# DESIGN CONSIDERATIONS FOR MULTIPLE-BEAM RFQ STRUCTURES

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*Abstract*

There are applications, which require MeV-range multiple-beams consisting of a large number of identical highly packed beamlets. The multiple-beam RFQ (MB-RFQ) arranged as a matrix array of longitudinal rod-electrodes is appropriate candidate. A configuration of MB-RFQ resonator should ensure identical quadrupole fields in every accelerating channel. The MB-RFQ resonators based on TEM transmission lines are studied. The resonators are designed by a periodical multiplication of a 4-rod unit cell in transverse direction. To understand fields of resonator the normal mode technique is applied. The resonator field is expanded into normal modes having simple field patterns. In general case of resonator with an arbitrary number of rods and normal modes, analysis becomes difficult. To simplify problem, only normal modes composed from four normal modes of a 4-rod unit cell are selected. Similar to normal modes of a 4-rod unit cell (coaxial, quadrupole and two dipole modes), selected normal modes of multi-rod resonator have clear field patterns. Novel configurations of MB-RFQ resonators based on these normal modes are generated. The RF properties of resonators are verified with computer simulations done with MAFIA code.

## 1 INTRODUCTION

Several multiple-beam RFQ (MB-RFQ) structures has been proposed to accelerate a number of identical beamlets [1]. These structures consist of matrix array of longitudinal electrodes. The problem is to define a configuration of resonator, which ensures identical accelerating fields in every accelerating channel and preserves high packing of beamlets.

In this paper, MB-RFQ structures are treated as the TEM transmission line resonator. The normal mode technique is applied to decompose a complicated field resonator into fields of normal modes.

## 2 MB-RFQ AS THE TEM RESONATOR

Let us consider MB-RFQ resonator with N quadrupole electrodes as a resonator based on the N-conductor shielded TEM transmission lines (NCSTL). The propagation of TEM waves is described by the system of the telegraph equations. To facilitate solution of the telegraph equation the normal mode technique is usually applied. The resonator field is expanded into normal modes having simple field patterns. In the transmission line with N-conductors there are N normal TEM modes.

This technique has been applied to study 4-rod RFQ using the four-conductor shielded transmission line (4CSTL) [2]. In the case of N>4, the analytical definition of normal modes becomes difficult. To facilitate the study, let us restrict a number of considered normal modes in the NCSTL. A 4-rod configuration with known normal modes is considered as a unit cell. Normal modes of the NCSTL are composed by a periodical multiplication of a 4-rod unit cell in transverse direction.

The normal modes in the 4CSTL can be observed in the resonator shown in Fig.1. All four electrodes are grounded at the same longitudinal position, $z$=0 and have open ends at the another end of resonator, $z$=$l$.

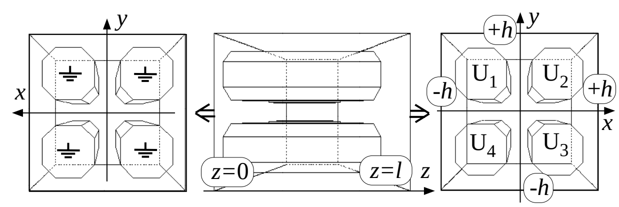


Figure 1: 4-rod RFQ allowing an observation of normal modes.

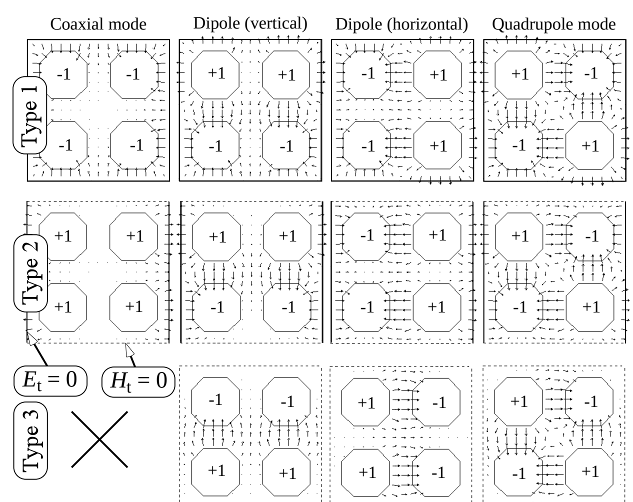


Figure 2: The E-line patterns of normal modes in the 4CSTL for three types of boundary conditions on shield.

Figure 2 shows the E-line patterns of TEM normal modes in the 4CSTL calculated with MAFIA code. Three different combinations of two boundary conditions (perfect conductor, $E_t$=0 or infinitely permeable, $H_t$=0) on the shield are presented. The first and second type has four normal modes (coaxial, quadrupole and two dipole). The third type with $H_t$ =0 on all four sides of the shield has only three modes, because it corresponds to opened transmission line.

The normal modes in the NCSTL can be observed by the similar way. The MB resonator with 4x4-matrix array of electrodes is shown in Fig.3. All electrodes are grounded at the same longitudinal position, $z$=0 and have open ends at the another end of resonator, $z$=$l$.

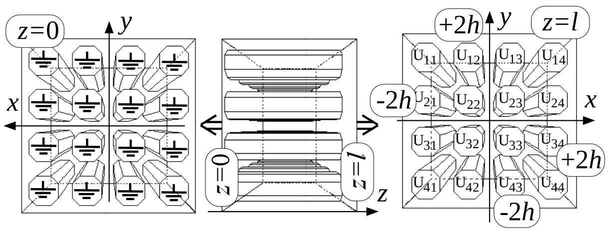


Figure 3: MB-RFQ resonator with a 4x4-matrix array of electrodes allowing an observation of normal modes.

