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THE CAPACITANCE OF FERRITE LOADED CAVITIES

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ABSTRACT

We have recently measured the capacitance of the coaxial quarter wave-length cavity. The object of the investigation is to determine the effect of the ferrite discs and cooling plates on the distributed capacitance of the cavity. The variations of the cavity capacitance were observed as a function of the number of ferrite rings. Experimental results showed that the capacitance decreased as the number of the ferrite discs increases. And the existence of the metallic cooling plates seemed to enhance the distributed capacitance of the cavity. Floating of the cooling plates, as compared to grounding, produced a smaller value of distributed capacitance. The experimental results were also compared with the results calculated from the Superfish code and the results were very consistent.

INTRODUCTION

The ferrite loaded cavity consists of several materials distributed along the longitudinal direction[1]. The impedance of the cavity can be calculated by means of a distributed constant analysis. It is well-known that the inductive part of impedance is due mainly to the inductance of the ferrite discs because of their high magnetic permeability. The inductance can be analytically calculated very well, but it is very difficult to estimate the distributed capacitance of the cavity.

The barrier cavity requires the smallest value of capacitance consistent with tuning of the ferrite inductance to keep the drive current as low as possible. To increase the barrier voltage per unit length, a multi-gap rf-station, which is made up of several short re-entrant cavities, has been considered as an AGS barrier system.

Generally, when the re-entrant cavity is filled with a uniform material the electromagnetic field is a transverse mode (TEM). However, in practically, as the ferrite stack is interleaved with thin metallic plates for cooling, the electric field around the metals should turn direction locally so as to cross perpendicular to their surface. Then, it seems as if the parallel-plate capacitors are in series along the co-axial cavity because of the high ferrite permittivity. These capacitors could be anticipated to enlarge the cavity capacitance if the number of the ferrite discs is reduced and the cavity becomes shorter.

In order to look into this effect, a very simple co-axial cavity was made [FIGURE-1] and the capacitance of it was measured precisely. Experimental results were also compared with the SUPERFISH calculations.

CAVITY

The co-axial cavity was of a simple design, avoiding the intricacies of both measurements and Superfish calculations. The cavity consists of the ø6" inner and ø21" outer conductors and both end plates. One of end plate is electrically grounded. The other end is opened to be the gap, where the external capacitors are attached for tuning the cavity. The cavity is designed so that the maximum 6 pieces of AGS 4L2 ferrite discs and cooling plates can be installed.

