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Radiating aperture on cylindrical surfaces for end fire applications

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Abstract This paper describes an aperture type antenna mounted on cylindrical structure for end fire application This type of structure is suitable for command links with ground from space-crafts and command guided weapons This polarization of the antenna is perpendicular to the cylindrical surface There is not much change in H-plane pattern For E-plane calculations, an equivalent monopole is replaced for the antenna Uniform theory of diffraction is used to calculate radiation patterns of the antenna in lit and shadow zones For calculations an infinite length of the cylinder is considered However, for measurements limited length of the cylinder is taken which is dictated by the quiet zone of the antenna test facility. Measurements are carried out in E-plane, and intermediate cuts of interests The experimental and the theoretical results are presented for these cuts

Keywords Aperture type antenna, cylindrical structure, end fire application

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1. Introduction

Spacecrafts or Aerospace vehicles need RF links with the ground stations. The RF links need suitable antennas mounted onboard the vehicles. The type of the antenna and its location on board is dictated by the aerodynamic profile of the cylindrical structure. To minimise the transmission losses it is desirable that the antennas be located near the transmitters and receivers. Hence, it is desirable that the antennas be mounted on the cylindrical structures ahead of the end sections. Figure 1 shows the antenna mounted on the cylindrical surface with coordinates used to calculate the radiation pattern of the antenna. Theoretical solution used in this paper employs the ray coordinates of the Geometrical Theory of Diffraction (GTD) [1]. The GTD was introduced by Keller [2] to formulate the diffraction in terms of rays. Uniform Theory of Diffraction (UTD) [3] has been used in this paper to calculate the E-plane radiation pattern of the antenna.

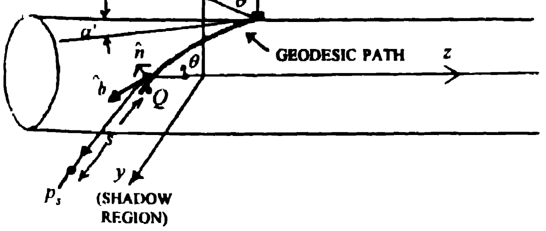

Figure 1. Antenna mounted on the cylinder.

2. Calculation of E-plane radiation pattern of the antenna

The antenna is replaced by an equivalent monopole on the cylindrical surface. The total space can be divided into lit region (directly seen by the antenna) and shadow region (obstructed by the cylinder). Monopole on the convex surface can be replaced by an infinitesimal electric current moment $d\bar{p}_e(l')$ given by [3] :

$$d\bar{p}_e(Q') = I(l')dl'n', \qquad (1)$$

where $I(l')$ denotes the electric current distribution on the monopole and l' is the distance along its length measured from the base at Q'. The total electric field $\bar{E}_e(p)$ can be calculated from field $d\bar{E}_e(p)$ by replacing the source strength $d\bar{p}_e(Q')$ by $\int_0^h d\bar{p}_e(l')\cos(kl'\cos\theta')$ if P is in lit region, or by $\int_0^h d\bar{p}_e(l')$ if P is in the shadow region. k is propagation wave number ($k = 2\pi/\lambda$, λ = wavelength).

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Shadow region :

The equivalent source $d\bar{p}_e(Q')$ at Q' excites waves that propagate along ray paths into the shadow region. The field at the point P_s is given by [3] :

$$d\bar{E}_e(P_s/Q') = d\bar{P}_e(Q').\bar{\bar{T}}_e(Q'/Q) \times \left[\rho_c/s(\rho_c+s)\right]^{1/2} e^{-jks} \qquad (2)$$

where the dyadic $\bar{\bar{T}}_e(Q'/Q)$ is a transfer function that describes the launching of the surface ray field at Q' and its amplitude and phase variation along the geodesic path from Q' to Q and also the diffraction of this surface ray field at Q. The dyadic is defined as :

$$\bar{\bar{T}}_e(Q'/Q) = \frac{-jkZ_0}{4\pi}\left[\hat{n}'\hat{n}\,T_5(Q')H + \hat{n}'\hat{b}\,T_6(Q')S\right]e^{-jkt} \times \left[d\psi_0/d\eta(Q)\right]^{1/2}\left[\rho_g(Q)/\rho_g(Q')\right]^{1/6}, \qquad (3)$$

where Z_0 is the free space wave impedance. $T_5(Q') = 1$ for circular cylinder, $\hat{t}$ is the unit vector tangent to the surface ray, $\hat{b}$ is the binomial unit vector at Q, $\hat{t}'$ and $\hat{b}'$ have the same meaning at Q'.

$$T_6(Q') = \frac{\sin 2\alpha'}{2a}\frac{a}{\sin^2\alpha'} \qquad H = g(\xi),$$

$$S = \frac{-j}{m(Q')}\tilde{g}(\xi), \qquad (4)$$

$g(\xi)$ and $\tilde{g}(\xi)$ are Fock integrals. The Fock parameter ξ for the "Shadow zone" is defined as

$$\xi = \int_{Q'}^{Q} dt'\frac{m(t')}{\rho_g(t')}; \quad m(t') = \left(\frac{k\rho_g(t')}{2}\right)^{1/3} \qquad (5)$$

The other symbols used here are the standard symbols used in GTD or UTD [3]. Eq. (2) will be used to calculate the field in the shadow region.

