Discone Design Using Simple N-connector Feed

Theodore S. Rappaport
Engineering Research Center for Intelligent Manufacturing Systems
Electrical Engineering Department
Purdue University
West Lafayette, IN 47907

Abstract

As part of an indoor multipath measurement system, discone antennas featuring simple N-connector feed systems have been fabricated for the 1.0 to 2.0 GHz band. 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. Results show 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 because of the large minimum cone diameter, are presented.

1. Introduction

The discone antenna is well documented in the literature and has been used extensively. The discone's main virtue is that it provides low VSWR over a bandwidth of several octaves. As part of an
experimental wideband indoor multipath measurement system, 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. It is shown here that antenna
performance is not compromised despite the large (λ/12 at high pass
cutoff) diameter of the feed connector. Design equations, which differ
slightly from Nail's because of the large minimum cone diameter, are
presented.

2. Antenna Construction

As shown in Figure 1, the discone may be characterized by the
dimensions $D$, $L$, $M$, $\theta$, $m$, $s$ and $w$, where $m$ is the minimum cone diame­
ter, $w$ is the diameter of the disc feed conductor and $s$ is the disc-to-cone
spacing. In the literature (e.g. refs. 2 and 5) it is usually assumed that
$s << D$, and $w$ is not considered. In fact, we have not seen previous data
discussing the effects $w$ and $s$ have upon antenna loading when $m$ is large
with respect to the high pass cutoff frequency of the antenna (as is the
case here). Nail found that useful design formulas (for $m \approx \lambda/75$ at high
pass cutoff) are

$$s = 0.3m \quad ; \quad D = 0.7M$$

(1)

regardless of $\theta$, where $L$ is slightly larger than $\lambda/4$ at cutoff$^2$. For the
case here, $m=\lambda/12$ at high pass cutoff and Nail's design formulas were
found to be helpful but incomplete.
Figure 1. The discone antenna.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ant. 1</th>
<th>Ant. 2</th>
<th>Ant. 3</th>
<th>Ant. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>$45^\circ$</td>
<td>$60^\circ$</td>
<td>$75^\circ$</td>
<td>$90^\circ$</td>
</tr>
<tr>
<td>$M$</td>
<td>74.2 mm (3&quot;)</td>
<td>95.2 mm (3 3/4&quot;)</td>
<td>108 mm (4 1/4&quot;)</td>
<td>120.6 mm (4 3/4&quot;)</td>
</tr>
<tr>
<td>$m$</td>
<td>19.1 mm (3/4&quot;)</td>
<td>19.1 mm (3/4&quot;)</td>
<td>19.1 mm (3/4&quot;)</td>
<td>19.1 mm (3/4&quot;)</td>
</tr>
<tr>
<td>$L$</td>
<td>73 mm (2 7/8&quot;)</td>
<td>73 mm (2 7/8&quot;)</td>
<td>73 mm (2 7/8&quot;)</td>
<td>73 mm (2 7/8&quot;)</td>
</tr>
</tbody>
</table>

Four cones made of pliable copper sheet were built with flare angles ($\theta$) of $45^\circ$, $60^\circ$, $75^\circ$ and $90^\circ$. The four cone dimensions are given in Table 1. Slant lengths of all four cones were cut for $\lambda/4$ at 1000 MHz. Each cone was soldered to the body of a UG-21D/U connector, giving each antenna a minimum cone diameter ($m$) of 19.0 mm (3/4"). The connector was positioned and soldered completely within the cone. The rear end of the connector was made flush with the (small) top of the cone. Care was taken so that solder did not flow into the clamp nut threads on
the rear of the connector. It was discovered through experimentation that the clamp nut is useful for tuning the antenna. Discs 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 con-mounted connector. Antenna feed was accomplished by simply mating the discone with 50 Ω coaxial cable having a female N-connector termination.

3. Experiments

3.1 Set-up

Reflection coefficient measurements were made by placing the antenna under test in a large clear area surrounded by electromagnetic absorption material. The measurement set-up consisted of a UHF signal generator, a dual directional coupler and a dual channel power meter that was programmed to read return loss \((= -20 \log |\Gamma|\text{, where } \Gamma \text{ is the reflection coefficient})\) referenced to a 50 ohm load. The system was calibrated across the band to remove the loss of the antenna feed cable as well as the frequency dependent variations of the equipment. Antenna return loss measurements were made at 50 MHz intervals across the 1000-2000 MHz band. Care was taken to insure power levels were sufficient to provide reliable measurements. Antenna performances were evaluated by the average value of the reflection coefficient across the 1.20 to 2.0 GHz band.
3.2 Results

Equation (1) was first used to develop four discones described in Table 1. Of particular importance, the antennas had parameters $s=0.33\ m$ and $w=0.16\ m$. Clamp nuts were not installed on the connectors, and a value of $D=0.7M$ was used for each antenna. The antenna loading characteristics of all four discones were disappointing, and are shown in Figure 2.