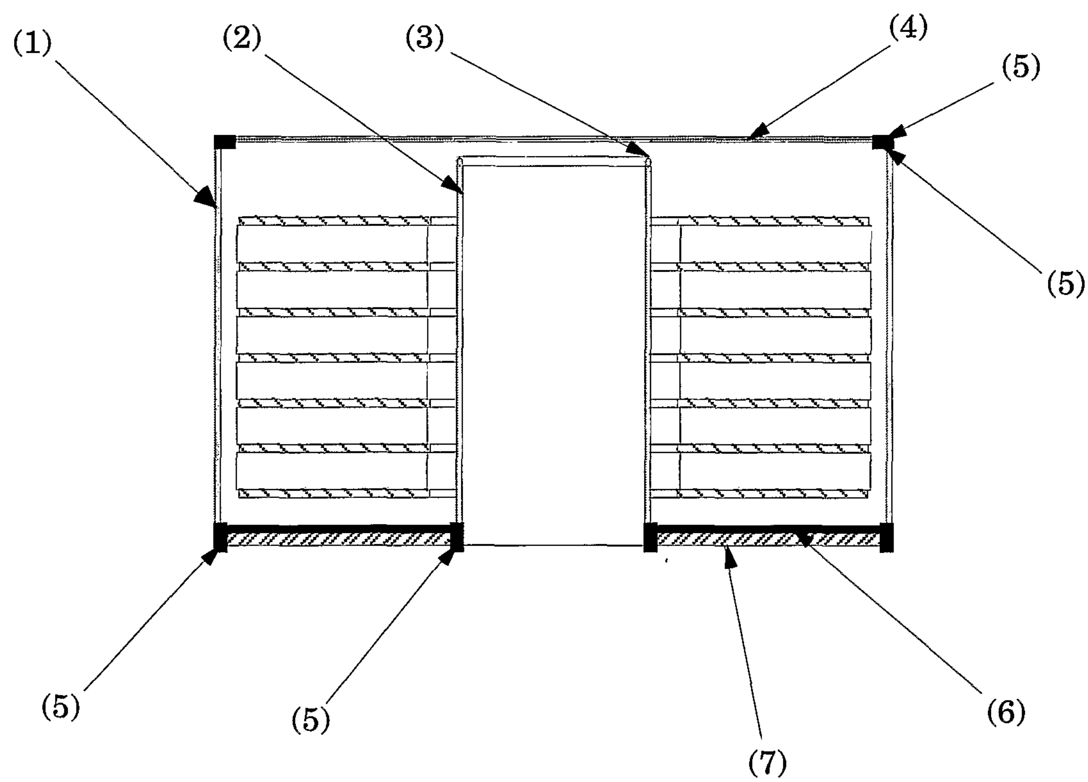


FIGURE-1 Cross-sectional view of the cavity:
(1) outer conductor : ID = 21", 13" height, (2) inner conductor : OD = 6", 11.5" height, (3) inner gap ring, (4) end plate (Top : gap side), (5) rf contact, (6) end plate (Bottom : short plate) and (7) base plate (wood)

MEASUREMENTS

The resonant frequency of the cavity is proportional to $\left(LC_T\right)^{-\frac{1}{2}}$. Total capacitance ($C_T$) is given by

$$C_T = C_{st} + C_{ext} \qquad (1),$$

where C_{st} is the distributed capacitance of the cavity and C_{ext} is the known capacitance externally attached to change the resonant frequency.

The value $\frac{1}{f^2}$ varies linearly with C_{ext}, provided that μ dose not depend on the frequency change. Therefore, by measuring the resonant frequency with various capacitors, one can deduce the unknown capacitance (C_{st}); see FIGURE-2 as an example. The impedance of the cavity was measured by a network analyzer directly, and the resonant frequency of the cavity is the frequency at which the imaginary part of impedance becomes zero.

