ANALYSIS OF APERTURE ANTENNA ATTACHED TO CUTOFF CAVITY FOR ICRF PLASMA HEATING

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RF plasma heating in the Ion Cyclotron Range of Frequency (ICRF) has proven to be an efficient means to heat ions in plasma experiments [1]. In these experiments, antennas to heat plasma have been half-turn loop antennas located inside tokamaks. Such antennas, however, have some disadvantages in a fusion reactor, where high power will be applied and impurity ions can be produced from metal materials of antennas and surrounding Faraday shields [1]. Under this circumstance, aperture antennas located on a tokamak wall and attached to cavity outside of vacuum vessel are proposed [2],[3]. Since available dimensions of port area of tokamak is limited and the frequency used to heat plasma is the order of 100MHz, the attached cavity would be cutoff even if a large tokamak were used. The purpose of this report is to show the basic properties of such an aperture antenna attached to cutoff cavity.

The geometry of the aperture antenna attached to rectangular cutoff cavity is illustrated in Fig.1, where the width of the aperture b is less than $\lambda/5$ even for large tokamaks. Surface current of antenna conductor $J(x,y)$ and tangential electric field $E_a(x,y)$ on the aperture are expressed respectively as follows:

$$J(x,y)=\sum_{k=0}^{K} I_k j_k(x,y)\hat{x}, \quad (1) \qquad \hat{z}\times E_a(x,y)=\sum_{l=0}^{L} V_l \hat{z}\times e_l(x,y), \quad (2)$$

where

$$j_k(x,y)=\frac{\Gamma(1/6)}{3w\sqrt{\pi}\,\Gamma(2/3)}\sqrt{\frac{2\varepsilon_k}{ab}}\cos\frac{k\pi x}{a}[1-(b-2y)^2/w^2]^{-1/3}, \quad (3)$$

and

$$e_l(x,y)=e^x_{mn}(x,y) \text{ or } e^y_{mn}(x,y) \quad (4)$$

$$e^x_{mn}(x,y)=\sqrt{\frac{2\varepsilon_m}{ab}}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\hat{x}, \quad e^y_{mn}(x,y)=\sqrt{\frac{2\varepsilon_n}{ab}}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\hat{y}, \quad (5)$$

are vector mode functions of LSE^x and LSE^y modes, respectively. Antenna current and aperture field expressed by (1) and (2) are substituted in integral equations which satisfy boundary conditions on the aperture and the antenna surface. Applying the Galerkin's method, one can obtain a $(K+L+2)\times(K+L+2)$ matrix equation involving unknowns I_k and V_l which can be easily solved numerically. Driving delta gap voltage is assumed at $x=0$ and $(b-$

$w)/2 < y < (b+w)/2$.

Fig.2 shows the input impedance of the aperture antennas attached to cutoff cavity comparing with experimental data. It is found that a resonance occurs below the frequency of $a=0.25\lambda$. Good agreement between theory and experiment can be observed indicating the validity of the analysis.

Input admittance of the aperture antenna is plotted in Fig.3 for the varying values of b/a. Sensitivity Q obtained from the admittance characteristics in the vicinity of resonant frequency and shortening coefficient η defined by $\eta=[a/\lambda]_{resonance}/0.25$ are plotted in Fig.4. As seen in Fig.3 and Fig.4, the conductance increases and the corresponding value of Q decreases rapidly with increasing b/a. This tendency indicates the significance of selecting dimension b as large as possible. Fig.5 and Fig.6 show the sensitivity Q and the shortening coefficient η as functions of d/a and s/a, respectively. Since the cavity is cutoff, it is expected that sensitivity Q can be improved by decreasing the depth of the antenna s. However, Fig.6 illustrates saturating tendency of Q as s decreases. This tendency can be interpreted as follows. For the case of large s, the aperture electric field is weak and radiation resistance becomes also small. For a small value of s, the distribution of electric field is not uniform as shown in Fig.7 and only the field in the vicinity of driving point is strong which yields rather small radiation resistance and a large value of Q.

