A low-profile conical beam loop antenna with an electromagnetically coupled feed system

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continuous refractive index it is necessary to use Fourier smoothing; the value $F = 100$ was used here. (Thorough numerical tests, including comparison with the exact solution mentioned below as well as convergence tests, have shown that the values of the smoothing parameter F we used give converged solutions within the error bars quoted.) Table I shows convergence studies for $n^2 = 2$ and $n^2 = 72$. Errors in the table (maximum absolute values in the far field) were obtained by comparison with a much more refined discretization: $F = 200$, $M = 100$, $N_r = 181$, and $N_\theta = 301$ in the case $n^2 = 2$, and $F = 200$, $M = 40$, $N_r = 301$, and $N_\theta = 295$ for $n^2 = 72$. Near field errors are generally larger by a factor of 10. As claimed, our algorithm resolves the $n^2 = 2$ configuration with an error of order $10^{(-5)}$ in a 13-s run. The restart parameter required by GMRES was taken to equal 4 in the case $n^2 = 2$ and to equal 40 for $n^2 = 72$. OH denotes the overhead, and NO and NT denote the normalized quantities NO $= 10^3$OH$/(M \cdot N_r)$ NT $= 10^3$(Time $-$ OH)$/$(Restart $\cdot$ Iter $\cdot$ $M \cdot N_r$). In order to insure that these tests give an accurate measure of the error we applied the same procedure to an off-center circle for which an analytical solution is known. This geometry provides a nontrivial test for our solver since it involves discontinuities in the refractive index within the domain of integration. Our test circle has radius one and is centered at (2, 0). For $n^2 = 2$ using $M = 10$, 20, and 40 our solver yields errors of $2(-4)$, $3(-5)$, and $4(-6)$, respectively. For $n^2 = 72$ using $M = 10$, 20, and 40 modes we obtained errors of $3(0)$, $2(-2)$, and $2(-3)$, respectively, in good agreement with the orders of the errors shown in Table I.

REFERENCES

[1] N. N. Bojarski, "The k-space formulation of the scattering problem in the time domain," *J. Opt. Soc. Amer.*, vol. 72, pp. 570–584, 1982.

[2] D. Colton and R. Kress, *Inverse Acoustic and Electromagnetic Scattering Theory*. New York: Springer-Verlag, 1992.

[3] Y. Saad and M. H. Schultz, "GMRES: A generalized minimal residual algorithm for solving non-symmetric linear systems," *SIAM J. Sci. Statist. Comput.*, vol. 7, pp. 856–869, 1986.

[4] P. Zwamborn and P. Van den Berg, "Three dimensional weak form of the conjugate gradient FFT method for solving scattering problems," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 1757–1766, Sept. 1992.

A Low-Profile Conical Beam Loop Antenna with an Electromagnetically Coupled Feed System

H. Nakano, K. Fujimori, and J. Yamauchi

***Abstract*—The radiation characteristics of a low-profile loop antenna are evaluated using the method of moments (MoM). The loop having a circumference of approximately two wavelengths is electromagnetically coupled to a bent feed line and radiates a circularly polarized conical beam. The frequency bandwidth for a 3-dB axial ratio criterion is calculated to be approximately 0.5% for an antenna height of $h = 0.064$ wavelengths. Over the same bandwidth, the input impedance is approximately 50 ohms and the gain is approximately 7 dB.**

***Index Terms*—Electromagnetically coupled feed, loop.**

I. INTRODUCTION

It is well known that a loop antenna is a linearly polarized (LP) radiation element [1], [2]. Recent theoretical study has revealed that, when two perturbation elements are added to a one-wavelength circumference loop [3], an LP axial beam can be changed to a circularly polarized (CP) axial beam.

Automobile communication systems often require a CP conical beam antenna in addition to a CP axial beam antenna. For this requirement, this letter presents a low-profile loop antenna that radiates a CP conical beam. For CP conical beam formation, a single perturbation element is added to a loop whose circumference is approximately two wavelengths.

Attention is paid to input impedance matching. To reduce the high-input impedance of the conventional loop antenna fed directly from a coaxial line, an electromagnetically coupled feed system is proposed. The feed line in this system is not in contact with the loop, leading to straightforward impedance matching.

