STUDIES OF THE FOUR-ROD RFQ USING THE MAFIA CODES *

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Abstract

A four-rod radio-frequency quadrupole (RFQ)[1,2] was studied using the MAFIA codes[3] in the hopes of reducing the maximum power loss density, an important consideration for CW operation. The 389.9-MHz calculated frequency was within 2.1% of the 407.5-MHz measured value, and a study of the magnetic field patterns[4] showed that the current flow, and hence power loss, was concentrated at the outer part of the rods. A simple modification of the rod shape reduced the power loss density in this region, which would ease the cooling problem. This modification, however, only improved the Q of the structure by about 1%, and further studies are needed to determine if the efficiency of the structure can be significantly improved.

Introduction

Because of its mechanical simplicity and robustness, the four-rod RFQ is an attractive focusing and accelerating structure at lower frequencies. At higher frequencies, e.g., around 425 MHz, the short distances and high capacitance between the rods can lead to high power-dissipation densities, but the structure is still worth studying, especially for CW work at high beam currents. For high beam currents the vacuum load caused by beam losses is a serious problem for a four-vane RFQ, but, because of the openness of the structure, not for a four-rod RFQ.

The three-dimensional MAFIA codes were used to study the current flow and distribution of power loss density in a four-rod RFQ in the hopes of eventually designing a more efficient structure.

Modeling the Structure

Figure 1 shows the structure being studied. The stub tuners used to tune the structure for flat fields, i.e., to make the structure look infinitely long, can be seen protruding from the back end plate. The tuners were removed from the front plate for the sake of the picture, in order to show the geometry of the structure. The dimensions of the structure are listed below; the distances between the plates were measured surface-to-surface.

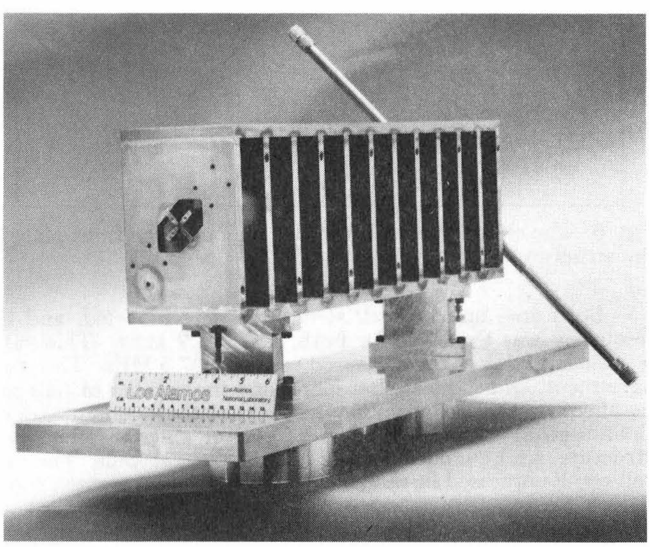

Fig. 1. The four-rod RFQ modeled by the MAFIA codes.

Thickness of vertical plates	1.07 cm
Distance between vertical plates	4.02 cm
Thickness of top and bottom plates	1.18 cm
Distance between top and bottom plates	14.93 cm
Width of vertical plates	11.50 cm

Figure 2 shows a scale drawing of the first plate, i.e., the plate closest to the viewer in Fig. 1. All odd-numbered plates have this same geometry. The dotted lines in Fig. 2 indicate the orientation of the slot for the even-numbered plates. If we call the rod in the first quadrant Rod 1, the rod in the second quadrant Rod 2, etc., one can see that Rods 1 and 3 are connected to the even-numbered vertical plates, and Rods 2 and 4 are connected to the odd-numbered vertical plates.

