Wide-Band Test Antennas

Simple-to-Build Discones Provide an Excellent Match at L Band

By Theodore S. Rappaport
Virginia Polytechnic Institute and State University

As part of an indoor multipath measurement system, discone antennas featuring simple N-connector feed systems have been designed for the 1.0 to 2.0 GHz band. Extensive experimentation reveals that excellent performance (VSWR < 1.5:1 across the band) can be obtained with a simple "snap-on" feed/mount method, and that VSWR is most sensitive to the diameter of the disc feed conductor. Performance data from over 70 discone antennas having a variety of flare angles, disc-to-cone spacings and feed conductor diameters are summarized here. Data shows that for N-connector mounts, best flare angles range between 45° and 75° and that the disc feed conductor should be 0.33 times the diameter of the cone top. The empirical data reveals that the antennas may be tuned for even better match by using a simple clamp nut tuning scheme. Design equations, which differ from Nail's (2) because of the large minimum cone diameter, are presented.

The discone antenna is well documented and has been used extensively (1-6). The discone's main virtue is that it provides low VSWR over a bandwidth of several octaves (1, 2). The antenna may be modeled as a high pass filter which has a high pass cutoff frequency equal to the reciprocal of four times the cone slant height (2). As part of an experimental wideband indoor multipath measurement system (7), several discone antennas for the 1.0 to 2.0 GHz band have been developed. Each antenna uses a standard male N-connector as both an RF feed and mechanical support. This technique affords quick and inexpensive antenna construction and deployment. The data shows that antenna performance is not compromised despite the large diameter (1/12 at high pass cutoff) of the feed connector.

Antenna Construction

As shown in Figure 1, the discone may be characterized by the dimensions D, L, M, θ, m, s and ω, where m is the minimum cone diameter, ω is the diameter of the disc feed conductor and s is the disc-to-cone spacing. In the literature (refs. 2 and 5) it is usually assumed that s << D, and ω is not considered. In fact, the author has not seen previous data discussing the effects that ω and s have upon antenna loading when m is large (on the order of λ/10) with respect to the high pass cutoff wavelength of the antenna (as is the case here). Nail found that discone design formulas (for m = λ/75 at high pass cutoff) are:

\[ s = 0.3m; D = 3.7M \]

regardless of θ, where L is slightly larger than 1/4 at cutoff (2). For a discone designed to operate at L band using a direct N-connector feed, m is equal to 1/12 at high pass cutoff, and Nail's design formulas were found to be helpful but incomplete.

Four cones made of pliable copper sheet were built with flare angles of 45°, 60°, 75° and 90°. The cones were formed by cutting and rolling the copper sheet around a wooden conical block of the desired flare angle, and then by soldering the sheet onto itself so that the cone would keep its shape. The four cone dimensions are given in Table 1. Slant lengths of all four cones were cut for 1/4 at 1000 MHz.

Each cone was soldered to the body of a UG-21DU N-connector, giving each antenna a minimum cone diameter (m) of 19.0 mm (1/4"). With the rear end of the connector made flush with the (small) top of the cone, solder was carefully applied to the connector/cone junction to form a mechanical and electrical connection.

![Figure 1. The discone antenna.](image)

![Figure 2. Discone antennas constructed on N-connectors.](image)

Care was taken so that solder did not flow into the clamp nut threads on the rear of the connector (the clamp nut is useful for tuning the antenna). A Teflon nut inserted into the rear of the connector while soldering is an excellent way to prevent solder from blocking the clamp nut threading.

Disks of varying diameters were centered and soldered on copper rods that were beveled and soldered to the removable center pins of the N-connectors. A discone antenna was formed by plugging a particular disc into a cone-mounted connector.
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were made with disc values of $D = 0.75M$. This is in close agreement with Nail (2).

Changing the diameter of the disc feed connector dramatically affected the loading performances of the antennas. Values used for $\omega$ range from 0.082 m to 0.41 m in 0.082 m increments. For each value of $\omega$, the disc-to-cone spacing ($s$) on each antenna was readjusted for lowest VSWR. It was found that best matching for nearly all antennas occurred for values $\omega = 0.33 m$, $s = 0.5 m$. Figure 5 illustrates the effect of variations in $\omega$ upon the loading characteristics of antenna 3 with $s = 0.5 m$ and all other antenna parameters fixed. The other three antennas demonstrated very similar behavior, although the 90° antenna provided a consistently poor match over the lower part of the band.

Figure 6 displays the loading characteristics of the four optimized disccone antennas, each having parameters $\omega = 0.33 m$, $s = 0.5 m$, $D = 0.75 M$, and cone dimensions given in Table 1.

From the data it appears that a large disc feed conductor diameter mitigates a substantial impedance mismatch within the connector. Due to the structure of the UG-211/U connector, the disc feed conductor travels a non-negligible distance ($\pi/2\ell$) before reaching the connector end. Thus it seems that a simple coaxial transmission line model of the feed conductor within the connector is applicable. The impedance of an air-dielectric coaxial transmission line is well known to decrease with increasing center wire diameter ($\ell$) and is solely a function of the ratio ($m/\omega$). Thus the results shown in Figure 5 are not surprising. For $\omega = 0.33 m$, the characteristic impedance offered by the feed conductor/connector transmission line segment is 66.5$\Omega$, very close to a 50$\Omega$ match.