II. DISCUSSIONS

Fig. 1 shows the configuration and coordinate system of a low-profile loop antenna. The loop is made of a thin wire of radius ρ. The loop of circumference C, backed by a conducting ground plane, has a perturbation element of length ΔL at point b. The distance from the ground plane to the loop section (antenna height) and the angle made by the x axis with line o'-b (perturbation angle) are designated as h and ϕ_b, respectively. The loop is supported by a dielectric material of relative permittivity ε_r.

The feed system consists of a bent wire f-c-d of radius ρ_F, which is electromagnetically coupled to the loop (EM-coupled feed). The curved section of the feed wire c-d is parallel to the loop and located just under the loop. The vertical section f-c and the parallel section c-d have lengths of L_V and L_H, respectively.

Throughout this letter, the following parameters are chosen to be as follows: $\rho = 0.003\lambda_0 = 0.6$ mm, $h = 0.064\lambda_0 = 12.8$ mm, $\varepsilon_r \approx 1$ (honeycomb material is used for a spacer), and $\rho_F = 0.0031\lambda_0 = 0.62$ mm, where λ_0 (=200 mm) is the wavelength at a design frequency of $f_0 = 1.5$ GHz.

The loop circumference, perturbation element length, and bent wire length are initially chosen to be $C = 2\lambda_0$, $\Delta L = 0.025$ C, and $L_V + L_H = \lambda_0/4$, respectively. Then these values are optimized such that

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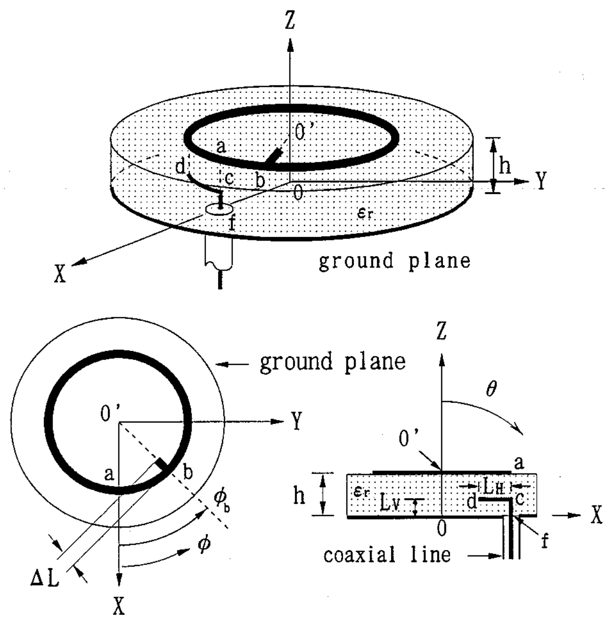

Fig. 1. Configuration and coordinate system.

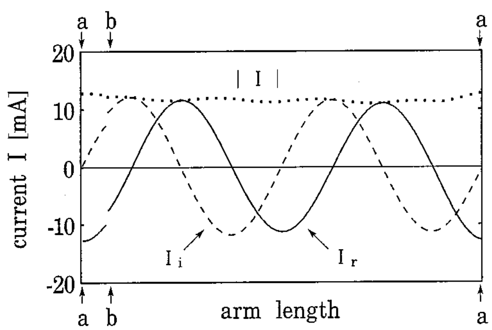

Fig. 2. Current distribution.

the antenna radiates a circularly polarized wave with an antenna input impedance of 50 ohms at the design frequency f_0, resulting in $C = 1.986\lambda_0$, $\Delta L = 0.05\lambda_0$, and $(L_V, L_H) = (0.023\lambda_0, 0.226\lambda_0)$. For confirmation of the analysis, experimental results are obtained for $f_0 = 1.5$ GHz, using these configuration parameters.

The method of moments (MoM) is used to obtain the current distribution. The theoretical radiation pattern, axial ratio, gain, and input impedance are evaluated on the basis of the obtained current distribution. Note that the ground plane in Fig. 1 is assumed to be of infinite extent.