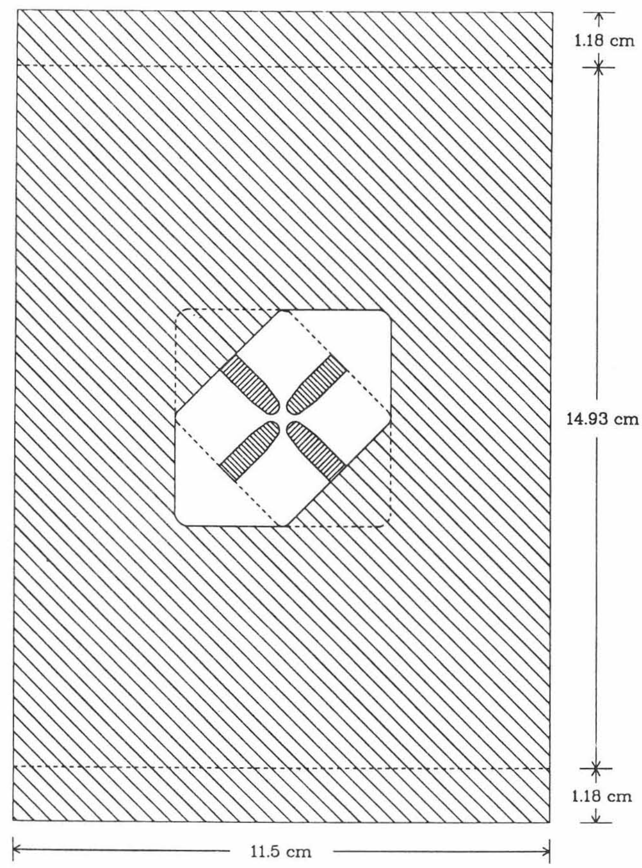

Fig. 2. Scale drawing of the odd-numbered plates. The dotted lines show the orientation of the slot for even-numbered plates.

Small rounded surfaces, such as the tips of the rods, cannot easily be modeled by the three-dimensional MAFIA codes, so the two-dimensional code SUPERFISH was used to find a simpler rod geometry with the same capacitance/unit length as in the experimental structure. More specifically, SUPERFISH was used to model a four-vane RFQ with vane tips the same shape as in the actual four-rod structure and with a 400.3-MHz frequency, roughly the measured four-rod frequency of 407.5 MHz. The vane-tip geometry was then modified until a more simple shape was found with a 399.4-MHz frequency, essentially the same as before. It was assumed that because the frequency did not change, the capacitance/unit length was the same for both geometries.

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The simplified rod shape was then used to model the structure by the MAFIA codes. Figure 3 shows the front plate of the MAFIA model, including the space allowed on both sides of the plates.

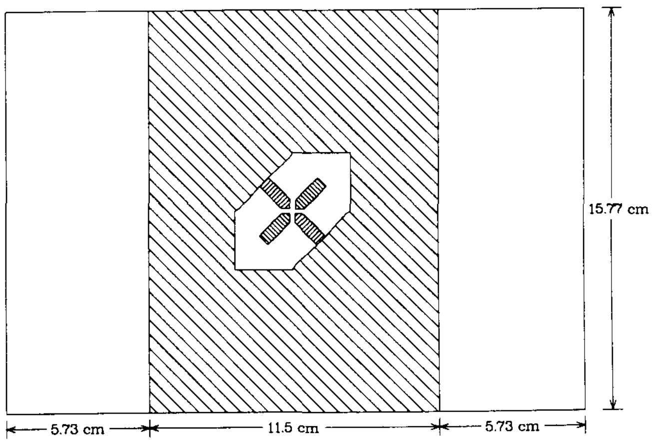

Fig. 3. Scale drawing of the front plate of the MAFIA model, including the space on both sides.

For boundary conditions we assumed that the tangential magnetic field was zero at both end plates and that the tangential electric fields were zero at the sides and tops of the region included in the model. Figures 4 and 5 show the magnetic field at approximately the middle of Cell 1. Figure 4 shows the whole plane; Fig. 5, a close-up view of the slot region. Figure 6 shows the electric fields in the slot region. This particular electric field plot was taken at the front plate, but the plots for the other planes look essentially the same. In the field plots, arrows indicate the transverse fields, and circles indicate the longitudinal fields. A cross within a circle indicates the vector is into the paper, i.e., towards the back of the structure; a dot within a circle indicates the vector is out of the plane of the paper, or toward the front of the structure. The diameter of a circle is proportional to the longitudinal field strength, and the length of an arrow is proportional to the transverse field strength.

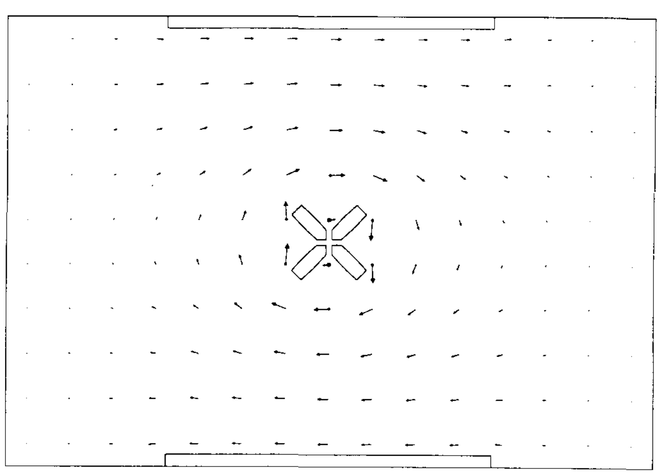

Fig. 4. Magnetic fields at approximately the middle of Cell 1.

