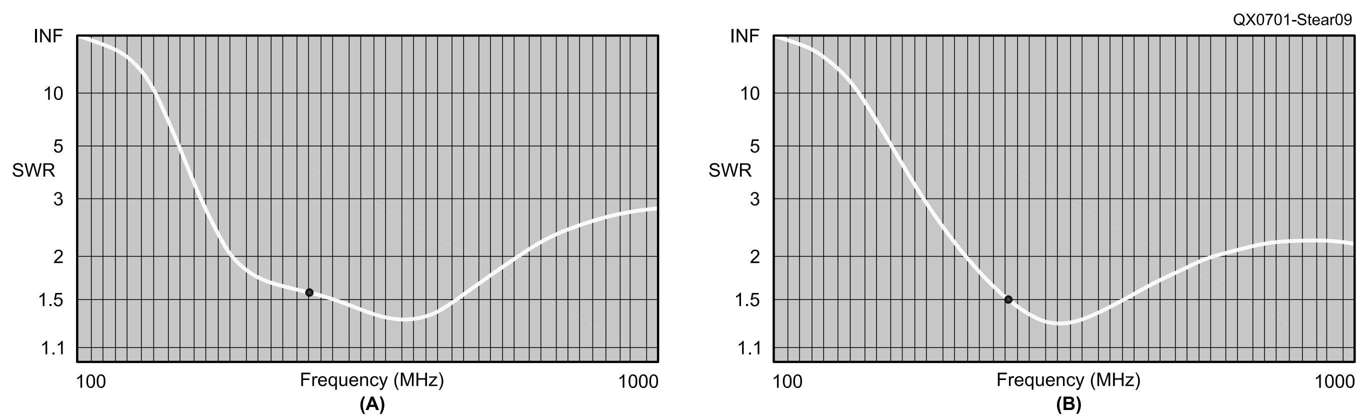

Figure 9 — SWR sweeps at (A) 50 Ω, and (B) 75 Ω; the marker is at 460 MHz.

radius as a variable. The goal is to find the cone angle and slant length that together minimize the maximum SWR between 470 MHz and 710 MHz. We'll find design dimensions for 50 and 75 Ω discones and a 300 Ω biconical dipole. A biconical dipole has a balanced feed point. When designing television antennas having balanced feed points, it is customary to make the feed point 300 Ω because this permits using both 300-Ω balanced twin lead and 75-Ω coaxial line with a 4:1 current balun.

Numerical optimization quickly finds the best lengths and cone angles. The optimum lengths are 29, 27, and 24 cm, with cone angles of 32°, 27°, and 19° respectively for 50 and 75-Ω discones and a 300-Ω bicone. Notice that the lengths are greater than those given by the rule of thumb. The reason is that the design bandwidth is narrow enough that lengthening the antenna moves an SWR valley down to fit the band. A more revealing explanation will be given shortly on a Smith Chart. Figure 6 shows the predicted results.

For a 75-Ω design impedance, the best combination of cone angle and length were found to be 27° and 27 cm. The predicted SWR is the darker curve in Figure 6. The maximum SWR between 470 and 710 MHz is predicted to be 1.82.

At this point we are ready to consider the effect of a finite disk radius. We'll check the theoretical predictions by using an *EZNEC* antenna model that includes a finite disk having Nail's recommended radius.

$$R = L \times 0.72 \times \sin\theta \qquad \text{(Eq 6)}$$

$$R = 27 \times 0.72 \times \sin 27° = 27 \times 0.72 \times 0.4540 = 8.8 \text{ cm}$$

The discone model's wire table and geometry are shown in Figures 7 and 8. The model was created easily by defining two wires as prototypes for the disk and cone, and then using *EZNEC*'s radial tool to complete the model. Wire 1 is the prototype wire for the disk. Wires 2 through 16 were created by *EZNEC*. Similarly, Wire 17 is the prototype wire for the cone, and Wires 18 through 32 were created by *EZNEC*. It's convenient to think of cone and disk wires as being grouped into 16 pairs, with 31 segments allocated to each pair. Segment lengths are made nearly equal by allocating 25% of the segments to the disk and 75% to the cone. Disk wires, therefore, have 8 segments, and cone wires have 23 segments. This gives segment lengths of 11 mm for the disk and 11.7 mm for the cone wires. The apex of the cone was offset by 11 mm from the plane of the disk to make room for a single-segment source wire, which is Wire 33. The total number of segments in the model is 497, and the segment size is under λ/25 up to 1 GHz, which is well above the upper band limit of 710 MHz.