Fig. 2 shows the theoretical current distribution at frequency f_0, where the perturbation angle ϕ_b is chosen to be $90°/4 = 22.5°$. A traveling-wave current flows along the loop section. The amplitude of the current $|I|$ $(I = I_r + jI_i)$ is almost constant. The discontinuity of the current at point b is due to the perturbation element. Note that Kirchihoff's current law is satisfied at branch point b.

The traveling current yields CP radiation. A right-hand CP wave is obtained with $\phi_b = 90°/4 + 90°n$ $(n = 0, 1, 2, 3)$, and a left-hand CP wave is obtained with $\phi_b = 90°(3/4) + 90°n$ $(n = 0, 1, 2, 3)$. The rotational sense alternates with an angle period of 45°. In the following discussion, the perturbation angle ϕ_b is fixed to be $\phi_b = 90°/4$.

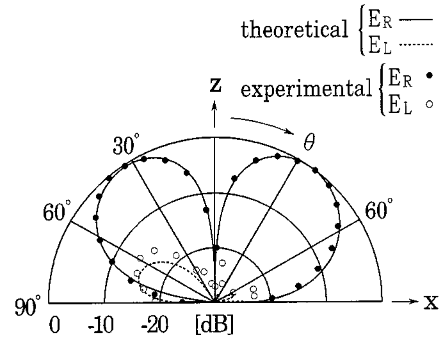

Fig. 3. Radiation pattern in the $\phi = 0°$ plane.

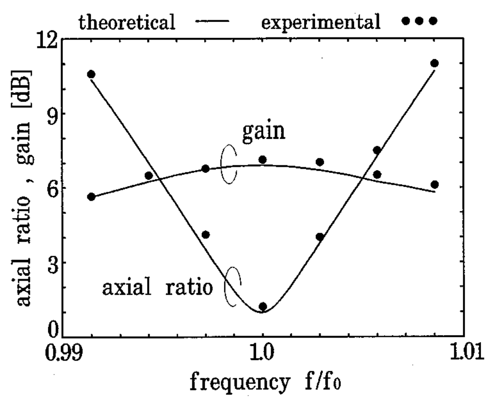

Fig. 4. Axial ratio and gain as a function of frequency.

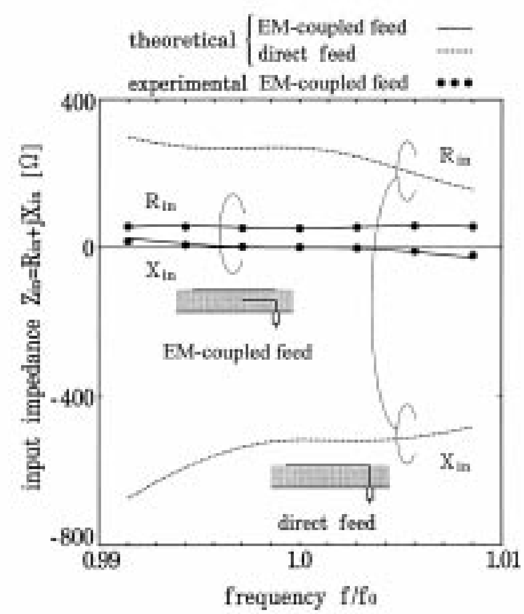

Fig. 5. Input impedance as a function of frequency.

Fig. 3 shows the theoretical radiation pattern at f_0 in the $\phi = 0°$ plane, where E_R (solid line) and E_L (dashed line) are the intensities of the right- and left-hand CP waves, respectively. The copolar component (E_R) has a maximum value in the $\theta = 34°$ direction and the variation in E_R at $\theta = 34°$ as a function of azimuth angle ϕ is very small (less than 1.1 dB). That is, a CP conical beam is formed. Note that the cross-polarization component (E_L) at $\theta = 34^\circ$ as a function of azimuth angle ϕ is very small, leading to good axial ratios of less than 2.2 dB.

The frequency response for the axial ratio in the direction $(\theta, \phi) = (34^\circ, 0^\circ)$ is shown in Fig. 4, together with the gain. The frequency bandwidth for a 3-dB axial ratio criterion is calculated to be approximately 0.5%. The gain within the same bandwidth is almost constant (approximately 7 dB).