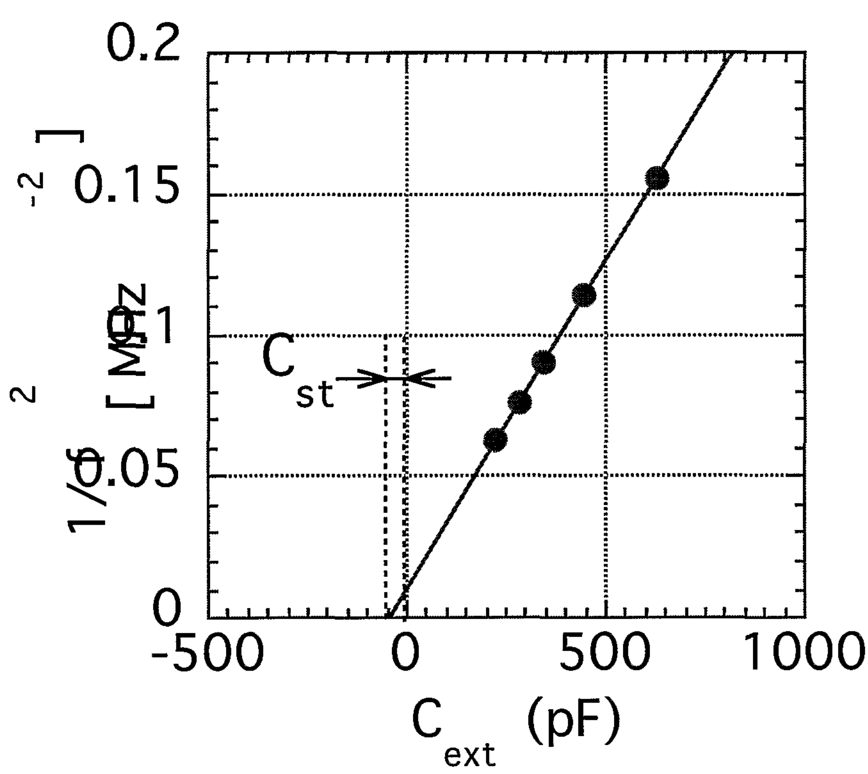


FIGURE - 2 : Typical plot

RESULTS AND DISCUSSIONS

(1) Capacitance variations as a function of the number of the ferrite discs :

The distributed capacitance originated from the cavity structure, and decreases with the number of the ferrite discs, as mentioned previously. A part of the cavity capacitance seems to be made up of the parallel-plate ferrite capacitors in series along the inner duct; see FIGURE-3.

(2) Effects of the ferrite cooling discs. The following three cases were carried out, in order to verify the effects of the cooling discs on the capacitance. For simplicity, the cavity with one ferrite disc was tested.

CASE-(A) : In the case that the cooling plates are electrically floated,

Cst = 105 ± 8 pF CT = 1434 pF [1430.5 pF].

CASE-(B) : In the case that the cooling plates are grounded to the outer conductor.

Cst = 178 ± 38 pF CT = 1508 pF [1494.1 pF].

CASE-(C) : In the case of stacking the ferrites without the cooling plates,

Cst = 70 ± 3 pF CT = 1399 pF [1396.3 pF].

Where the value in the square brackets [ ] shows the total capacitance computed by using the SUPERFISH code. Both results are very consistent. Also, it is obvious that the existence of the cooling plates has an effect upon the distributed capacitance of the cavity.

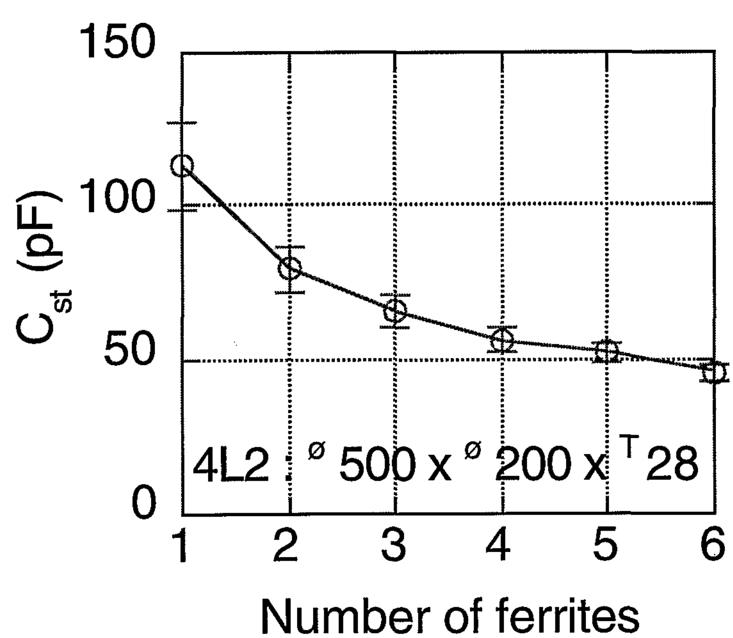


FIGURE-3 The variation of the capacitance as a function of the number of the ferrites, in the case that the ferrite cooling discs are electrically floating.