Figure 9 shows the SWR predicted by *EZNEC* for 50 and 75-Ω reference impedances. The graphs' vertical scales are nonlinear in SWR but linear in reflection coefficient magnitude. Allowing for graph distortion created by the nonlinear scale, the 75-Ω SWR curve on the right can be compared to that for the 75-Ω conical monopole shown in Figure 6 (darker curve) which was computed from Schelkunoff's asymptotic formula. The two curves are highly similar in both shape and value. It's clear that the dimensions obtained by optimizing Schelkunoff's formula are quite good, but there's still room for improvement. At this point one might choose to either build and test the antenna with the current dimensions or refine the *EZNEC* model.

It is noted that the model performs well as a 50-Ω antenna as shown in the left curve of Figure 9A. The computed SWR is 1.54 and 1.58 at the band edges and achieves a minimum of 1.30 at 610 MHz. Although not explicitly optimized for 50 Ω, the dimensions are fairly good for that impedance too. This is not mere coincidence but a consequence using Nail's recommended disk size, which is for a 50-Ω design, rather than a 75-Ω design.

EZNEC's 500-segment restriction limits the bandwidth for which it can be used. A minimal NEC model would have eight wires for the cone and eight wires for the disk. If the length of each wire is a quarter wavelength or $\lambda_1/4$ at the lowest frequency f_1, then the total length of all 16 wires is 8 λ_1. The segment length should be no greater than $\lambda_2/20$ where f_2 is the highest frequency. The number of segments, obtained by dividing the segment length into the total length, is 80 λ_1/λ_2. Because *EZNEC* can handle at most 500 segments, the frequency ratio cannot exceed $f_2/f_1 = 500/80 = 6.25$, or 2.6 octaves. So, very broadband design should be done with a modeling program that can handle more than 500 segments, at least 80 f_2/f_1 segments.

It's always a good idea to check whether a simple impedance matching network can improve the match over the band. The first step when designing a matching network is to plot the antenna impedance data on a Smith Chart. We'll use the impedance data that *EZNEC* computed. *EZNEC*'s frequency sweep feature allows the option of creating output data files for *MicroSmith* or *winSMITH*. It's best to choose *MicroSmith* to avoid *winSMITH*'s limit to 15 frequencies. *EZNEC* puts complex reflection coefficient (scattering parameter S_{11}) data in a .GAM text file. It should be opened with Microsoft Word, where it can be manipulated into a standard format for whatever EDA program you use, such as *ARRL Radio Designer*, Ansoft *Serenade SV* (featured in January 2001 *QST*), Agilent *ADS*, AWR *Microwave Office*, *RFSim99*, or even good old *SPICE*. I have found that Ansoft *Serenade SV* has the best capabilities for the money.

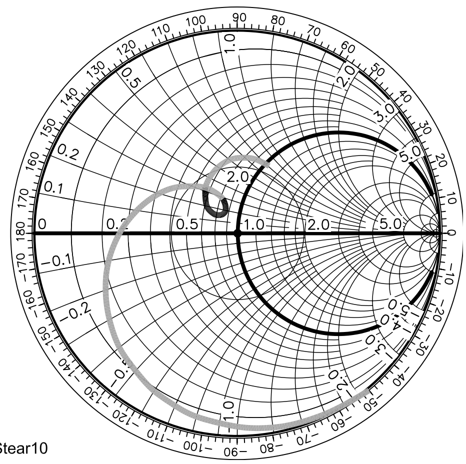

Figure 10 — Discone impedance on 75 Ω Smith Chart; UHF TV band highlighted with a darker band.