The behavior of the input impedance, $Z_{\rm in} = R_{\rm in} + jX_{\rm in}$, as a function of frequency is shown in Fig. 5. For comparison, the input impedance when the loop is directly fed from a coaxial line (designated as the direct feed), as shown in the inset in Fig. 5, is also presented. It is found that the high-input impedance for the direct feed is reduced to 50 ohms using the EM-coupled feed, by which the antenna is easily matched to a commercially available coaxial line.

III. Conclusion

A low-profile loop antenna (antenna height $h = 0.064\lambda_0$), whose circumference is approximately two wavelengths, has been analyzed using the MoM. This loop has a single perturbation element. It is found that the loop radiates a circularly polarized conical beam with a gain of approximately 7 dB over a frequency bandwidth of approximately 0.5%. It is also found that the EM-coupled feed leads to an input impedance of 50 ohms.

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References

[1] R. C. Johnson, *Antenna Engineering Handbook*, 3rd ed. New York: McGraw-Hill, 1993, ch. 5.

[2] H. Nakano, S. R. Kerner, and N. G. Alexopoulos, "The moment method solution for printed wire antennas of arbitrary configuration," *IEEE Trans. Antennas Propagat.*, vol. 36, pp. 1667–1674, 1988.

[3] H. Nakano, "A numerical approach to line antennas printed on dielectric materials," *Computer Physics Commun.*, vol. 68, pp. 441–450, 1991.

A Coupled Surface-Volume Integral Equation Approach for the Calculation of Electromagnetic Scattering from Composite Metallic and Material Targets

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***Abstract*—A coupled surface-volume integral equation approach is presented for the calculation of electromagnetic scattering from conducting objects coated with materials. Free-space Green's function is used in the formulation of both integral equations. In the method of moments (MoM) solution to the integral equations, the target is discretized using triangular patches for conducting surfaces and tetrahedral cells for dielectric volume. General roof-top basis functions are used to expand the surface and volume currents, respectively. This approach is applicable to inhomogeneous material coating, and, because of the use of free-space Green's function, it can be easily accelerated using fast solvers such as the multilevel fast multipole algorithm.**

I. Introduction

Recently, advance in fast algorithms for computational electromagnetics demonstrated great potential to solve scattering problems with realistic targets. However, significant reduction of computational complexity has been achieved for scattering problems with conducting targets only. To expand the capability of fast solvers to include material or material coated targets, it is necessary to investigate solvers that can model material-coated targets. This is the motivation for the coupled integral-equation approach presented in this letter. It should be pointed out that scattering calculation for composite conducting and dielectric objects has been studied previously [1]–[4] using coupled surface-integral equations and coupled surface- and volume-integral equations [5]. However, [5] used pulse-basis functions and applies to rectangular shaped objects. In this letter, we present a similar formulation but with general roof-top basis function expansion and the tetrahedron discretization of the dielectrics. Hence, the approach from this letter applicable to arbitrarily shaped objects. In the following formulation, the time factor is $\exp\{-i\omega t\}$ and is suppressed.

II. Formulations

The problem is to calculate electromagnetic scattering from material-coated objects. The incident wave induces surface current $\overline{J}_S$ on the conducting surface S of the objects, and also induces volume current $\overline{J}_V$ in the dielectric region V. The total scattered field is the superposition of radiations from the surface current and volume current. Let the radiation from $\overline{J}_S$ and $\overline{J}_V$ be $\overline{E}_S^{sca}$ and $\overline{E}_V^{sca}$, respectively, then

$$\overline{E}_\alpha^{sca} = i\omega\mu_b \int_\alpha \overline{\overline{G}}(\overline{r}, \overline{r}') \cdot \overline{J}_\alpha d\overline{r}', \qquad \alpha = S \text{ or } V \tag{1}$$

where $\overline{\overline{G}} = (\overline{\overline{I}} + \nabla\nabla/k_b^2)\exp\{ik_b|\overline{r} - \overline{r}'|\}/4\pi|\overline{r} - \overline{r}'|$ is the 3-D dyadic Green's function, and k_b is the wavenumber for the background media. The surface integral equation is formed based on the boundary

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