SIMULATION OF THE TRIUMF SPLIT-RING 4-ROD RFQ WITH MAFIA

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To complete the analysis of the 4-rod split-ring RFQ started with cold model studies, computer simulations have also been made using the MAFIA code. Computations of voltage and magnetic field distributions were done for both a three and a ten module RFQ for a range of structure dimensions such as, minor to major radius ratio r/R, ring width, tank diameter, and spacing between adjacent rings. Shunt impedance and power densities derived from these computations were then used to optimize the dimensions of a three module split-ring RFQ now under construction.

I INTRODUCTION

A radioactive ion beam facility is part of the long range plan at TRIUMF. A proposal to install an ISOL (isotope-separator-on-line) and post-accelerator RIB facility at TRIUMF was first made in 1985[1]. Although the full project was not funded at that time, an on-line target/ion source and mass separator test facility were installed on one of the TRIUMF proton beam lines, and has been used since 1987 for both target development, and to provide low energy radioactive beams for experimenters. This project was revisited some years ago and a new proposal is being developed. The radioactive nuclei will be produced by the interaction of an intense and energetic proton beam on a thick target. After ionization and mass analysis the beam will be sent to a post-accelerator.

This post-accelerator is mainly dedicated to the nuclear astrophysics and applied physics program. The main characteristics are the following; 1) cw operation and good transmission are required to preserve beam intensity, 2) must be able to accelerate singly charge ions with mass A ≤ 30 and 3) the energy must be continuously variable from 0.2 to 1.5 MeV/u.

In our design of the post-accelerator the front end is an RFQ. It has the merit that it can accelerate very low velocity ions with a good efficiency, ≥ 90 %. The main issue requiring development for the post-accelerator is the front end RFQ since there is no known RFQ operating at low frequency and 100% duty cycle for such a low charge to mass ratio, (q/A≥1/30). It is important to select from candidate RFQ structures, one that has a high specific shunt resistance, so that the overall RF power requirement is minimized. After building several cold models to study different types of RFQ structure [2], the split-ring 4 rod RFQ structure has been chosen, because of its relatively high specific shunt impedance, mechanical stability, and absence of vane voltage asymmetries in the end regions.

The electromagnetic code MAFIA [3] was used to simulate both three and ten module versions of several split-ring 4 rod RFQ configurations and to assist in optimizing the dimensions of the selected configuration. This obviates construction of a large number of cold models during the optimization process.

II STRUCTURE OPTIMIZATION

The common way to determine the RFQ's RF power requirement is to measure the transverse shunt resistance of the structure. We define the specific shunt resistance of an RFQ by the following expression,

$$R_S = \frac{V_P^2}{2P/l},$$

where V_P is the inter electrode peak voltage, P the power loss and l the RFQ length. Many parameters affect the specific shunt resistance; the most important are the ratio r/R, the ring width, the tank diameter and the spacing between adjacent split-rings. Fig. 1 shows a schematic drawing of the split-ring 4-rod RFQ used in our simulation.

A. Rs vs the ring width, z

Two simulations for ring widths of 10 cm and 15 cm gave computed shunt resistances of 503 kW m and 560 kW m respectively. Since wider ring would be impractical from a mechanical point of view the 15 cm width was chosen for all subsequent calculations.
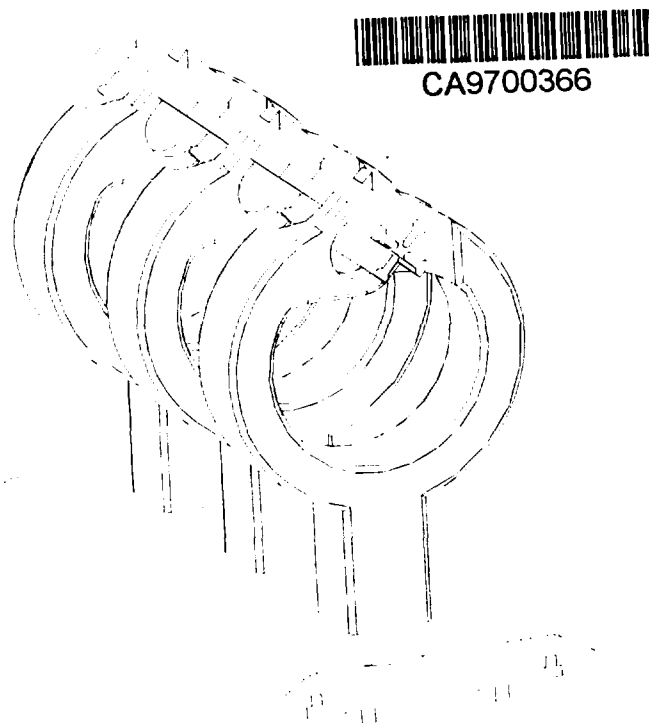
Fig. 1 - Schematic drawing of the split-ring 4-rod RFQ composed of three modules.