SUPERFISH

Assuming C_{st} in eq. (1) is represented by,

$$C_{st} = \varepsilon_f \ A + B \tag{2}$$

where A and B are the constants and ε_f is the relative permittivity of the ferrite. When C_{ext} in eq.(1) is fixed the total capacitance (C_T) is rewritten as a linear function of ε_f,

$$C_T(\varepsilon_f) = \varepsilon_f \ A + C_o \tag{3}$$

where Co denotes the capacitance which comes from the cavity itself without the ferrite discs and the externally connected tuning capacitor. Since eq.(3) is a linear function of ε_f, the contributions of both the ferrite disc and cooling plates on C_T can be evaluated by changing ε_f and looking into the variation of C_T. FIGURE-4 shows the variations of C_T as a function of ε_f in two case of CASE-(A) and CASE-(B). In both cases, the values of Co in eq.(3) are very same when ε_f goes to zero. Those values are also very close to total capacitance (CT) in CASE-(C). In the calculations, the values Co were 40 pF in CASE-(A) and 96 pF in CASE-(B), which was derived by the existing ferrites and cooling plates.

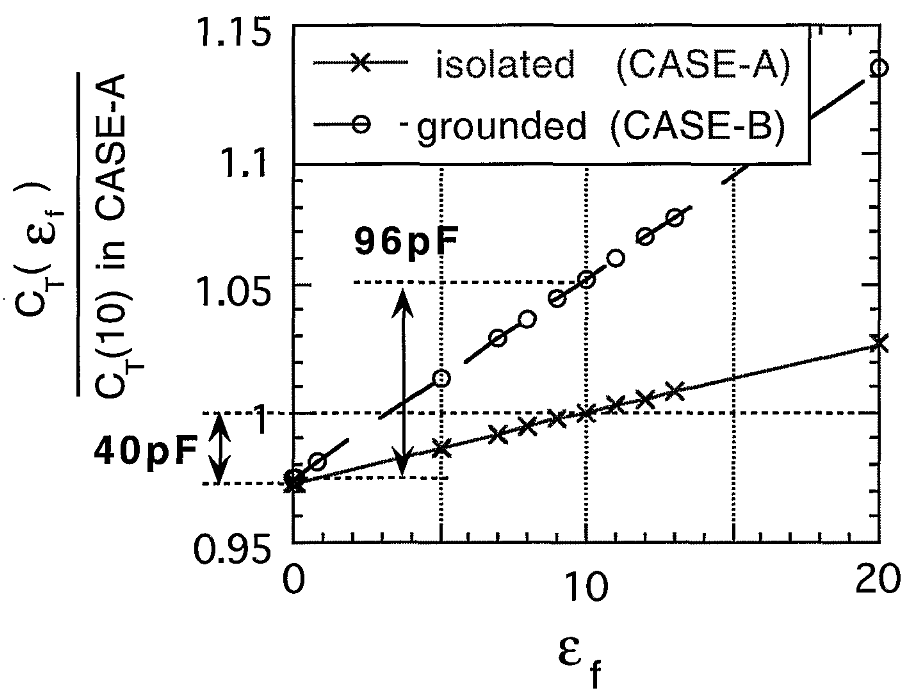


FIGURE-4 The variation of the total capacitance as a function of the di-electric constant of the ferrite (SUPERFISH): the capacitance at $\varepsilon_f \rightarrow 0$ gives the cavity capacitance when the ferrite disc does not exist.

(Permittivity of 4L2 ferrite is $\varepsilon_f = 10$.)