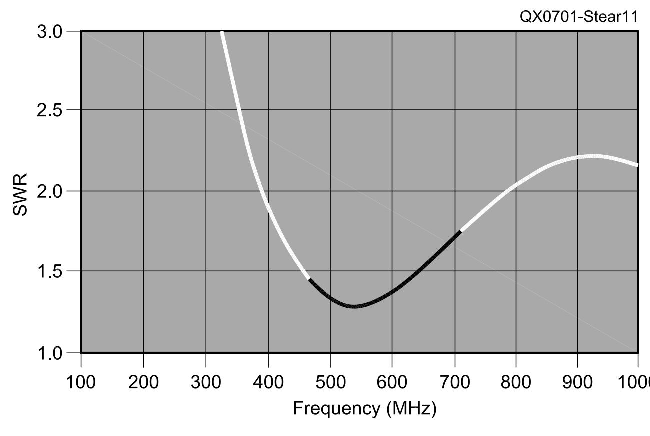

Figure 11 —SWR of unmatched discone (referenced to 75 Ω).

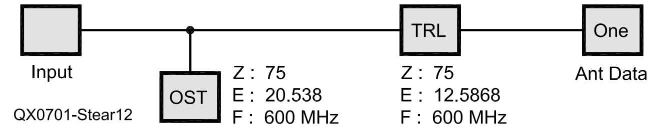

Figure 12 — An open stub impedance-matching network for 75 Ω.

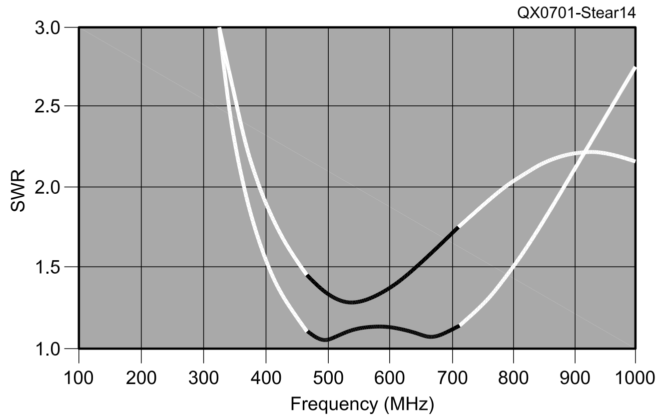

Figure 13 — The match performance of an open stub is shown on a 75 Ω Smith Chart.

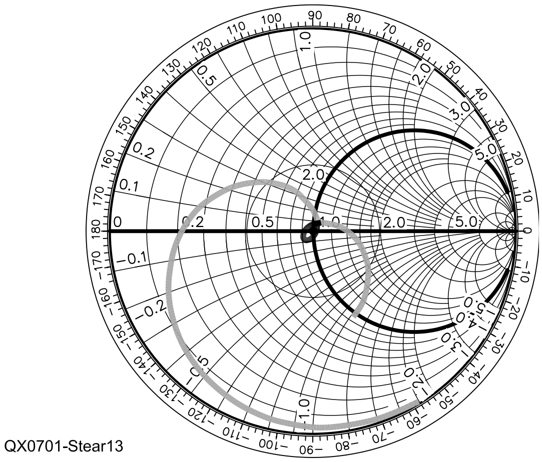

Figure 14 — The matching stub reduces the maximum SWR from 1.28 to 1.12 on the UHF TV band.

