RF DESIGN OPTIMIZATION OF A 176 MHZ CW RFQ*

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Abstract

We have recently designed a 176 MHz CW RFQ for the SARAF upgrade project. A full 3D model of the structure including vane modulation was developed. The design was heavily optimized using large scale electromagnetic simulations. Following the choice of the vane type and geometry, the shape and dimensions of the undercuts were optimized to produce a flat field along the structure. Simulations of the same structure with different lengths were performed to verify that the design length produced the best separation of the operating mode from neighboring modes. If built as designed, the RFQ should not need dipole rods for mode separation, but their effect were studied in the case of manufacturing errors. Finally, the tuners were designed and optimized to tune the main mode without affecting the field flatness. The design optimization was mainly performed using CST Micro-Wave Studio and the results were verified using both HFSS and ANSYS. The results of these studies will be presented and discussed.

INTRODUCTION

Soreq NRC, Israel's national laboratory, is exploring the possibilities of upgrading the existing SARAF linac [1]. One of the potential projects is an RFQ upgrade in collaboration with Argonne. In this paper, we present the rf design optimization for a 176 MHz cw RFQ. The proposed design is based on the successful ATLAS upgrade RFQ design [2].

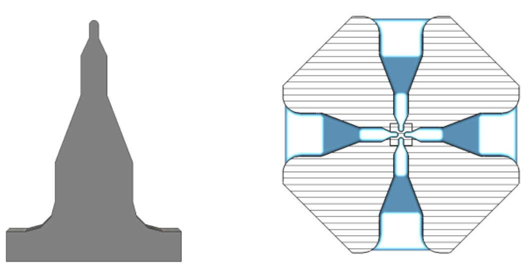

Figure 1: Vane profile (left) and RFQ cross section (right) with an inner diameter of ~ 36 cm.

RFQ STRUCTURE AND PARAMETERS

The selected structure for this RFQ is a 4-vane. The vane profile is based on the ATLAS upgrade RFQ except that this design is a full-vane, not a split-coaxial. At this frequency the transverse size of the RFQ is manageable. Both the vane profile and the RFQ cross section are shown in Figure 1. The structure is about 4 m long divided into 4 segments. The RFQ design parameters are summarized in Table 1. The output energy could be increased by applying trapezoidal modulation while keeping the same vane voltage and power.

Table 1: RFQ Design Parameters

Parameter	Value
q/A	½
Input energy, keV/u	20
Output energy, keV/u	1300
Frequency, MHz	176
Voltage, kV	75
Design current, mA	5
Power, kW	125
Average radius, mm	4.4
Max. modulation	2
Min. transverse phase advance, deg	33
Norm. trans. acceptance, π mm·mrad	2.2
Peak surface field, Kilpatrick units	1.6
Number of cells	250

RF MODELING AND OPTIMIZATION

The electromagnetic design and optimization were mainly performed using the CST Micro-Wave Studio (MWS) [3] and the final results were verified using HFSS and ANSYS. A full 3D model of the RFQ was developed in MWS. Detailed views of the geometry including the undercuts and the modulations are shown in figure 2. This model has pure sinusoidal modulations along the whole RFQ.

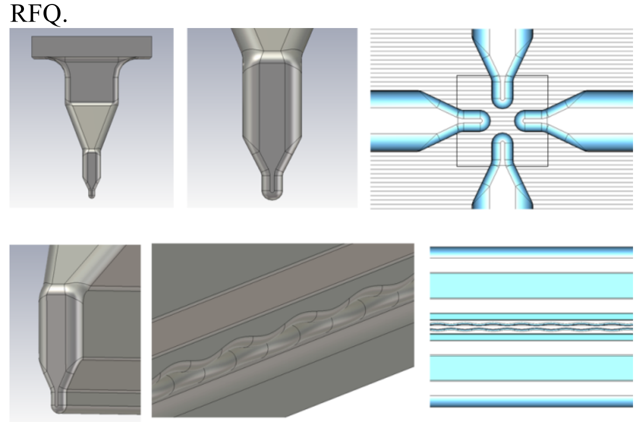

Figure 2: 3D modelling of the RFQ in MWS.

