STUDY OF A FOUR-ROD RFQ STRUCTURE AT 470 MHZ*

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Abstract

The four-rod RFQ structure, originally developed at Frankfurt, is a viable alternative to the four-vane structure. The four rod structure is easier to construct and maintain. Also the unwanted dipole mode is not a problem since the opposite rods are connected by the rod support structure. However, this structure has not been studied extensively for frequencies much above 200 MHz. We have developed a four-rod cavity design which can resonate at higher frequencies. In this paper we present our design for a 470MHz structure and show results of computer simulation using the MAFIA codes.

Introduction

The radio frequency quadrupole is now the most favored method for low energy acceleration and bunching of both light and heavy ion beams. Among different RFQ structures, the Frankfurt four-rod design[1] has the advantage of simpler construction and better field quality. By introducing small variations into the Frankfurt geometry and replacing the "U" shaped supports with cylindrical cavities, we have been able to achieve higher frequencies for a resonable cavity size[2] (Fig. 1). The basic unit cell consists of a cylinder with two end caps which are connected to the four rods; each end cap is connected to two opposing rods. The structure is made up of a series of such cells next to each other. This structure retains many virtues of the regular four-rod structure. For example opposite rods are connected to each other eliminating the dipole mode. Also, since the fields are confined within the cavities, the structure can be put together and tuned before it is inserted into the vacuum vessel.

A simple formula[2] relates the resonance frequency to the geometrical characteristics of a unit cell:

$$f = \frac{1}{\left[2\pi\mu_c \ell(\ell - T)C_T \ln \frac{R_2}{R_1}\right]^{1/2}}, \qquad (1)$$

where C_T is the capacitance of the four rods per unit length. ℓ is the length of the cell, T is the thickness of end plates, R_2 is the radius of the cavity, and R_1 can be viewed as the effective radius of the combined four rod assembly. We have made calculations using the MAFIA code[3], and by changing different parameters, confirmed the basic relationship above. Moreover, the results of MAFIA calculations agree closely with a cold model for a 407 MHz structure. When designing, we use the relationship of equation 1 to guide us in adjusting the parameters of the structure. The final results are then obtained using MAFIA. In the rest of the paper we will discuss the design of a 470 MHz structure for an H^- RFQ.

The 470 MHz Structure

In order to simplify the construction, we have changed the end plates from a circular shape to a square shape, as shown in figure 2. In this way the structure will consist of a series of square plates supporting the four rods and four long rectangular plates making the four sides of the structure. The corners of the cavities have been left open to provide access to the rods. The reasons we can do this are: First, the diagonal planes going through the opposing corners are the symmetry planes of the structure; therefore, there should be no currents crossing these planes, or in other words, the $\vec{B}$ field is perpendicular to these planes. Second, the fields are weak at the corners, so leaving the corners open should not appreciably change the resonance frequency or the Q. Fig 3 shows the magnetic field for a cross section at the middle of a cell ($z = \ell/2$.) showing that $\vec{B}$ is negligible at the corners.

The actual shape of a rod with round tips is shown in figure 2; however, they were replaced with a simpler shape, more acceptable to mesh generation in the MAFIA codes. The capacitances of both shapes where checked by the CAP program which we have developed by simple modifications to the POISSON code. The relative difference in the two capacitances was about 0.1%, as shown by Fig. 4.

Table 1: Parameters of the RFQ

frequency	470 MHz
ion	H
initial energy	30 keV
final energy	2 MeV
total length	85.6 cm
aperture	0.333 cm
intervane voltage	110 kV
unit cell length	5.4 cm
width of endplates	9.38 cm
thickness of the plates	0.635 cm
capacitance of rods	95.8 pf/m
MAFIA results:	
frequency	466 MHz
Q	9800

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The rods are attached to the plates by "L" shaped holders as shown in Fig. 5. This will increase the surface for rf joints, and thus decrease the current density on the rods near the joints. In addition, since these holders are located in high field regions, by making small changes in their shapes, one can change the resonant frequency. Therefore they could serve as the tuner for the last few MHz. Our RFQ parameters and the results of MAFIA calculations are listed in Table 1.

