Wire Antennas in Proximity of Conducting Cylinders and Wedges

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INTRODUCTION

Behavior of antennas in the vicinity of conducting bodies such as circular cylinders and wedges has received considerable attention in the past [1]-[5]. These canonical structures can be used to model a wide range of scatterers or mounting platforms for antennas in practice. Usually the supporting structure is of finite extent for which the exact solution does not exist, however, the analytic solution that is found for infinite cylinders or wedges is still very useful in predicting the radiation characteristics of practical antennas mounted on large conducting bodies.

Radiation from axial current elements in front of conducting cylinders and wedges is a classic textbook problem [6]-[7], however, the problem of horizontal antennas in radial or azimuth direction in presence of metallic cylinders or wedges is much more complicated. In [1] the principle of reciprocity was used to calculate the far field patterns of horizontal Hertzian dipoles in proximity of conducting cylinders, however, no practical wire antenna such as monopole or half wave dipoles were considered. In case of conducting wedges, such far field calculations usually involve diffraction theory or numerical methods [5] although in [3] radiation patterns of horizontal Hertzian dipoles in front of a conducting wedge were derived using a spherical wave expansion.

Dyadic Green's functions for arbitrarily oriented electric dipoles in front of conducting cylinders and wedges are given by Tai [8] in terms of infinite series of cylindrical wave functions. These series are not useful for calculating near field parameters such as antenna impedance because of their extremely slow convergence. However, in this paper, far field patterns are derived from these Green's functions and it is shown that they are highly convergent. Furthermore, to show the applicability of the analytic solutions, radiation patterns of three types of resonant wire antennas in the vicinity of a conducting cylinder and a wedge will be presented that do not seem to have been published before.

HORIZONTAL ANTENNAS NEAR CONDUCTING CYLINDER

Consider an infinite cylinder of radius a on the z-axis with an electric current element in radial direction located at a nearby point (ρ', φ', z'). After extracting the $\hat{z}$ components of electric and magnetic fields from the dyadic Green's functions given in [8], the radiation fields are calculated using the method of stationary phase:

$$\begin{aligned} E_\theta &= k\eta \frac{\cos\theta}{2} \frac{e^{-jkr}}{r} \sum_{n=0}^{\infty} \varepsilon_n j^n \left(J_n'(k\rho'\sin\theta) - \frac{J_n(ka\sin\theta)}{H_n^{(2)}(ka\sin\theta)} H_n^{(2)\prime}(k\rho'\sin\theta) \right) \cos n(\varphi-\varphi') \\ E_\varphi &= -\frac{e^{-jkr}}{r} \eta \csc\theta \sum_{n=1}^{\infty} \frac{j^n n}{\rho'} \left(J_n(k\rho'\sin\theta) - \frac{J_n'(ka\sin\theta)}{H_n^{(2)\prime}(ka\sin\theta)} H_n^{(2)}(k\rho'\sin\theta) \right) \sin n(\varphi-\varphi') \end{aligned} \quad (1)$$

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Far fields of an electric Hertzian dipole in azimuth direction are also found in a similar manner after asymptotic evaluation of electric and magnetic fields obtained from the dyadic Green's functions:

$$
\begin{aligned}
E_\theta &= -\frac{e^{-jkr}}{r}\eta \cot\theta \sum_{n=1}^{\infty}\frac{n\, j^n}{\rho'}\left(J_n\left(k\rho'\sin\theta\right) - \frac{J_n\left(ka\sin\theta\right)}{H_n^{(2)}\left(ka\sin\theta\right)} H_n^{(2)}\left(k\rho'\sin\theta\right)\right)\sin n\left(\varphi-\varphi'\right) \\
E_\varphi &= \frac{e^{-jkr}}{r}k\,\eta \sum_{n=0}^{\infty}\frac{\varepsilon_n j^n}{2}\left(J_n'\left(ka\sin\theta\right) - \frac{J_n'\left(ka\sin\theta\right)}{H_n^{(2)\prime}\left(ka\sin\theta\right)} H_n^{(2)\prime}\left(k\rho'\sin\theta\right)\right)\cos n\left(\varphi-\varphi'\right)
\end{aligned}
\tag{2}
$$

HORIZONTAL ANTENNAS NEAR CONDUCTING WEDGE

Consider an infinite conducting wedge of angle 2α which extends from $\varphi=\alpha$ to $\varphi = 2\pi-\alpha$ and its apex is on the z-axis. Moreover, consider an electric current element in radial direction located at point (ρ',φ',z'). The radiation fields obtained from asymptotic evaluation of the dyadic Green's functions are given by:

$$
\begin{aligned}
E_\theta &= \frac{k\,\eta\pi}{(\pi-\alpha)}\cos\theta\frac{\mathrm{e}^{-\mathrm{jkr}}}{r}\sum_{n=1}^{\infty} j^{\nu_n} J_{\nu_n}'\left(k\rho'\sin\theta\right)\sin\nu_n\left(\varphi-\alpha\right)\sin\nu_n\left(\varphi'-\alpha\right) \\
E_\varphi &= \frac{\eta\pi}{(\pi-\alpha)\rho'}\csc\theta\frac{\mathrm{e}^{-\mathrm{jkr}}}{r}\sum_{n=1}^{\infty}\nu_n j^{\nu_n} J_{\nu_n}\left(k\rho'\sin\theta\right)\cos\nu_n\left(\varphi-\alpha\right)\sin\nu_n\left(\varphi'-\alpha\right)
\end{aligned}
\tag{3}
$$