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Optimization of Vane Undercuts

In full-vane RFQ structures, vane undercuts are often used to flatten the inter-vane field along the RFQ. These undercuts are applied at both ends of the RFQ and could in principle be of any geometry. We have studied two types of vane undercuts, the first is trapezoidal while the second is square as shown on Figure 3. By optimizing the

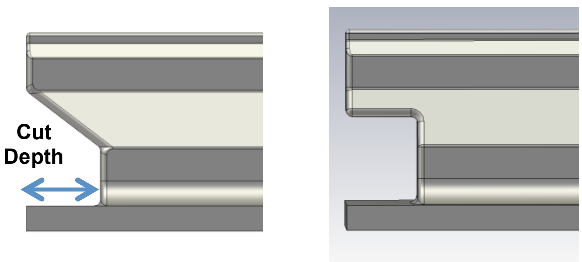

Figure 3: Trapezoidal (left) and square (right) vane undercuts.

cut depth, we were able to obtain a flat inter-vane voltage for both options as shown on Figure 4. However when checking the peak surface magnetic field on the cut planes we realized that it is about 10% lower for the trapezoidal cut shape which should lead to a lower power dissipation.

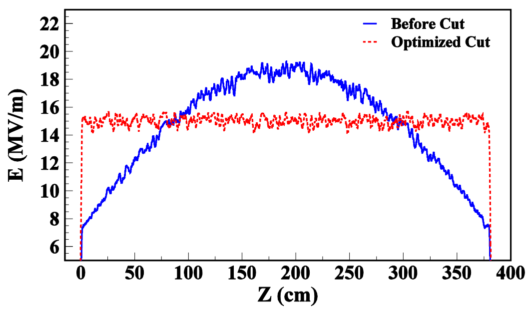

Figure 4: Inter-vane field along the RFQ before and after applying the appropriate vane undercuts.

Therefore we selected the trapezoidal undercut geometry for this RFQ. It is worth noting that these optimizations were done including vane modulations, which has led to non-symmetric entrance and exit undercut depths while before modulations the cuts were symmetric.

RFQ Modes as Function of Length

In order to study the RFQ mode separation as function of length, we have simulated several RFQs with the same cross section and undercuts but with different lengths. The results are shown on figure 5 for mode frequencies as function of length. The modes are identified as Q for quadrupole and D for dipole. The dipole modes marked by (2) are degenerates, their separation shows up for longer structures due only to memory limit in the simulations. The cut-off frequency for this structure is about 170 MHz. At a length of about 1.63 segments, the lowest quadrupole and dipole modes have the same frequency which corresponds to about 0.9×λ. This length is to be avoided because it would be hard to tune the structure for the operating quadrupole mode. The mode separation is best for a length of 4 segments where it is about 3 MHz wide and symmetric around the design frequency. At a length of about 5.5 segments the second dipole mode crosses the main quadrupole mode frequency which will also lead to tuning problems and superposition of quadrupole and dipole fields. The current RFQ design is 4 segments long and has the best mode separation.

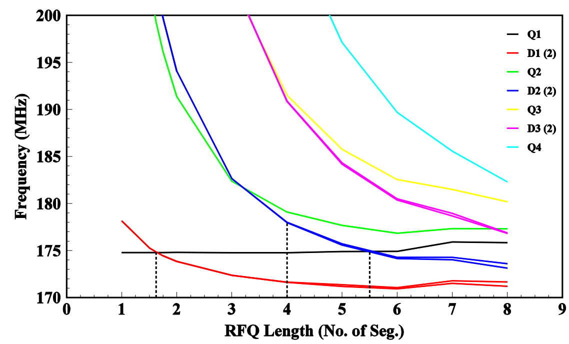

Figure 5: RFQ modes frequencies as function of length in segments (~ 1m).

DIPOLE RODS DESIGN AND OPTIMIZATION

Dipole rods are movable finger-shaped rods attached to the RFQ end plates which could be inserted into the RF volume as needed. Their main purpose is to produce additional separation of the main mode from the neighbouring dipole modes if needed. They are inserted into the quadrupole symmetry planes so they do not affect the quadrupole modes but they are capable of changing the frequency and fields of dipole modes. Based on the actual mode separation for the 4-segments RFQ, we should not need the dipole rods but in the event of manufacturing errors, they are may be useful for correction. The first study performed on the 4-segment RFQ showed low sensitivity of the mode separation to variations in the parameters of the dipole rods, namely the radius, location and penetration. Based on the previous section's results, their effect should be more significant for the 1.63 segment model where the main mode and the first dipole mode have the same frequency. The corresponding results are shown on Figure 6. We clearly see that the dipole mode frequency is more sensitive to the location of the rods with respect to the beam axis. The closer to the axis, the more effective they are. However, the main mode frequency and field are least affected by the rods when they are at mid distance between the beam axis and the cavity side walls, which is the location of maximal quadrupole symmetry. At this location the rods have to be inserted 15" into the RF volume to see a 0.5 MHz separation between the main mode and the dipole mode. The frequencies are not very sensitive to the rod diameter beyond 0.5" and when checking the field stability, a thicker rod disturbs the field more, so a 0.5" rod diameter is near optimal.

