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A 3-D ANALYSIS OF ARBITRARILY SHAPED ICRF ANTENNAS AND FARADAY SHIELDS*

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I. Introduction

Cavity antennas with Faraday shields[1] are proposed to couple ion cyclotron radio frequency (ICRF) power for heating fusion plasmas. This application requires small, high-power, low-frequency antennas. We present the results of a theoretical study of the ICRF antennas[2,3] being developed for this purpose at the Radio-Frequency Test Facility (RFTF). The objectives of this work are to optimize experimental designs and to confirm test results.

Complete analyses of the antennas and Faraday shields are performed using a three-dimensional (3-D) analysis[4] that computes the full wave field and resonance frequency of an antenna by solving the boundary problem of Maxwell's equations or Helmholtz's equations, using the finite difference method with a successive overrelaxation (SOR) convergence scheme. This analysis allows us to model an antenna and Faraday shield of arbitrary shape in Cartesian coordinates. (This does not imply that only right-angle edges and corners are allowed as the cavity boundaries.) The analysis is easily converted to cylindrical coordinates if this is necessary or desirable. We have applied the analysis to three areas: the folded waveguide antenna,[2] the cavity antenna,[3] and the Faraday shield.[3] We describe the model in Section II and discuss the applications in Sections III and IV.

II. Theory Model

For simplicity, we assume that our antenna system is source free and is a perfect conductor. By combining Maxwell's four equations, we find that the wave equation is

$$(\nabla^2 + \mu_0\epsilon_0\omega^2)\begin{pmatrix}\vec{E}\\ \vec{H}\end{pmatrix} = 0\ , \tag{1}$$

and the boundary conditions on a perfectly conducting wall are

$$\hat{n}\cdot\vec{E} = 0\ , \tag{2a}$$

$$\hat{n}\times\vec{H} = 0\ , \tag{2b}$$

where n is a unit vector outward normal to the surface of the boundary. We solve the scale components of Eqs. (1) and (2) to obtain the full wave field and the resonance frequency ω.

III. The Folded Waveguide

We calculate the lowest few modes of the folded waveguide described in detail by Owens.[2] The fundamental resonance frequency of a 12-cm-wide, 14.5-cm-high, 21.75-cm-deep folded waveguide is 782 MHz, much lower than the resonance frequency (1243 MHz) of a rectangular waveguide of the same size. Figures 1 and 2 show H_x and H_z, respectively, for the folded waveguide. The resonance frequency and the fields, except for H_x, are in excellent agreement with the experimental measurements; H_x is qualitatively consistent with the experiments, but the relative amplitudes between vanes disagree. The measured result[2] shows that H_x has a higher field at the center of the mouth of the waveguide. This discrepancy may arise because the effect of the coaxial input is not properly considered or because the H_x field is mixed with the second harmonic mode, which has a high field at the center of the waveguide mouth and a resonance frequency very close to the fundamental. In Fig. 3, the fundamental resonance frequency is shown as a function of the distance between the end of the vane and the wall. We find that the minimum resonance frequency occurs when this gap is equal to the distance between adjacent vanes.

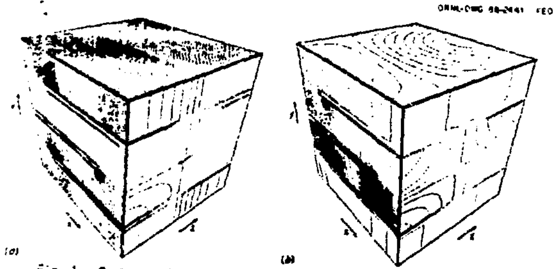

Fig. 1. Contour plots of H_x. (a) Fundamental mode. (b) Second harmonic mode.

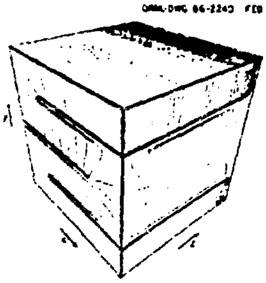

Fig. 2. Contour plot of H_z.

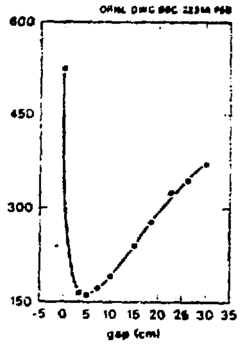

Fig. 3. The fundamental resonance frequency as a function of the gap for a 30 × 48.75 × 97.5 cm folded waveguide with 5 vanes.

IV. Cavity Antenna and Faraday Shield

We have applied our theory to the antenna and Faraday shield being tested for Doublet III-D, as described in Ref. 3. The fundamental driven mode is determined. The current strap is considered as a free parameter. The resonance frequency f is used to determine the inductance L, while the magnetic field (at the plasma edge) per unit current is correlated to the plasma load. A Faraday shield has been added to this antenna configuration to study its effects on the power limits. Table I and Fig. 4 summarize the comparison of theory and experiment. The Faraday shield reduces the inductance of the antenna and the magnetic field passing through the shield. Merely calculating the drop across the shield is not enough to determine how coupling is altered. The current distribution on the strap substantially increases the field near the shield, thereby softening the shield's impact. However, in this calculation, we have assumed that the current and the magnetic field on the strap are constant. A more detailed and realistic current profile is required for further studies.

Table I. Comparison of theory and experiment

	Theory	Measurement
f_{NF}/f_{FS}	55.07/57.20	55.843/58.348
L_{NF}/L_{FS}	1.08	1.11

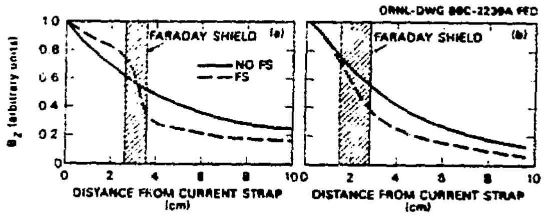

Fig. 4. Toroidal magnetic field B_z vs distance from the current strap. (a) Theory. (b) Measurement.

References

1. For example, S. C. Chiu, Bull. Am. Phys. Soc. 30(9), 1587 (1985); C. M. Fortgang et al., Bull. Am. Phys. Soc. 30(9), 1570 (1985).

2. T. L. Owens, "A Folded Waveguide Cavity Coupler for ICRF Heating," presented at this conference.

3. D. J. Hoffman et al., "ICRH Coupling in DIII-D," presented at this conference.

4. J. H. Whealton et al., A 3-D Analysis of Maxwell's Equations for Cavities of Arbitrary Shape, ORNL/TM-9792, March 1986.

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