A DISK MONOPOLE ANTENNA WITH 1:8 IMPEDANCE BANDWIDTH AND OMNIDIRECTIONAL RADIATION PATTERN

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1. INTRODUCTION
A fundamental thin wire monopole antenna and its variants[1] have the common features to be omnidirectional and structurally simple, but narrowband. By replacing the wire element with a conducting disk, the resultant monopole antenna exhibits an extraordinary bandwidth of 1:8 (maybe more), defined by return loss less than -10 dB, and maintains omnidirectional coverage [2]-[4]. These experimental results are briefly reviewed and the broadband omnidirectionality is theoretically examined.

2. ANTENNA STRUCTURE
The lowest design frequency is 3GHz, and so the diameter of disks is 25mm (a quarter wavelength at this frequency). Two types of disks are used: one is simply made of copper plate 0.5mm thick; the other is a printed disk of 35μm thickness. This thin disk is backed up by the same sized PTFE laminate disk whose thickness and relative permittivity are 1.6mm and 2.5, respectively.

An edge of either disk is soldered with a center conductor of 50Ω SMA connector as shown in Fig.1. The edge is just in contact with the connector surface and so there is no gap between them. The connector itself is flushmounted in the center of the square ground plane sized 300x300mm. The y-z plane containing the disk is parallel to two edges of the square ground plane and naturally orthogonal with the remaining two.

3. EXPERIMENTAL RESULTS
Figure 2 shows the return loss for 2 to 20GHz measured using a Wiltron network analyzer. The lower limit of the above defined bandwidth is recognized lower than 2.5GHz, while the upper is out of the frequency range. Hence the 1:8 bandwidth is at least confirmed.

Impedance matching can be further improved by removing stray capacitance between the disk and the ground plane[4]. This improvement was examined using a printed disk, whose lower portion near the ground was cut away by means of etching as indicated in Fig.1 with cut angle α. The results are shown in Fig.3. For α=20° the return loss less than -15dB is achieved at least in the frequency band from 2.5 to 12GHz(1:5).

Radiation patterns at four frequencies in the band are shown in Fig.4. The patterns in the vertical planes were measured for azimuth angle φ fixed at every 10 degrees starting from 0° (x-z plane).
Fig. 2 1:8 bandwidth of a copper disk monopole antenna.

Fig. 3 Return loss for printed disks with cut angle \( \alpha \) varied.

Fig. 4 Omnidirectional radiation patterns of the antenna as for Fig. 2.
plane) to 90° (y-z plane)[2]–[3]. All of them are plotted in one figure to observe omnidirectional radiation. The three dimensional radiation pattern is almost unchanged in the band, although for higher frequencies crosspolar component appears (when $\phi=30,40,50,60$ degrees) and the horizontal radiation tends to cease.

For lower frequency applications the bulky disk element and the ground plane can as usual be approximated by their appropriate wire-grid models. As an example such a model was successfully developed to cover all over the Japanese television channels expanding from 90 to 770MHz (1:9)[3].

4. THEORETICAL CONSIDERATION

According to the multipole expansion[5], any current source whose maximum dimension is much smaller than wavelength is equivalent to an electric dipole as far as the far field is concerned. This is the basic reason for unexceptionally omnidirectional radiation patterns of various monopole-type antennas. In addition to this reasoning, there are symmetries of current distribution in the case of disk monopole antennas. In the following examined is the effect of these symmetries on the broadband omnidirectionality.

The ground plane is assumed to extend infinitely and the image theory is applied. Let the real current on the disk as well as the image current be denoted by $J(r', \theta')$, where the primed arguments refer to a source point as indicated in Fig.1. The symmetries, which are obvious from the structural symmetry, are expressed as follows.

$$J_x(r', -\theta') = J_x(r', \theta')$$
$$J_x(r', \pi - \theta') = J_x(r', \theta')$$
$$J_y(r', -\theta') = -J_y(r', \theta')$$
$$J_y(r', \pi - \theta') = -J_y(r', \theta')$$

(1)
(2)

The conventional vector potential $A$ is given by

$$A = \int \frac{\mu J e^{-jkR}}{4\pi R} dS'$$

(3)

$$R = \sqrt{r'^2 + (r')^2 - 2rr'\cos \psi}$$

(4)

$$\cos \psi = \sin \theta \sin \phi \sin \theta' + \cos \theta \cos \theta'$$

(5)

By applying the addition theorem for a spherical Hankel function of the second kind, eq.(3) can be written as follows.

$$A = -j \left( \frac{k\mu}{4\pi} \right) \sum_{n=0}^{\infty} (2n + 1) P_n(\cos \psi) J(r', \theta')$$

(6)

Taking into account the above symmetries, all the terms for $n$ odd are found to vanish. Especially the second term ($n=1$), which corresponds to a magnetic dipole as well as an electric quadrupole[5] and violates omnidirectional pattern with increasing frequency, does not exist inherently. For this reason disk monopole antennas exhibit the broadband omnidirectionality.

Consider the remaining terms for $n$ even. The Taylor series of a spherical Bessel function of order $n$ starts with the $n$ powers of its argument, and the value of argument that gives the first maximum of the function increases with increasing order[6]. Hence in eq.(6) the increase of $n$ means the contribution from the current further from the feed point.

For $n=0$, $P_0(\cos \psi)=1$ and the integral over the real and image disks is a function of wavenumber (frequency) only, which is denoted by $C_0(k)$. Then the vector potential from this term is given by

$$A_0 = \frac{2\mu C_0(k)}{4\pi} e^{-jkr}$$

(7)
This is the familiar form for a monopole or a dipole. If the frequency is not so high that neglect of higher order terms is justifiable, the radiation pattern is unaffected by the specific current distribution in accord with the abovementioned multipole expansion. It should be noted here that eq.(7) is obtainable, unlike the expansion, without taking the first term of the Taylor series of a spherical Bessel function because of the symmetries.

For \( n=2 \), \( P_2(\cos \psi) = (3/2) \cos^2 \psi - 1/2 \) and a straightforward analysis following standard procedure shows that the azimuthal and elevational angle dependencies of copolar and crosspolar components are given by

\[
H_\phi = C_{21}(k) \sin \theta + C_{22}(k) \cos^2 \theta \sin^2 \phi + C_{23}(k) \sin^3 \theta \sin^2 \phi
\]

\[
H_\theta = D_2(k) \sin(2\theta) \sin(2\phi)
\]

respectively, where \( C \)'s are derived from \( J_2 \) and \( D_2 \) from \( J_y \). The crosspolar radiation observed in Fig.4 can be understandable by the present result.

5. CONCLUSION

The disk monopole antennas are claimed to have 1:8 (maybe more) impedance bandwidth and broadband omnidirectional radiation pattern. The latter is theoretically shown to be due to the symmetries of current distribution on the disks.

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References


* Although these papers are originally written in Japanese, their English versions translated by the authors are available.