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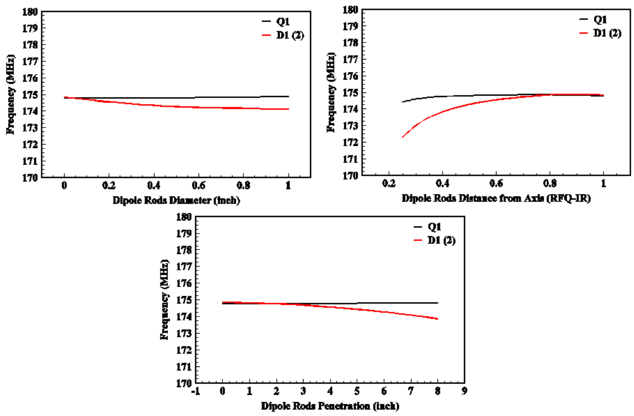

Figure 6: Effect of dipole rods geometric parameters on mode separation for a 1.63 segments RFQ.

TUNERS DESIGN AND STUDIES

A four-vane RFQ is usually built for a frequency just below the operating frequency to make sure it is tunable to that frequency. For the SARAF RFQ, the design target frequency is 175.4 MHz including all the geometry details. The simulation error is estimated not to exceed 0.2 MHz. So the tuners should have a range of at least 1 MHz. The RFQ will have two tuners per quadrant per segment making a total of 32 tuners as shown in Fig. 7. The tuner diameter is 2.5" and could go in up to 2" deep. Figure 8 shows a comparison of the inter-vane field between a case where the tuners are inserted to the same depth uniformly and a case of non-uniform tuning. The latter shows a slope in the inter-vane field which cannot be corrected. Based on these results we decided that the tuners ports should be separate from coupling and vacuum ports to allow for uniform tuning that preserves the field flatness. The simulated frequency sensitivity to the tuners is 37.5 kHz per tuner per inch, which is a 2.4 MHz tuning range if all tuners were inserted 2 inches deep into the cavity.

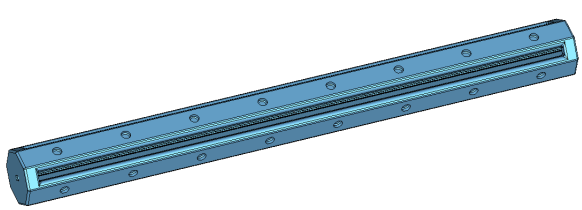

Figure 7: Full RFQ model showing the location of the tuners.

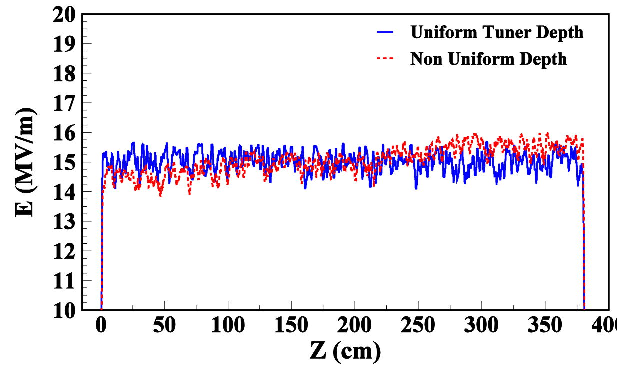

Figure 8: Uniform and non-uniform tuning effect on the inter-vane field along the RFQ.

SUMMARY

We have optimized the RF design for a 176 MHz CW RFQ. The RFQ is a 4-vane structure with optimized trapezoidal vane undercuts for a flat inter-vane field. It is a ~ 4 m long structure made of 4 segments with the best mode separation as function of length. This design should not need dipole rods but we have designed and optimized them to correct eventual manufacturing errors. The RFQ has 2 tuners per quadrant per segment, a total of 32 with a full tuning range of 2.4 MHz. The tuners ports will be separate from the coupling and vacuum ports to allow uniform tuning with minimal effect on field flatness. As successfully implemented in the ATLAS upgrade RFQ, we are planning to design trapezoidal vane modulation which would increase the output energy for the same RFQ length and power.

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