Basic characteristics of the aperture antenna attached to a cutoff cavity are investigated. Good agreement between theory and experiment is observed indicating the validity of the analysis. Further investigation of the aperture antenna in the presence of anisotropic plasma medium can be performed by extending the present analysis.

REFERENCES

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[3] F.W.Perkins and R.F.Kluge,"A Resonant-Cavity ICRF Coupler for Large Tokamaks",IEEE Trans.Plasma Science,PS-12(2), pp.161-172(1984).

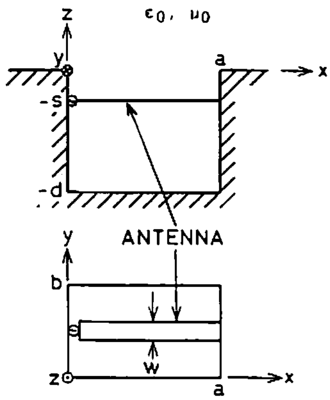

Fig.1 Coordinate system of the aperture antenna attached to cutoff cavity.

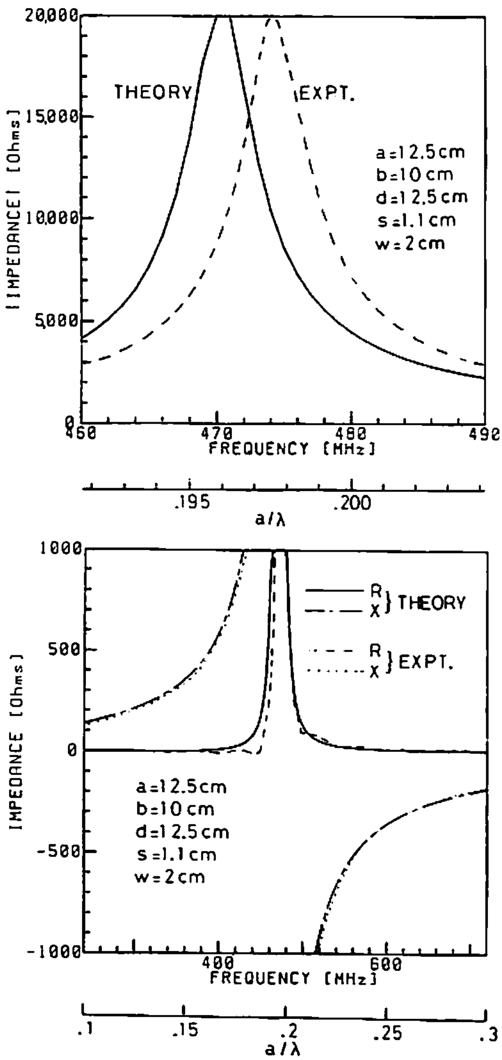

Fig.2 Input impedance of the aperture antenna as a function of frequency.

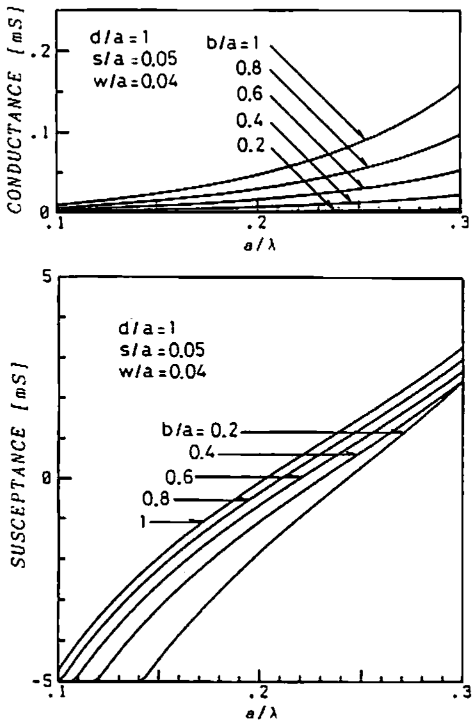

Fig.3 Input admittance as a function of a/λ with the varying values of b/a.

Table I Included Modes in calculations in Figs.2-6.