B. Variation of Rs with the ratio r/R

Figure 2 shows the computed shunt resistance of a 35 MHz split-ring structure with a module length of 40 cm, as a

function of the ratio r/R, where r is the radial half thickness and R is the mean ring radius, A value for r/R between 0.15 and 0.25 seems to be a good design choice. It should be noted that the inductance of the ring is proportional to R and decreases with increasing r/R, so choosing a larger value for this ratio also implies increasing R if a fixed design frequency is to be maintained.

Shunt Resistance of the Split Ring 4 rod RFQ as a function of the ratio r/R
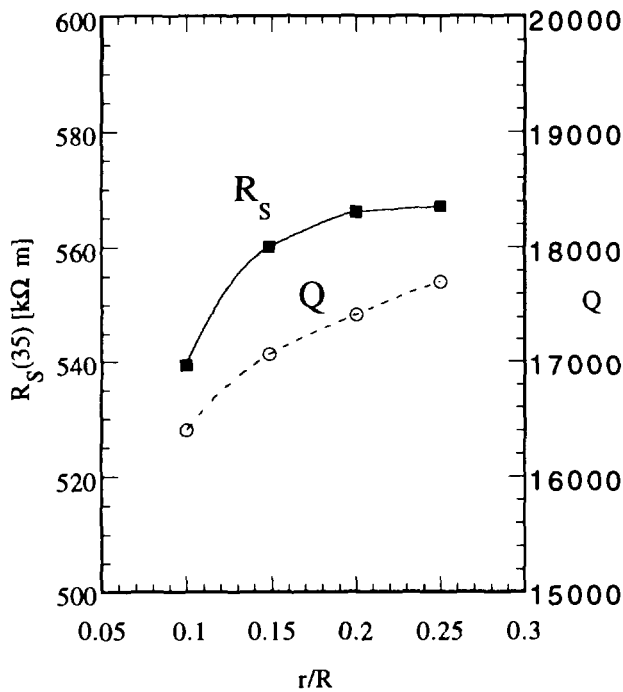

Fig. 2 - The computed shunt resistance and Q value of the split-ring 4-rod RFQ as a function of the ratio r/R for L_{MOD} and z equal 40 and 15 cm, respectively.

C. Rs vs Tank Diameter, D

Each split ring module acts as a half wave transmission line resonator, inductively loaded at the center, having current nulls at rod ends and a voltage null at the ring support stem. If a sufficiently large enclosing tank is chosen so capacitance between the module and the tank wall is small, tank wall currents and power dissipation are then correspondingly small. In Fig. 3 the calculated shunt impedance and Q are plotted as a function of tank diameter for a 35 MHz resonant frequency and a module length of 40 cm. It appears from this that a tank diameter 1 meter or more in diameter is desirable. With this size the tank has little influence on the resonant frequency and serves then only as the necessary vacuum enclosure.

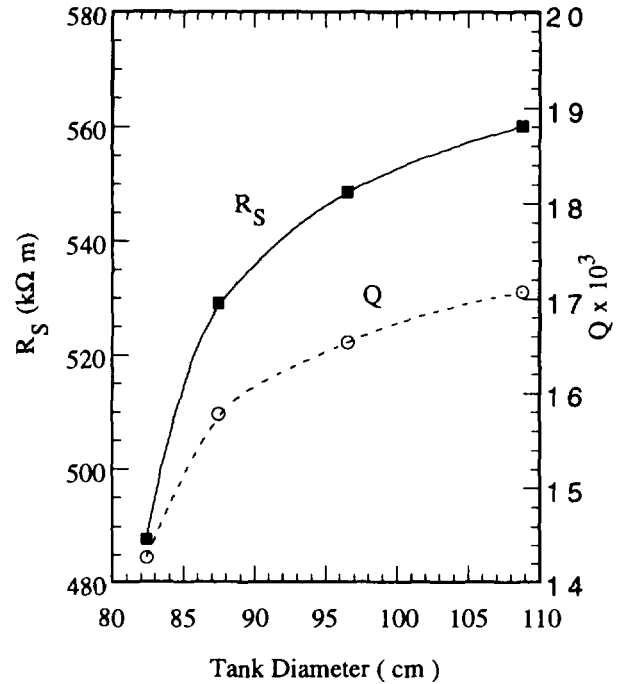### Variation of the Shunt Resistance as a function of the tank diameter

Fig. 3 - Shunt resistance and Q value of the split-ring 4-rod RFQ as a function of the tank diameter.