Modification of the End Cells

Now let us consider the fields just before entering the structure. Since there is no magnetic field outside the cells, there is no potential difference between the two rods attached to the first plate and the outside world. In other words they are grounded. However, the other two rods attached to the second plate, which is located at the interface between the first two cells, are floating at $V\cos\omega t$, where V is the maximum voltage between two adjacent rods (typically about 100kV.) For example, a particle out of the ion source sees two of the rods at zero potential and the other two at $V\cos\omega t$, giving a net potential difference of $\frac{V}{2}\cos\omega t$ between the ion source and the RFQ. To solve this problem we have added a small single gap cavity at the entrance of the structure (see Fig. 5). The function of this cavity is to operate in the TM mode and produce an electric field of $-\frac{V}{2}\cos\omega t$ to compensate for the change in the potential. This extra cavity makes the two rods connected to the first plate have a voltage equal to $-\frac{V}{2}\cos\omega t$, and produces a net potential of zero along the axis from the ion source to the RFQ. To make this extra cavity operate at the right phase (to make sure that it subtracts and not add the $\frac{V}{2}\cos\omega t$,) the two opposite corners of the first plate have been opened wider to let the magnetic field couple the single gap cavity to the first cell of the RFQ. The resonant frequency is kept constant by decreasing the length of the first cell in the RFQ structure from 5.4cm to 5.0cm.

The same solution could be used for the other end of the RFQ, however at higher energy with a bunched beam, one may or may not care about small fluctuations. Table 2 lists the parameters for the single gap cavity.

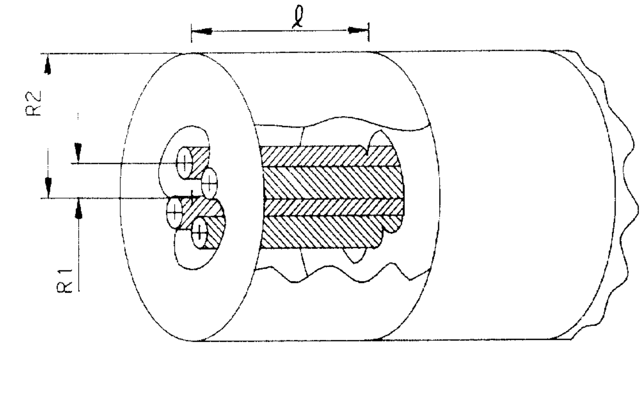

Figure 1: The four-rod cavity RFQ.

Table 2: Dimensions of the single gap cavity.

length	3.8cm
size of the gap	0.3cm
inner aperture	2.5cm
outer aperture	9.38cm

Conclusion

We have developed a simple design combining a four rod RFQ with a cavity structure for use at 470 MHz. We have shown using MAFIA that a single gap cavity at the front end will reduce the entrance potential seen by the beam to a negligible level.

References

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3. R. Klatt et al., "MAFIA – A Three-Dimensional Electromagnetic CAD System for Magnets, RF Structures, and Transient Wake-Field Calculations," in *Proceedings of the 1986 Linear Accelerator conference*, p. 276–278 (1986).

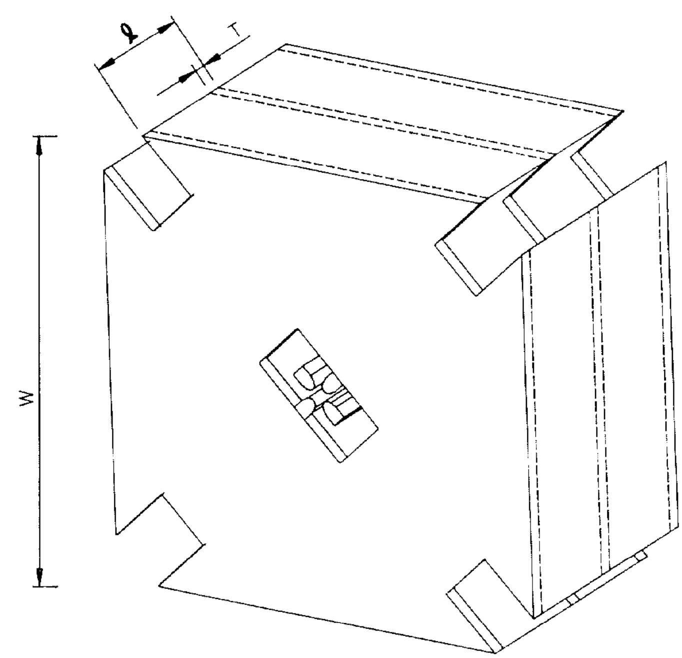

Figure 2: The 470 MHz RFQ.