In which $\nu_n = n\pi/(2\pi-2\alpha)$ for $n = 0,1,2,\cdots$ Similarly, the radiation fields of an electric Hertzian dipole in azimuth direction placed at (ρ',φ',z') are given by:

$$
\begin{aligned}
E_\theta &= \frac{\pi\eta}{\rho'(\pi-\alpha)}\cot\theta\frac{\mathrm{e}^{-\mathrm{jkr}}}{r}\sum_{n=1}^{\infty}\nu_n j^{\nu_n} J_{\nu_n}\left(k\rho'\sin\theta\right)\sin\nu_n\left(\varphi-\alpha\right)\cos\nu_n\left(\varphi'-\alpha\right) \\
E_\varphi &= \frac{\pi\eta k}{2(\pi-\alpha)}\frac{\mathrm{e}^{-\mathrm{jkr}}}{r}\sum_{n=0}^{\infty}\varepsilon_n j^{\nu_n} J_{\nu_n}'\left(k\rho'\sin\theta\right)\cos\nu_n\left(\varphi-\alpha\right)\cos\nu_n\left(\varphi'-\alpha\right)
\end{aligned}
\tag{4}
$$

NUMERICAL RESULTS

Convergence of infinite series: Numerical convergence of infinite series in (1)-(4) was investigated and the results are shown in Fig.1. For two cylinders with radius $a = 0.5\lambda, 5\lambda$ and for both cases of radial and azimuthally directed dipoles, convergence of the series in (1) and (2) is shown in Fig.1a. These dipoles are placed at distance $\lambda/4$ from the cylinder. For a right-angled wedge with a Hertzian dipole perpendicular to its face at distance $d = 0.5\lambda, 5\lambda$ from the edge, convergence of the series in (4) is shown in Fig.1b. In all cases, no more than 50 terms are needed for the infinite series to converge which shows the numerical efficiency of the modal expansions for far field calculations. As the radius of cylinder or the distance of the source from the edge of the wedge increase more terms must be added as expected.

Quarter wavelength monopole mounted on a cylinder: A resonant monopole antenna perpendicular to the surface of a conducting cylinder, as shown in Fig. 2a, was studied. Normalized far field patterns in xoz and xoy planes are shown in Fig.3. Radiated fields are calculated by integrating (1) over the half cosine current distribution on the antenna.

Half wavelength circumferential dipole: A half-wave resonant dipole wrapped around a cylinder in azimuth direction, as shown in Fig.2b, was considered. The antenna is $\lambda/4$ away from the surface and carries a sinusoidal current. Normalized E- and H-plane patterns are presented in Fig.4a and Fig.4b, respectively.

Quarter wavelength monopole antenna on a wedge: a $\lambda/4$ monopole antenna perpendicular to one side of a right-angled wedge, as shown in Fig.2c, was examined. The antenna is placed at distance d from the edge and carries a half cosine shape current. Radiation patterns of this antenna in horizontal plane for two cases of $d = 0.5\lambda, 5\lambda$ are illustrated in Fig.5.

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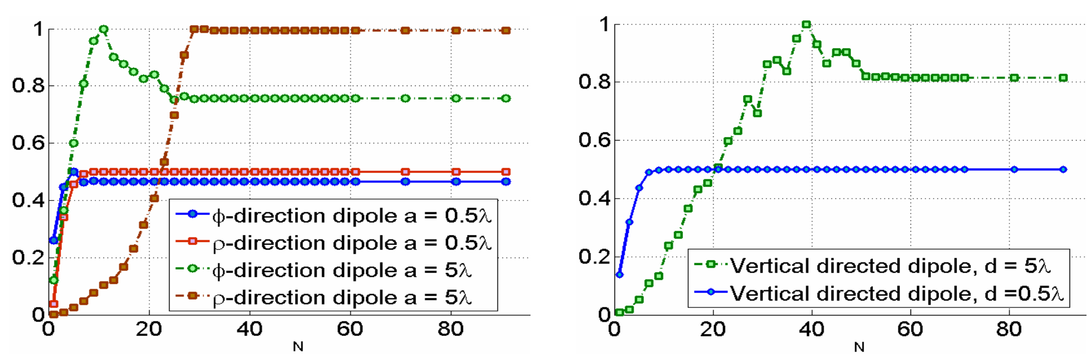
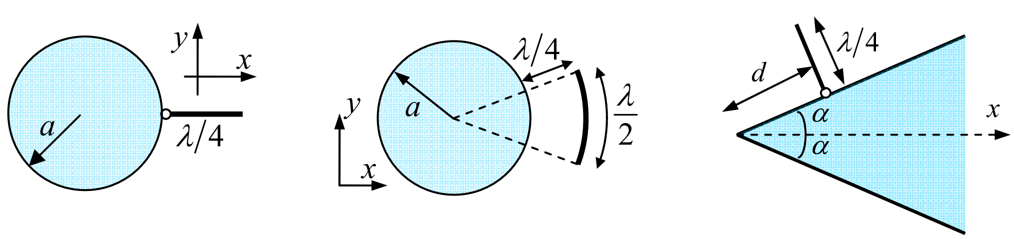