Table 1
An *EZNEC* .GAM Date Table Converted to .FLP Format for Analysis by *Serenade*

```
antdata 100MHz 1000MHz 91 50 S
EZNEC data for UHF TV discone antenna created on 2/28/2006.
  100MHz  0.9957904 -34.86269
  110MHz  0.9935989 -38.95737
  120MHz  0.9905544 -43.24265
                •
                •
                •
  980MHz  0.4676752  42.40280
  990MHz  0.4689465  41.08628
 1000MHz  0.4697061  39.79027
```

The .GAM file is formatted to Ansoft's .FLP format within Microsoft *Word* in a few simple steps. First, delete the header line, leaving only the data lines. Next, use the text-to-table converter in *Word* to put the data into a four column table. Cut the contents of columns two and three and paste to columns three and four, leaving column two empty. Type the frequency unit "MHz" as the first entry in Column two, and paste it into all cells down the column. Next, do a table-to-text conversion, specifying a "space" character as the delimiter. Finally, remove the space between the frequency number and its unit by a global replacement of "[space]M" with "M." The data lines are now finished. Just add two header lines before the data lines, making sure to specify "50 S" on the first line to indicate that the data is scattering parameter data referenced to 50 Ω. This is the same convention that *EZNEC* used when making the output data. Finally, save the file as a text file with the .FLP name extension to a *Serenade* project folder. The file should look like Table 1

Once the .FLP file has been saved, we open *Serenade SV* and define a one-port that references the file to represent the discone antenna. Run a frequency sweep, then use the report editor in *Serenade SV* to graph the antenna impedance on a Smith Chart by asking for a polar plot of S_{11} and specify Z or Y coordinates, or both.

The discone model's impedance is presented in Figures 10 and 11. Both figures assume a 75 Ω reference impedance. Figure 10 shows the complex impedance curve on the Smith Chart. For antennas, which are passive loads, the curve bends clockwise as frequency increases. Figure 11 shows the resulting SWR, whose agreement with Figure 9B confirms that the *EZNEC* data conversion was done correctly. The data is plotted for the one-decade band from 100 MHz to 1,000 MHz. The 0.6-octave UHF TV band, from 470 MHz to 710 MHz, is highlighted with a darker line. This is the region where we want to match the impedance.

The secret to understanding the behavior of this medium bandwidth discone is to note that discone impedance curves aren't uniform concentric spirals on a Smith Chart, like a dipole would be. Instead, the impedance curves have a small loop in the middle of every large loop. By varying the cone angle and disk radius, a small loop can be moved to the center of the Smith Chart. Then, by merely scaling the dimensions, nearly an octave of bandwidth can be slid into the small loop. This yields a moderately broadband low-SWR antenna, such as our example discone.

These steps can be done in reverse order: first put the UHF TV band in a small loop and then move the loop to the center of the Smith Chart by inserting an impedance matching network at the discone's feed point. With more work, however, the steps can be done in the original order, and the impedance matching network eliminated.

The simplest impedance matching network for the discone model is the 75 Ω open stub shown Figure 12. The stub was designed to match the antenna to 75 Ω and is made of 75-Ω transmission line. The stub is inserted in a 75-Ω feed line at the proper distance from the feed point. The stub's electrical length and position from the feed point (20.5° and 12.6° at 600 MHz) translate to physical lengths of 29 mm and 17 mm times the velocity factor of the transmission line. The network can be constructed by using a 75-Ω coaxial T connector. Because a physical stub terminates in a fringing capacitance rather than an ideal infinite-impedance open circuit, a real stub must be made shorter to achieve the predicted performance. Rather than calculate the fringing capacitance, it's easy to trim the stub by measurement during construction.

The impedance matching performance of the stub matching network is shown in Figures 13 and 14. Figure 14 shows before and after SWR curves. The matching network reduces the maximum SWR in the UHF TV band from 1.28 to 1.12.

Although most amateurs think of low SWR as important for transmitting, it is also important for receiving digital modulations such as DTV signals. The game here is not about power transmission. Rather, it is about avoiding waveform distortion caused by frequency selectivity of the communications channel. Wideband digital signals hate reflections, regardless of source. Reflections from multipath propagation and transmission line discontinuities are equally bad. The question of where reflected power goes is, ultimately, unimportant because communication is about getting information through, not power. Power transmission is merely a means to a greater end, not the end in itself. Reflections should be avoided.