The disc separation, $s$, was then varied in increments of $0.082\ m$ over the range $[0m, 0.66m]$ for each of the four antennas to obtain lowest average VSWR over the band. For antenna 1, optimum separation was found to be $0.41\ m\ (8.0\ mm, 5/16")$. Antennas 2, 3 and 4 were optimized when $s=0.5\ m\ (9.6\ mm, 3/8")$. These values are 50% larger than the values suggested by (1). Even with optimum disc-to-cone spacing, the loading characteristics of all four antennas were still poor. For each antenna, the VSWR averaged about 2.0:1 throughout the band. Thus, the data indicates that for large $m\ (m \cong \lambda/10)$, the common discone design equations (e.g. found in refs. 2 or 5) are lacking.

With $s$ optimized, the disc diameter $D$ was varied in $0.05\ M$ increments over the range $[0.55M, 0.75M]$. The loading characteristics of each antenna was slightly affected, most noticeably at the low frequency end and at the first harmonic of the cutoff frequency. A value of $D=0.70\ M$ provided the best broadband response for antennas 2 and 3, whereas antennas 1 and 2 performed slightly better with $D=0.75\ M$. All subsequent measurements were made with disc values of $D=0.75M$. This is in close agreement with Nali².
Changing the diameter of the disc feed conductor dramatically affected the loading performances of the antennas. Values used for \( w \) ranged from 0.082 m to 0.41 m in 0.082 m increments. For each value of \( w \), 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 \( w = 0.33 \) m, \( s = 0.5 \) m. Figure 3 illustrates the effect of variations in \( w \) 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 4 displays the loading characteristics of the four optimized discone antennas, each having parameters \( w = 0.33 \) 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-21D/U connector, the disc feed conductor travels a non-negligible distance \((\approx \lambda/10)\) within the throat of the connector before reaching the connector end. Hence, a simple coaxial transmission line model of the feed conductor within the connector seems applicable. The impedance of an air-dielectric coaxial transmission line is well known to decrease with increasing center wire diameter\(^8\) and is solely a function of the ratio \((m/w)\). Thus the results shown in Figure 3 are not surprising. For \( w = 0.33 \) 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 \( w \) and \( s \) when \( m \) is large, on
Fig. 2. Loading Characteristics of Discone Antennas (Designed from (1)).

Fig. 3 Loading Characteristics as function of \( w (\theta = 75^\circ) \).

Fig. 4 Loading Characteristics of Discone Antennas (Designed from (2)).
the order of $\lambda/10$ at high pass cutoff. Our data suggests the following:

$$\text{For } m \approx \lambda/10, \ s = 0.5m \ ; \ w = 0.33m \ ; \ D = 0.75M$$  \hspace{1cm} (2)

Because the impedance relationship within the feed housing is not a function of just $m$ alone, (2) should hold for any discone coaxial feed system with large $m$.

A second independent set of four discone antennas was fabricated using eqn. (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 4 for most frequency points.

4. Clamp nut tuning

Further experiments were conducted to see how inserting the clamp nut into the connector would affect antenna loading characteristics. In particular, we strived to improve the match of the 90° discone.

An immediate benefit of the clamp nut is $s$ 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 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 substantially, however, with the clamp nut installed (when $D=0.75M$).

An optimum $w$ value of 0.25 m (4.8 mm, 3/16") was found to hold for each of the three discones. Disc-to-cone spacing was kept at 0.5 m
(9.6 mm, 3/8''); however, with the clamp nut inserted, $s_{eff}$ (the effective value of $s$) was decreased by 3.2 mm (1/8") due to the protrusion of the clamp nut from the cone top. Clamp nut penetration into the connector was measured to be 7.9 mm (5/16"). All other parameters remained the same. Figure 5 illustrates the loading behaviors of the three discone antennas with clamp nuts securely fastened on the top of the cones.

![Diagram](image)

**Fig. 5.** Loading Characteristics of Discone Antennas (w/ clamp nut).

![Diagram](image)

**Fig. 6.** 45° Discone Antenna optimized for 1.1 - 1.4 GHz.
For other disc feed conductor diameters, clamp nut tuning improved the reflection coefficient (i.e. those shown in Figure 3) 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 strived to lower the high pass cut off frequency without changing the cone dimensions. Figure 6 shows the matching characteristics of an optimized 45° discone 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 λ/10 at high pass cutoff), antenna loading anomalies due to disc feed conductor diameter, w, and disc-to-cone spacings, s, can be neutralized by a cable clamp nut (a standard part supplied with all coaxial connectors).

5. Conclusion

Discone antennas are quickly and easily constructed as appendages to coaxial connectors. Such antennas are easily deployable and are suitable for use in UHF/microwave wideband indoor communications systems. In this paper, 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 λ/10 at high pass cutoff. For this case, the data illustrates the significance of antenna parameters s and w upon antenna loading. For discone antenna design using coaxial connector feeds, Nail's equations must be modified to include the effect of the diameter of the disc feed.
By selecting the disc feed conductor diameter to be about 0.33 m, the experiments reveal that a VSWR below 1.3 :1 is easily achievable across an octave and further suggest that cone flare angles between 45° and 75° yield best results. Eqn. (2) is a suitable modification of the well-accepted discone design equation and should hold for any discone coaxial feed system when m is large. By using a simple clamp nut adjustment and slightly decreasing the diameter of the disc feed conductor (w), it is possible to optimize VSWR characteristics of a discone antenna mounted on a coaxial connector. When used in conjunction with clamp nut tuning, lowering the operating frequency of the antenna may be accomplished by increasing the disc diameter. 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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