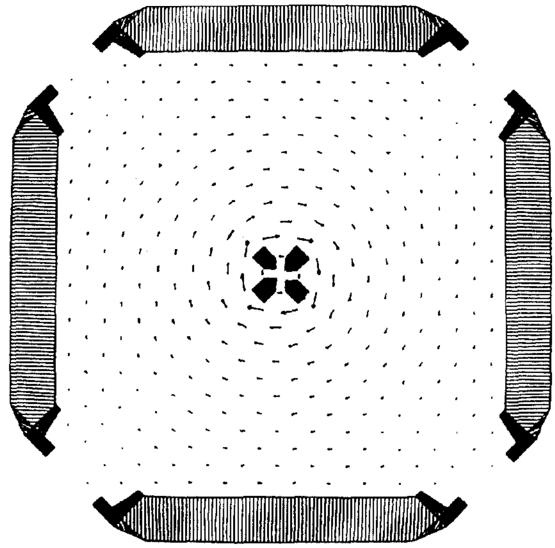

Figure 3: Plot of $\vec{B}$ for constant z at the center of a cell.

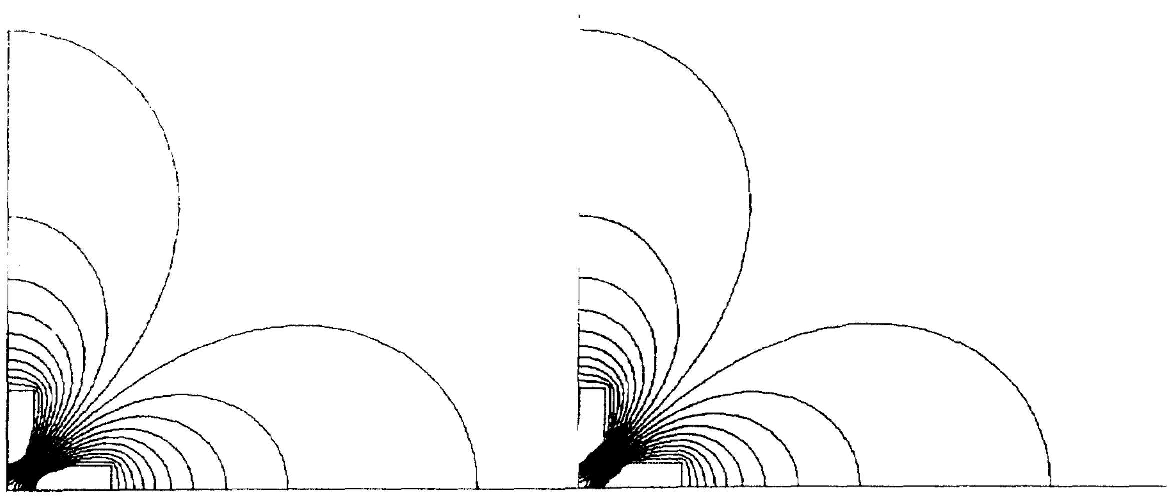

Figure 4: a) Actual rod shape. b) Shape as input to MAFIA.

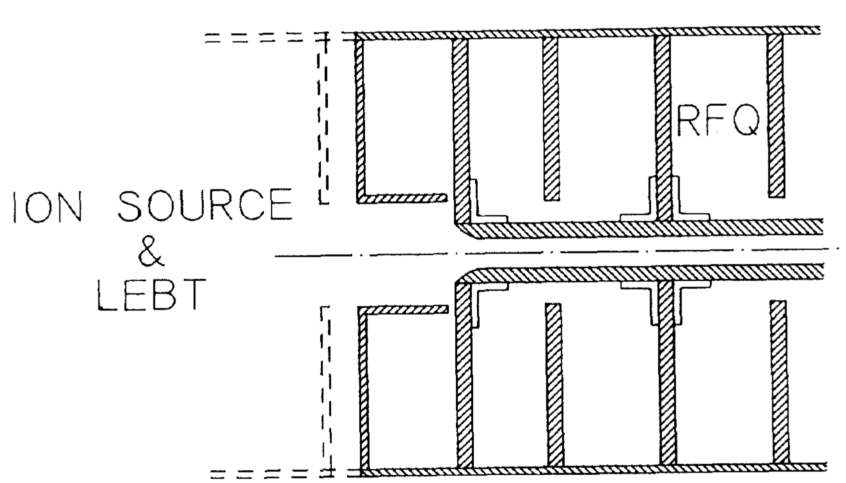

Figure 5: The cross section of the RFQ showing the single gap cavity in front of the RFQ.