Discones and bicones are better antennas for receiving HDTV signals than bow-tie or flat triangle antennas although the latter are better than log periodics and Yagis when phase distortion is considered. A bicone is easier to design than a discone because you build two identical cones. The question of disk size disappears. That's one fewer variables to get right. Other things to consider are pattern and polarization. Antennas should be mounted with the correct polarization — vertical for VHF/UHF communication signals and horizontal for receiving FM and television broadcast signals. When mounted horizontally, the azimuthal gain pattern is like that of a horizontal dipole — a figure eight for low frequencies and increasingly multi-lobed as frequency increases. At high frequencies, a discone's main lobe lies in the half-space on the cone side of the disk. As frequency increases from low to high, the main lobe shifts from the plane of the disk toward the direction of the cone, and minor lobes emerge on both sides of the disk.

Acknowledgments:

I am grateful to my colleagues at Northrop Grumman's Electromagnetic Systems Laboratory who were students of the late John Daniel Kraus, W8JK, of Ohio State University. In particular, I wish to thank Dr A. G. Jennetti, KF6FO, Keith Snyder, KI6BDR, and Jim Peterson, K6EI, for comments and ideas that contributed to this article.

Parts of this article appeared in the newsletter of the Foothills Amateur Radio Society, an ARRL affiliated club. Those portions are included here with permission.

Notes

[1]The Institute of Radio Engineers (1912-1963) merged with the older American Institute of Electrical Engineers (1884-1963) to form the Institute of Electrical and Electronics Engineers (IEEE) in 1963. The IRE was instrumental in the creation of the Federal Radio Commission in 1927, which became the FCC in 1934.

[2]Mathematically skilled readers will find the papers by Hahn and Fikioris and by Samaddar and Mokole contain rigorous extensions of Schelkunoff's original analysis.

Steve Stearns, K6OIK, started in Amateur Radio while in high school at the height of the Heathkit era. He holds an FCC Amateur Extra license and a commercial General Radiotelephone Operator license with Radar endorsement. He previously held Novice, Technician, and 1st Class Radiotelephone licenses. He studied electrical engineering at California State University Fullerton, the University of Southern California, and Stanford University, specializing in electromagnetics, communication engineering and signal processing. Steve works at Northrop Grumman's Electromagnetic Systems Laboratory in San Jose, California, where he developed smart antenna and digital demodulation technology for eliminating interference and is currently developing ways to design and fabricate metamaterials to control electromagnetic phenomena. He has over 50 professional publications and eight US patents and numerous foreign patents. Steve is an ARRL Life member, has served as an assistant director of ARRL Pacific Division, and is currently the vice-president of Foothills Amateur Radio Society serving Silicon Valley. Steve has received numerous awards for professional and community volunteer activities. He can be reached at **k6oik@arrl.net** *or* **stearns@ieee.org**.

Bibliography

Engineering literature:

Howe, G. W. O., "The Nature of Electromagnetic Waves Employed in Radio-Telegraphy and the Mode of Their Propagation," *The Electrician*, 19 Sep 1913, pp 965-969.

Howe, G. W. O., "The Capacity of an Inverted Cone and the Distribution of its Charge," *Proceedings of the Physical Society of London*, Vol 29, 1917, pp 339-344.

Shelkunoff, S. A., "Transmission Theory of Spherical Waves," *AIEE Transactions*, Vol 57, 1938, pp 744-750.

Carter, P. S., "Simple Television Antennas," presented at National Convention of IRE, San Francisco, Jun 1939. Published in *RCA Review*, Vol 9, Oct 1939, pp 168-185.

Schelkunoff, S. A., "Theory of Antennas of Arbitrary Size and Shape," *Proceedings of the IRE*, Vol 29, Sep 1941, pp 493-521; corrections published in Nov 1941, p 603, and Jan 1943, p 38. Reprinted without corrections in *Proceedings of the IEEE*, Vol 72, no. 9, Sep 1984, pp 1165-1190. Refer to Figure 2A with θ_1 or θ_2 equal to $\pi/2$.