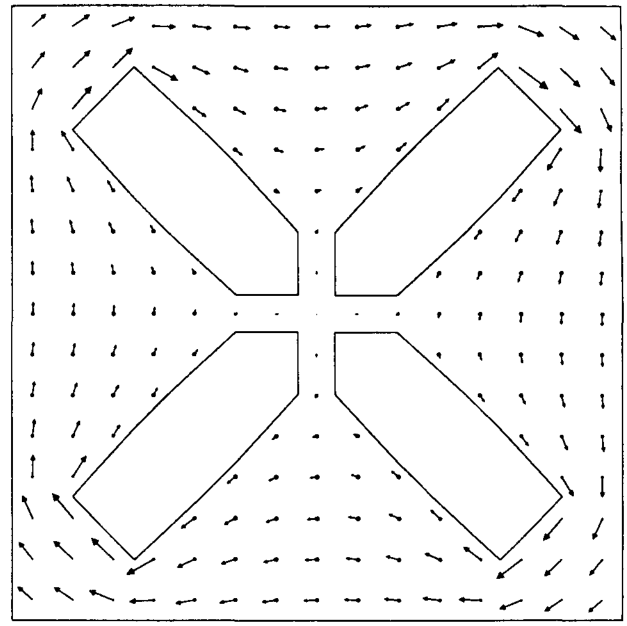

Fig. 5. A close-up view of the magnetic fields in the slot region at approximately the middle of Cell 1.

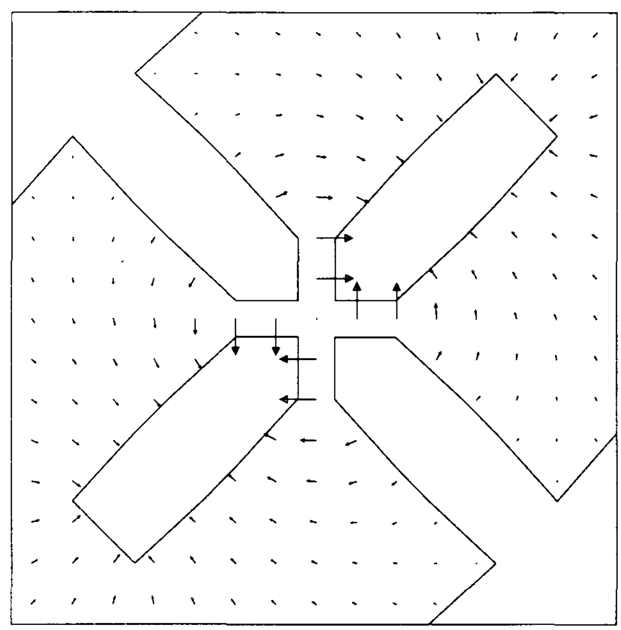

Fig. 6. The electric fields in the slot region at the front plate of the structure.

Both one- and two-cell structures were modeled, and the frequency was the same for both, i.e., 398.9 MHz. This value was within 2.1% of the measured value of 407.5 MHz. This close agreement, and the fact that increasing the number of cells had no effect on the frequency, indicates that the boundary conditions used at the end plates were correct and that the whole structure can be modeled using only one or two cells. The two-cell results are used in the analysis below.

Reducing the Power-Loss Density

The schematic in Fig. 7 illustrates the current flow in the first cell. The dotted arrows represent the displacement current, which causes the variation in the magnitude of the currents. The currents in the second cell are a mirror image, reflected through the boundary between the cells, of the currents in the first cell. In other words, the transverse currents in the second cell are in the same direction as the transverse currents in the first cell, whereas the longitudinal currents change direction.