The experimental results justify the modification of Nail’s original design equations to include relationships for $\omega$ and $s$ when $m$ is large, on the order of $\ell/10$ at high pass cutoff (lowest frequency of operation). Our data suggests the following design equations for the case when the cone top has a diameter of $\ell/10$ at high pass cutoff:

$$s = 0.5m; \omega = 0.33m; D = 0.75m;$$
$$L = 1.15\ell/4$$

In Equation 2, the value for $\lambda$ corresponds to the lowest desired frequency of operation for the antenna. Because the impedance relationship within the feed housing is a function of both $m$ and $\omega$, Equation 2 should hold for any disccone coaxial feed system with a large $m$ dimension.

A second independent set of four disccone antennas was fabricated using Equation 2 to test the reliability of the design formula. Measurements performed on the second set of antennas yielded results within ±2.0 dB of those shown in Figure 6 for most frequency points.

Figure 4. Loading characteristics of disccone antennas (designed from Equation 1).

Figure 5. Loading characteristics as function of the disc feed conductor diameter (θ = 75°).

Figure 6. Loading characteristics of disccone antennas (designed from Equation 2).
Clamp Nut Tuning

Further experiments were conducted to see how inserting the clamp nut into the connector would affect antenna loading characteristics. An immediate benefit of the clamp nut is that dimensions can easily be adjusted. In addition, the clamp nut serves to further reduce the impedance mismatch created within the connector, and may be thought of as a low impedance transmission line segment in a short tapered line.

By fastening the clamp nut into the connector, improvement in VSWR performance for three of the four antennas was accomplished. The 45° discone performance deteriorated with the clamp nut installed (when D = 0.75 M).

An optimum \( \omega \) value of 0.25 m (4.8 mm, 3/16") was found to hold for each of the three discones using clamp nut tuning. Disc-to-cone spacing was kept at 0.5 m (9.6 mm, 3/8"); however, with the clamp nut fully inserted, the distance from the top of the clamp nut to the disc (\( s_b \)) was decreased to 0.33 m (6.4 mm, 1/4"). All other parameters remained the same. Figure 7 illustrates the loading behaviors of the three discone antennas with clamp nuts securely fastened on the top of the cones. For other disc feed conductor diameters, clamp nut tuning improved the reflection coefficient (see Figure 5) by 5 dB on the average throughout the band.

For the 45° discone, additional experiments were conducted to determine the effects of disc diameter upon loading when clamp nut tuning is used. In particular, we strive to lower the high pass cutoff frequency without changing the cone dimensions. Figure 8 shows the matching characteristics of an optimized 45° discone measured at 25 MHz increments across the 1.0-1.4 GHz band. The data illustrates that with clamp nut tuning, better low frequency response may be obtained by simply increasing the disc diameter. The results also suggest that for large minimum cone diameters (on the order of \( \lambda/10 \) at high pass cutoff), antenna loading anomalies due to disc feed conductor diameter, \( \omega \), and disc-to-cone spacings, \( s \), can be neutralized by a cable clamp nut (a standard part supplied with the built-in Israel by Elgal Electronics, a major supplier to the Israeli defense effort. Call or write Amplifier Research, exclusive USA distributor, for further information.

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Conclusion

Discone antennas are quickly and easily constructed as appendages to coaxial connectors. Such antennas are easily deployable and are suitable for use in bench testing in UHF/microwave wide-band indoor communication systems. In this article, extensive experimental data were analyzed to determine design equations for discone antennas mounted on N-connectors. Such a mounting forces the minimum cone diameter \( m \) to be on the order of \( \lambda/10 \) at high pass cutoff. For this case, the data illustrates the significance of antenna parameters \( s \) and \( \omega \) upon antenna loading. For discone antenna design using coaxial connector feeds, Nail’s equations (2) must be modified to include the effect of the diameter of the disc feed conductor. By selecting the disc feed conductor diameter to be 0.33 \( m \), the experiments reveal that a VSWR below 1.3:1 is easily achievable across an octave and further suggests that cone flare angles between 45° and 75° yield best results. Equation 2 is a suitable modification of the well-accepted discone design equation

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\text{and should hold for any discone coaxial feed system when } m \text{ is large. By using a simple clamp nut adjustment and slightly decreasing the diameter of the disc feed conductor (}\omega\text{, it is possible to optimize VSWR characteristics of a discone antenna mounted on a coaxial connector. The construction, design and tuning techniques described here should be valid for discones designed to operate at much higher frequencies, although this must be borne out by experimentation.}
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The antenna described is being patented and any party wishing to license, buy or market the product can either contact the author at the number listed or Dr. Bill Baitinger of Purdue University at (317) 494-5785.

References


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