Kandoian, A. G., *Broad Band Antenna*, U.S. patent no. 2,368,663, 6 Feb 1945.

Kandoian, A. G., "Three New Antenna Types and Their Applications," *Waves and Electrons*, Vol 1, no. 2, , Feb. 1946, pp 70W-75W, a separate section within *Proceedings of the IRE*, Vol 34. Reprinted in *Electrical Communication*, Vol 23, no. 1, Mar 1946, pp 27-34.

Kandoian, A. G., W. Sichak, and G. A. Felsenheld, "High Gain with Discone Antennas," *Proceedings of the National Electronics Conference*, Vol 3, Chicago, Nov. 1947, pp 318-328. Reprinted with additional figures in *Electrical Communication*, Vol 25, no. 2, June 1948, pp 139-147.

Smith, P. D. P., "The Conical Dipole of Wide Angle," *Journal of Applied Phys*ics, Vol 19, no. 1, Jan 1948, pp 11-23.

Tai, C. T., "On the Theory of Biconical Antennas," *Journal of Applied Phys*ics, Vol 19, no. 12, Dec 1948, pp 1155-1160.

Tai, C. T., "Application of a Variational Principle to Biconical Antennas," *Journal of Applied Phys*ics, Vol 20, no. 11, Nov 1949, pp 1076-1084.

Leitner, A. and R. D. Spence, "Effect of a Circular Groundplane on Antenna Radiation," *Journal of Applied Phys*ics, Vol 21, no. 10, Oct 1950, pp 1001-1006.

Schelkunoff, S. A., "General Theory of Symmetric Biconical Antennas," *Journal of Applied Phys*ics, Vol 22, no. 11, Nov 1951, pp 1330-1332.

Schelkunoff, S. A., *Advanced Antenna Theory*, Section 2.21, Wiley, 1952. Refer to Figure 1.18 on p 93.

Schelkunoff, S. A. and H.T. Friis, *Antennas: Theory and Practice*, Wiley, 1952.

Brown, G. H. and D.M. Woodward, "Experimentally Determined Radiation Characteristics of Conical and Triangular Antennas," *RCA Review*, Vol 13, no. 4, pp 425-452, Dec. 1952.

Nail, J. J., "Designing Discone Antennas," *Electronics*, Vol 26, Aug 1953, pp 167-169.

Crowley, T. H. and W. Marsh, *Discone Type Antennas*, technical report 510-13, Ohio State Research Foundation, 30 June 1954.

Wait, J. R., "Electromagnetic Radiation from Conical Structures," Chapter 12 in *Antenna Theory, Part 1*, R. E. Collin and F. J. Zucker (eds.), McGraw-Hill, 1969, ISBN 0070117993.

Lakshminarayana, Y., Y. R. Kubba, and M. E. Madhusudan, "A Wide Band Discone Antenna," *Indian Journal of. Electro-Technology*, Vol 15, no. 2, Mar/Apr 1971, pp 57-59.

Kadakia, D. R. and J. G. Fikioris, "Monopole Antenna Above a Hemisphere," *IEEE Transactions on Antennas and Propagat*ion, Vol 19, no. 5, Sep 1971, pp 687-690.

Spanos, W. M., *Broadband Discone Antenna having Auxiliary Cone*, US patent no. 3,618,107, 2 Nov 1971.

Hahn, R. F. and J. G. Fikioris, "Impedance and Radiation Pattern of Antennas above Flat Discs," *IEEE Transactions on Antennas and Propagat*ion, Vol 21, no. 1, Jan 1973, pp 97-100.

Woodman, K. F., "Dielectric-Clad Discone," *Electronics Letters*, Vol 13, no. 9, 28 Apr 1977, pp 264-265.

Smith, C. E., C. M. Butler, and K. R. Umashankar, "Characteristics of a Wire Biconical Antenna," *Microwave J*ournal, Vol 22, no. 9, Sep 1979, pp 37-40.

Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, Section 6.2, Wiley, 1981, ISBN 047104458X.

McNamara, D. A., D. E. Baker and L. Botha, "Some Design Considerations for Biconical Antennas," *IEEE AP-S Int'l Symp. Digest*, Vol 22, Jun 1984, pp 173-176.

Rappaport, T. S., *Tunable Discone Antenna*, US patent no. 4,851,859, 25 Jul 1989.

Austin, B. A. and A. P. C. Fourie, "Characteristics of the Wire Biconical Antenna Used for EMC Measurements," *IEEE Transactions on Electromagnetic Compatibility,* Vol 33, no. 3, Aug 1991, pp 179-187.

Champion, J. R., et al, *Portable Rapidly Erectable Discone Antenna*, US patent no. 5,608,416, 4 Mar 1997.

Samaddar, S. N. and E. L. Mokole, "Biconical Antennas with Unequal Cone Angles," *IEEE Transactions on Antennas and Propagati*on, Vol 46, no. 2, Feb 1998, pp 181-193.

Meitzler, W., W. Turney, and L. T. Malek, "Biconical Antenna Scans 4.8 to 5.8 GHz," *Microwaves & RF*, Vol 44, no. 8, Aug 2005, pp 53-61.

Apostolos, J. T., *Collapsible Wide Band Width Discone Antenna*, US patent no. 6,967,626, 22 Nov 2005.

Marsan, L. A. and E. A. Urbanik, *Compact Low RCS Ultra-Wide Bandwidth Conical Monopole Antenna*, US patent no. 7,006,047, 28 Feb 2006.

Amateur Radio literature:

Boyer, J. M., W6UYH, "Discone — 40 to 500 Mc Skywire," *CQ*, Jul 1949, pp 11-15 & 69-71. Reprinted in *CQ Anthology*, Cowan Publishing, 1958.

Seybold, M., W2RYI, "The Low-Frequency Discone," *CQ*, July 1950, pp 13-16, 60. Reprinted in *CQ Anthology*, Cowan Publishing, 1958.

Orr, W. I., W6SAI, (ed.), *Radio Handbook*, 14th ed, "The Low-Frequency Discone," Editors and Engineers, 1956, pp 369-370 in.

Pappenfus, E. W., WB6LOH, "The Conical Monopole Antenna: Four-to-One Frequency Coverage with a Vertical," *QST*, Nov 1966, pp 21-24.

Wintzer, M., PAØMWI/DJ4GA, "Dipole Passe? Some Experiments on Discone Arrangements," *QST*, Oct 1974, pp 15-21.

Belrose, J. S., VE2CV/VE3DRC, "The HF Discone Antenna," *QST*, Jul 1975, pp 11-14, 56; Feedback, *QST*, Sep 1975, p 88.

Geiser, D., WA2ANU, "An Inexpensive Multiband VHF Antenna," *QST*, Dec 1978, pp 28-29.

Geiser, D., WA2ANU, "More on Discone Antennas," *QST*, May 1979, p 44.

White, T. E., K3WBH, "A Discone Antenna for 10 and 6 Meters and Lo-Band Public Service Monitoring," *CQ*, Jun 1980, pp 74-75.

Orr, W. I., W6SAI, "A 160-Meter Discone Antenna," *Ham Radio*, Jul 1987, pp 57-58.

Miller, D., NZ9E, "A 'Universal' VHF/UHF Antenna," *QST*, Dec 1994, p 75.

Krupp, D. A., W8NWF, "Two HF Discone Antennas," *The ARRL Antenna Compendium Vol* 5, ARRL, 1996, ISBN 0872595625, pp 121-127.

Todd, M., VK6JMA, "The Discone," *The International Antenna Collection*, G. Brown (ed.), RSGB and ARRL, 2003, ISBN 1872309933, pp 218-219.

Patterson, R., K5DZE, "A VHF/UHF Discone Antenna," *QST*, May 2003, pp 40-41. QEX