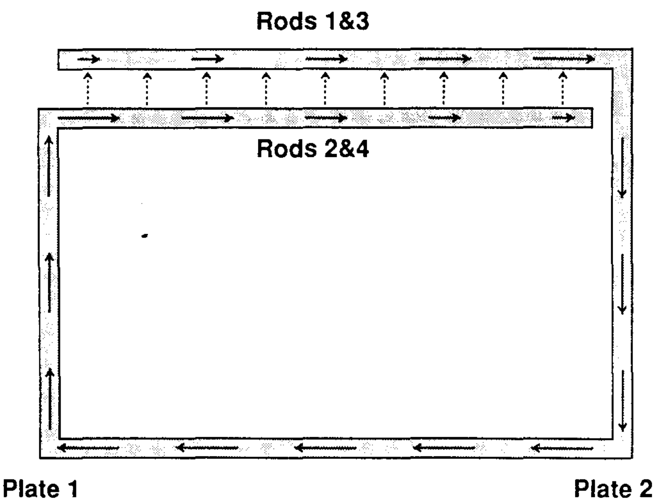

Fig. 7. Schematic of the currents flowing between the vanes in the first cell. The dashed lines represent the displacement current between Rods 1 and 3 and Rods 2 and 4.

One consequence of the currents on the four rods being primarily in the same direction is that the magnetic fields at the tips of the rods tend to cancel. Thus the transverse magnetic field and the current density are strongest at the outer part of the rods. (See Figs. 4 and 5.) The concentration of current in this region suggests that increasing the width of the outer part of the rods could spread the current over a wider area, hence reducing the power loss density. In fact, this is exactly what happens. Figure 8 shows the front plate of a structure (with 398.0-MHz frequency) with more surface area at the outer part of the rods. Figure 9 compares the average power-loss density from longitudinal currents as a function of distance for the two rod shapes and shows that the average power-loss density did indeed decrease.

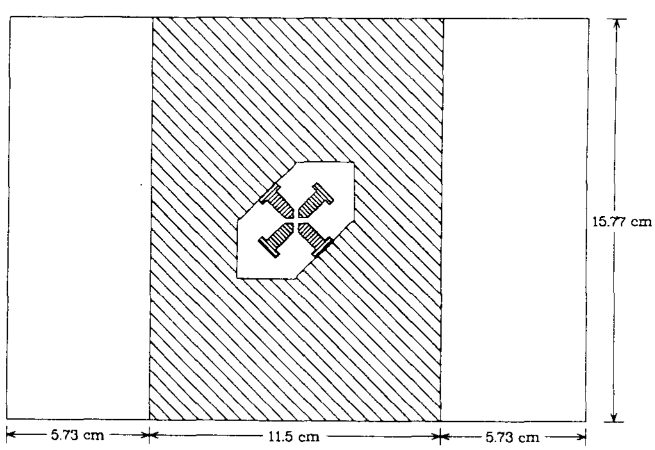

Fig. 8. Front plat of the MAFIA model with increased surface area at the outer part of the rods.

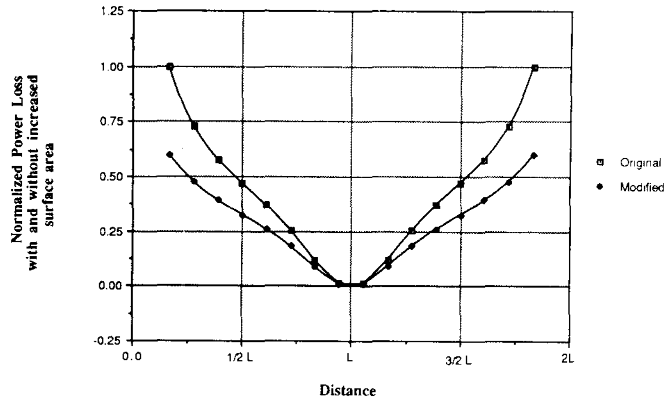

Fig. 9. A comparison of the average power loss density from longitudinal currents for the original and modified MAFIA structures. The power-loss density was averaged over the outer surface of Rod 2, and the values are normalized so that the largest value is 1. Distances are expressed in terms of the cell length, L.

On the other hand, the calculated Q changed only by about 1%, having a value of 7510 for the original structure, 7600 for the modified structure. This result is not surprising, because the surface area of the rods increased as the power loss density decreased.

Conclusions

When a complicated resonant structure such as the four-rod RFQ can be modeled by the three-dimensional MAFIA codes, the codes can give invaluable insight. In the case of the four-rod RFQ, the codes have demonstrated a way of reducing the maximum power-loss density, an important problem for CW structures. The simple modification of the rod shape tested here had little effect on the the Q of the structure; therefore, further studies are needed to determine whether the efficiency of the structure can be significantly improved.

Acknowledgment

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