Lit region :

The equivalent source $d\bar{p}_e(Q')$ at Q' excites waves propagating directely into the lit region through GO paths. The field strength at the point p_L is given by :

$$d\bar{E}_e(p_L/Q') = d\bar{p}_e(Q')\bar{\bar{T}}_e^{\,l}\frac{e^{-jks}}{S} \qquad (6)$$

where $\bar{\bar{T}}_e^{\,l} = \frac{-jkZ_0}{4\pi}\left|\hat{n}'\hat{n}M + \hat{n}'\hat{b}N\right|$,

$$M = \sin\theta'\left[H^l + T_0^2\,\tau\cos\theta'\right],$$

$$N = \sin\theta'\,T_0\,\tau,$$

$$\tau = \frac{S^l - H^l\cos\theta'}{1 + T_0^2\cos\theta'}$$

$$T_0 = T(Q')\rho_g(Q'),$$

$$T(Q') = \frac{\sin 2\alpha'}{2a},$$

$$\rho_g(Q') = \frac{a}{\sin^2\alpha'},$$

$$H^l = g(\xi_l)e^{-j\xi_l^{3/3}},$$

$$S^l = \frac{-j}{m_l(Q')}\tilde{g}(\xi_l)e^{-j\xi_l^{3/3}}.$$

In the above equations, g and $\tilde{g}$ are Fock functions The Fock parameter ξ_l for the lit region is given by

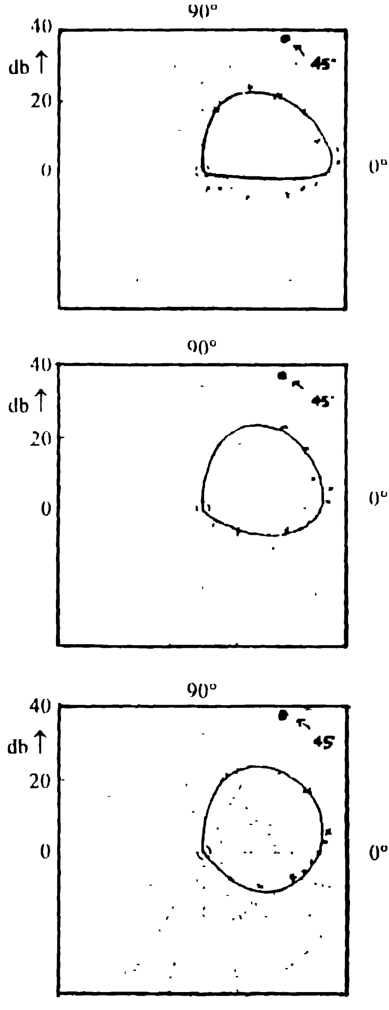
$$\xi_l = -m_l(Q')\cos\theta',$$

$$m_l(Q') = \frac{m(Q')}{\left[1 + T_0^2\cos^2\theta'\right]^{1/3}}.$$

The other symbols used here are the standard symbols used in GTD or UTD [3]. Eq. (6) will be used to calculate the radiation pattern of the antenna in the lit region

3. Theoretical and experimental results

An open ended rectangular waveguide antenna with aperture dimensions 0.7λ and 0.35λ has been designed to meet the beamwidth requirements For theoretical calculations infinit



(a) $\alpha' = 25°$

(b) $\alpha' = 20°$

(c) $\alpha' = 35°$

Figure 2. Antenna radiation patterns with varying α'. Theoretical · —— , Experimental ××××××

length of the cylindrical section is assumed. Eq. (2) is used to calculate the radiation pattern in the shadow zone and eq. (6) is used to calculate the radiation pattern in the lit zone. Figures 2(a-c) shows the results for $\alpha' = 2.5$, 20 and 35 deg respectively. The measurements are carried out in a Compact Antenna Test Range at RCI, Hyderabad. The antenna is mounted on a cylinder of length 40λ and diameter of 10λ. The length of the cylinder was dictated by the quiet zone of the test facility. The measurements are carried out for values of $\alpha' = 2.5$, 20 and 35 deg and are shown in Figure 2 with the theoretical results.

4. Conclusions

A surface mounted radiating aperture for end fire applications suitable for airborne/aerospace to ground communication link is designed, fabricated and tested. Single antenna covers only half of the desired space. For conical coverage two antennas are used. Uniform theory of diffraction has been used to calculate the radiation patterns of the antenna to freeze the antenna design. For theoretical calculations infinite length of the cylinder has been assumed Experimental measurements are carried out on a limited length of the cylinder. In the lit region the theoretical and experimental results match closely However, the difference between the theoretical and experimental results in the shadow zone for small α' is because of limited length of the cylinder during measurements

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