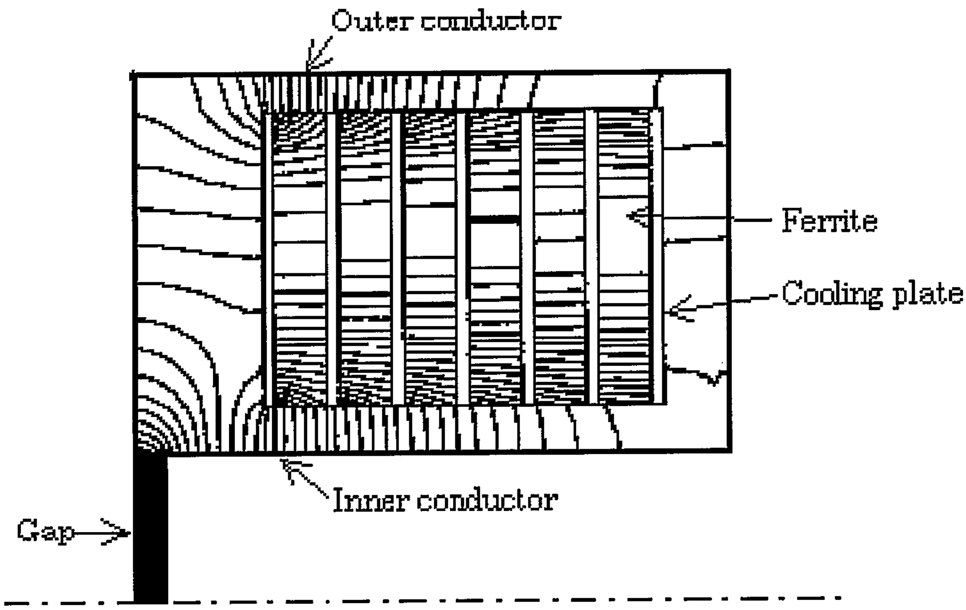
In SUPERFISH code, a very high di-electric material was artificially installed at the gap in order to change the resonant frequency of the cavity, instead of putting the external capacitors.

CONCLUSION

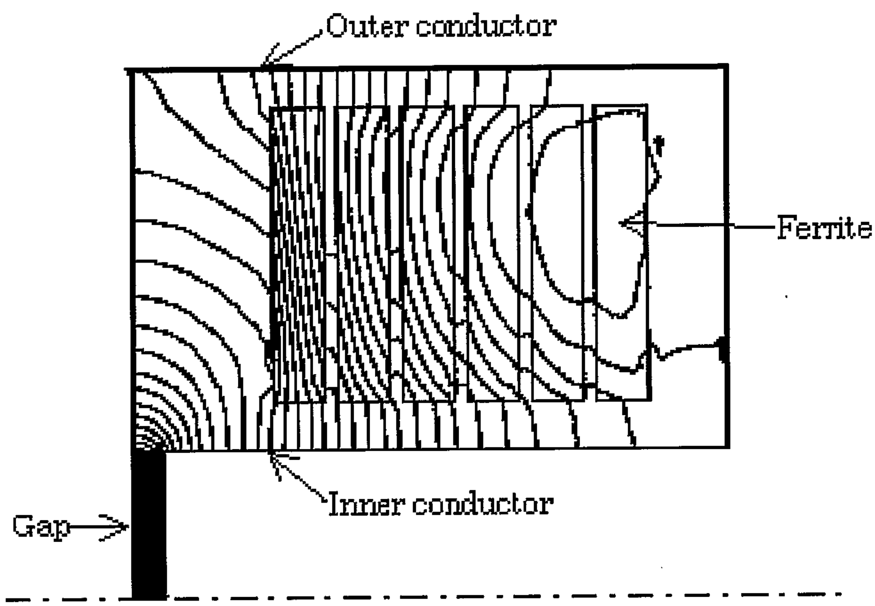
The cooling plates force the electric field in the ferrite to exist in the longitudinal direction because of the shielding effects or boundary condition of the existing metallic plates. The electric field is normal to a metallic surface; see FIGURE-5. It seems as if the parallel-plate ferrite capacitors might be existing in series. For conventional usage of the ferrite-loaded cavity, these capacitors are negligible. However, to minimize the capacitance in a barrier cavity, these contributions should not be ignored. The computations by SUPERFISH were very helpful. The SUPERFISH explained the experimental results qualitatively and visibly very well, but quantitatively, there were some small discrepancies between the two.

REFERENCES

[1] I.S.K.Gardner, Ferrite Dominated Cavity, CAS RF Engineering for Particle Accelerators. Vol.II, CERN 92-03 (1992)



(a) Ferrite discs with cooling plates



(b) Ferrite discs with no cooling plate

FIGURE - 5 Superfish Field Plots :
Electric field lines in the ferrite loaded cavities with the cooling plates (a), and without the plates (b) are displayed. Each cross-sectional view shows a half of the cavity