D. Rs vs module spacing

The spacing between adjacent rings is one of the most important parameters in the design of a split- ring RFQ. Intuitively we expect an optimum value for the spacing since if it is large, the capacitive loading per module is large because of the increased rod length. On the other hand a very small spacing means significant capacitance between the rings. In either case the increase in capacitve load ultimately leads to reduced shunt impedance, so an optimum module length that maximizes shunt impedance is expected.

Initial calculations were done for a three module simulation. Capacitive end effects were however apparent. To circumvent these the space between the rood and the endplate was increased from 5cm to 10 cm and a longer, 10 module structure was simulated. Shunt impedances were calculated for module lengths between 25 cm and 50 cm. Since the resonant frequency changed with module length, all results were scaled to 35 MHz before plotting in Fig. 4. A broad peak centered at a module length of 33 cm is evident for both the 3 module and 10 module simulations. This is in good agreement with the cold model measurements which indicated an optimum length of 35 cm [2].
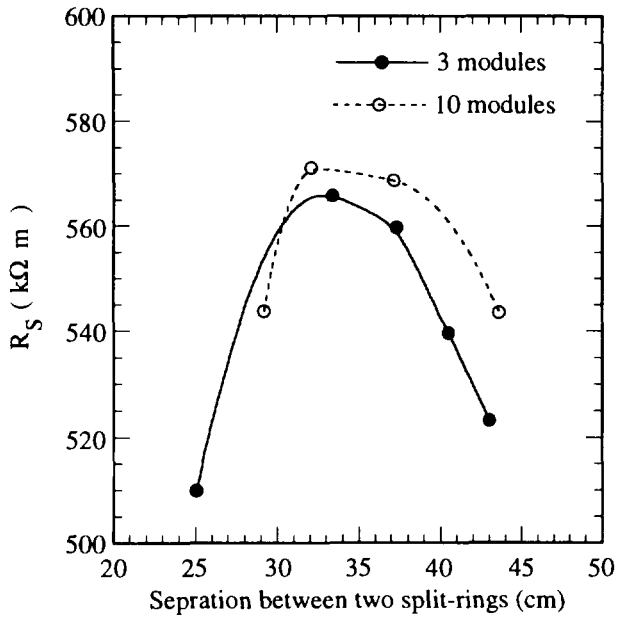
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Fig. 4 - Shunt resistance of the split-ring 4-rod RFQ as a function of the separation between two split-rings. The full line and the dashed line represent the simulation of 3 and 10 modules, respectively.

Table 1 -Basic parameters of the RFQ prototype

RF frequency (MHz)	35
Bore radius R_0 (mm)	8.6
Vane tip radius (mm)	7.0
Radial ring thickness 2r (mm)	80.
Ring radius R (mm)	220
Tank diameter D (mm)	1200
Ring thickness z (mm)	150
L_{Mod} (mm)	400
Peak inter-electrode voltage V_p (kV)	85
Number of modules	3
RFQ length (mm)	1200
MAFIA estimations	
Unloaded Q	15495
Specific Shunt Impedance (kΩ•m)	506
RF power (kW)	8.3

III CONCLUDING REMARKS

Several MAFIA simulation runs have been done in order to complete the analysis of the 4 rod split-ring RFQ started with the cold model studies. The shunt resistance of the split-ring 4-rod RFQ was optimized for different values of the following parameter; ratio of the minor to major radius, r/R, ring width, z, tank diameter, D, and spacing between two adjacent rings.

MAFIA simulations and split-ring 4-rod RFQ's cold model studies are in agreement. Both predict an optimum separation between two adjacent split-ring around 35 cm.

From these simulation, we are confident that an effective shunt impedance of at least 300 kΩ•m is achievable and as a consequence, that the power dissipation per unit length will be easily manageable. Combining the results of these studies with beam dynamics RFQ design calculations allow us to make the basic parameter selection as given in Table 1, for a prototype 3 modules RFQ.

References

[1] G. E. McMicheal, B. G. Chidley and R. M. Hutcheon, AECL 8960/TRI-DN-85-3.

[2] P. G. Bricault, D. Joffe and H. R. Schneider, "RFQ Cold model Studies", this conference.

[3] MAFIA, the general purpose electromagnetic code produced by THD-DESY-KFA collaboration, T. Weiland, 6100 Darmstadt, Germany.