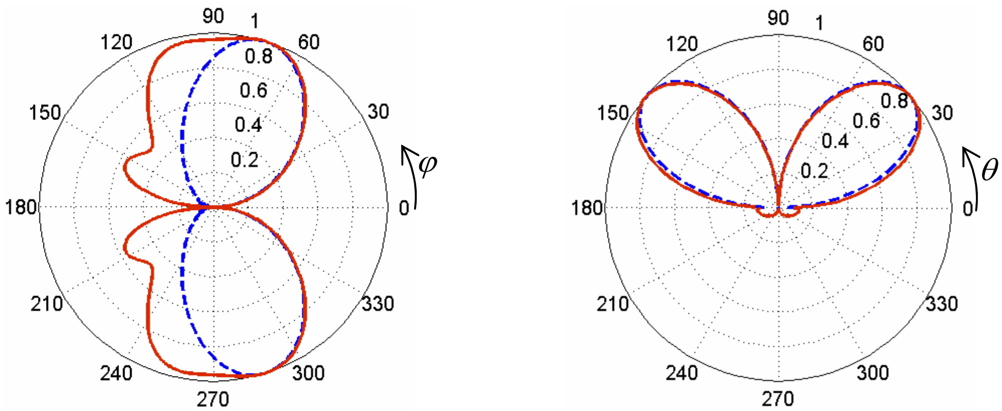
(a) Cylinder (b) Wedge

Figure 1: Number of terms required for the modal series to converge – see the text



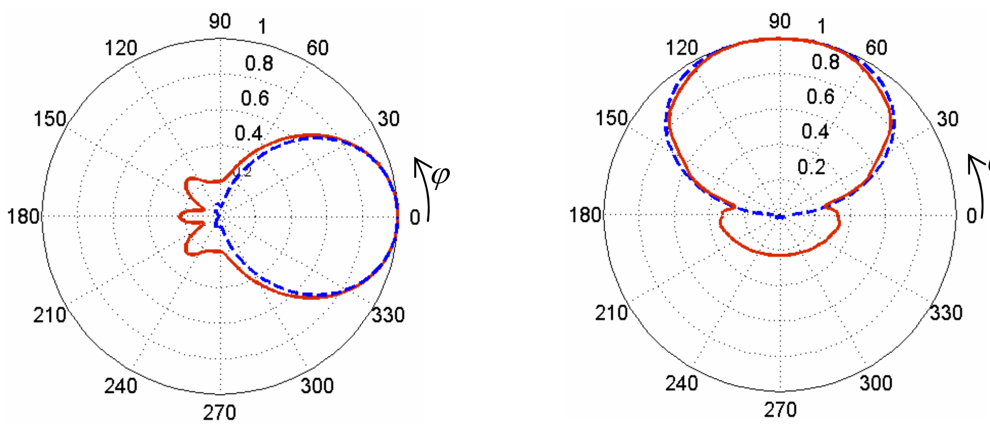
(a) (b) (c)

Figure 2: Structure of antennas considered in this paper



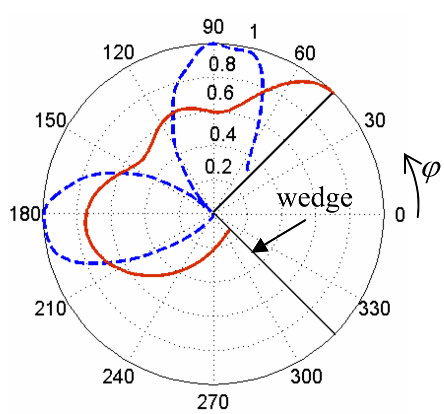
(a) E_{φ} in xoy plane (b) E_{θ} in xoz plane

Figure 3: Normalized far fields of the monopole antenna mounted perpendicularly on a conducting cylinder with radius $a = 0.5\lambda$ (solid line) and $a = 5\lambda$ (dashed line)



(a) E_{φ} in xoy plane (b) E_{φ} in xoz plane

Figure 4: Normalized radiation pattern of half-wave wraparound dipole in front of conducting cylinder with radius $a = 0.5\lambda$ (solid line) and $a = 5\lambda$ (dashed line)



(a) E_{φ} in xoy plane

Figure 5: Normalized radiation pattern for a quarter wavelength monopole antenna mounted on the face of a right-angled wedge at distance $d = 0.5\lambda$ (solid line) and $d = 5\lambda$ (dashed line) from the edge