$k=0,1,2,\ldots\ldots\ldots,14\ (K=14)$

l	0	1	2	3	4	5	6	7
LSE mode	x 0 1	x 1 1	y 1 1	x 2 1	y 2 1	x 3 1	x 1 3	x 0 3

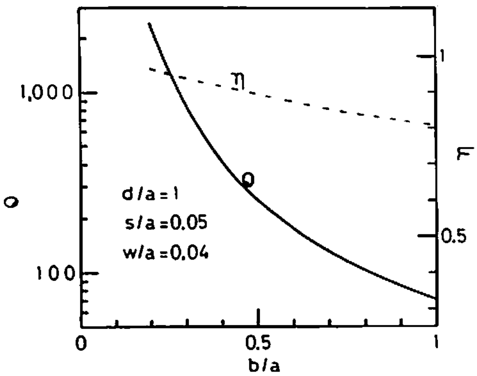

Fig.4 Sensitivity Q and shortening coefficient η as a function of b/a.

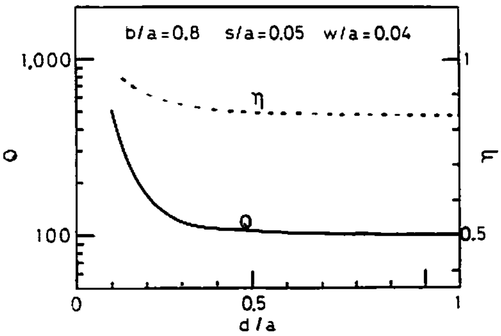

Fig.5 Sensitivity Q and shortening coefficient η as a function of d/a.

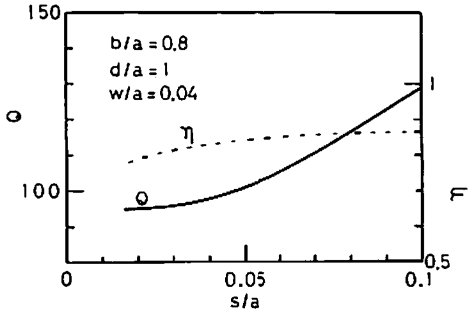

Fig.6 Sensitivity Q and shortening coefficient η as a function of s/a.

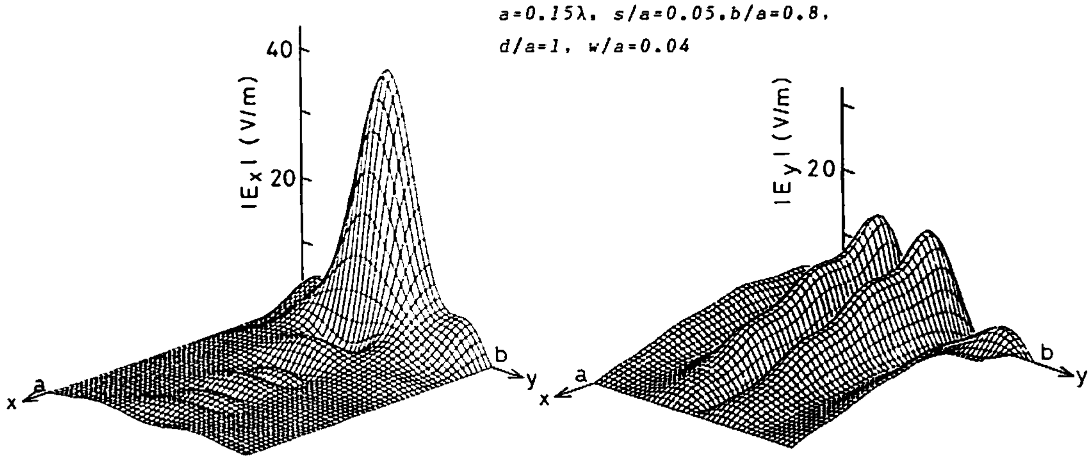

Fig.7 Aperture electric fields (K=14, L=44). Included modes in the calculation are LSE^x_{mn} (m=0,1,..7, n=1,3,5) and LSE^y_{mn} (m=1,2,..7, n=1,3,5).