Figure 4 shows the E-line patterns of normal TEM modes calculated by MAFIA code. Three types of boundary conditions on the shield are presented. The values of conductor potentials are shown on the conductor cross-sections.

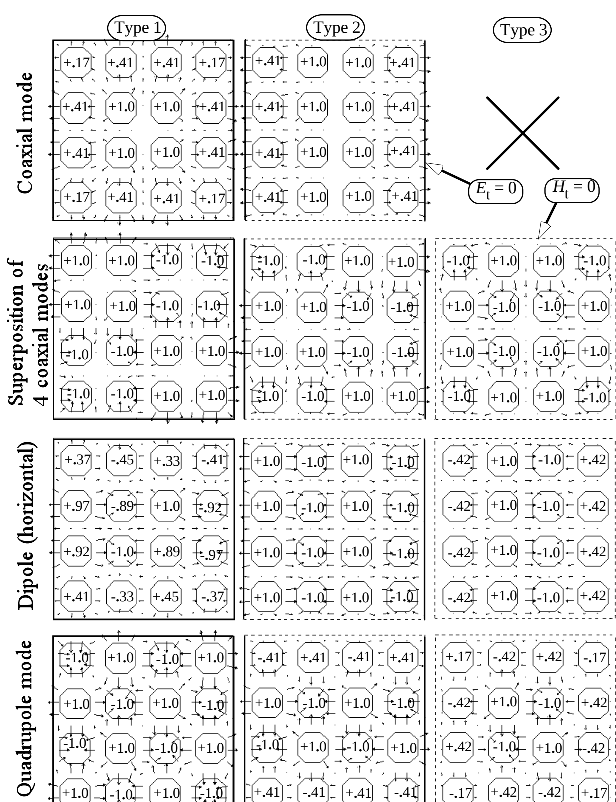


Figure 4: The E-line patterns of normal modes in the MB-RFQ resonator for three types of boundary conditions on the shield.

The quadrupole mode of the type 1 has correct-balanced quadrupole potentials for all channels. The field of the quadrupole mode increases sinusoidally along z-direction. This MB-resonator can be used as an initial matching section.

Figure 5 shows the MB resonator designed using an extension of 4-rod RFQ in the transverse direction. All electrodes are divided into two groups in a chess order. The electrodes of two groups are grounded in opposite manner.

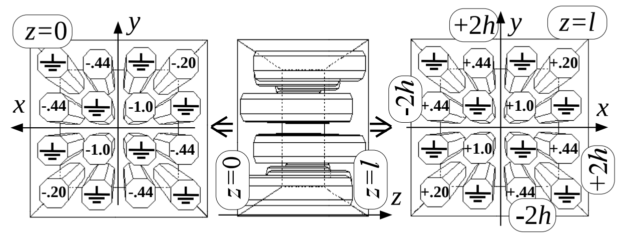


Figure 5: MB-RFQ resonator composing by an extension of 4-rod RFQ.

The field in this MB-resonator can be interpreted in terms of normal mode technique. The field of the original 4-rod resonator is described by combination of quadrupole and coaxial mode, which has been presented in [2]. In contrast to 4-rod resonator, the coaxial mode of MB-RFQ (see Fig.4, Coaxial mode of type 1) has unequal potentials of electrodes. Therefore, the combination of quarupole and coaxial modes in the MB resonator does not provide a correct excitation of the electrodes. The voltages on the electrodes surrounding RFQ-channels deviate from quadrupole symmetry.

Figure 6 shows the MB resonator designed using a periodical multiplication of 4-rod unit cell in the transverse direction. The field of the 4-rod unit cell of the resonator is described by combination of the quadrupole mode and the normal mode shown in the second row of the first column of Fig.4. The voltages on electrodes provide a balanced excitation and every second RFQ-channel can be used for an acceleration of beamlets.

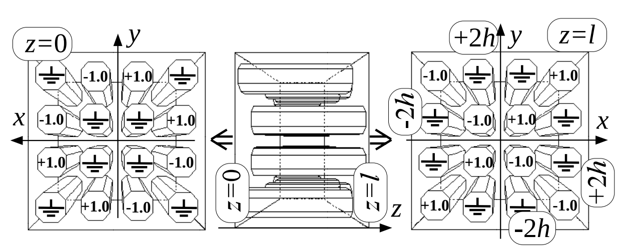


Figure 6: MB-RFQ resonator composing by a periodical multiplication of 4-rod unit cell.

Recently, a new MB-RFQ structure has been proposed [1,3]. To preserve high packing of beamlets this structure allows discrete connections of adjacent RFQ electrodes. The beam dynamics in RFQ-channels is modified. Beams perform "slalom" motions, utilizing transverse oscillations. The Figure 7 shows the MB-resonator.

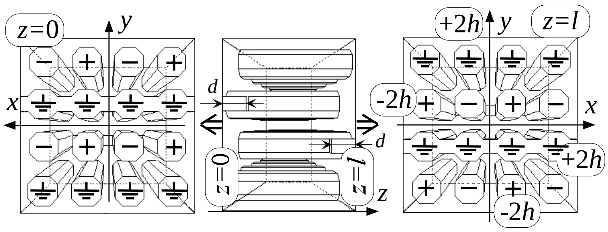


Figure 7: MB-RFQ resonator with 4x4-matrix array of electrodes.

The field of the MB-resonator with a "slalom" beam is superposition of quadrupole mode and dipole mode, which are summed at a $\lambda/4$ phase shift between each other. Figure 8 shows voltage distributions for this combination of quadrupole and dipole modes in the case of 4-rod unit cell. The result of summation is given on the right side of the Fig. 8.

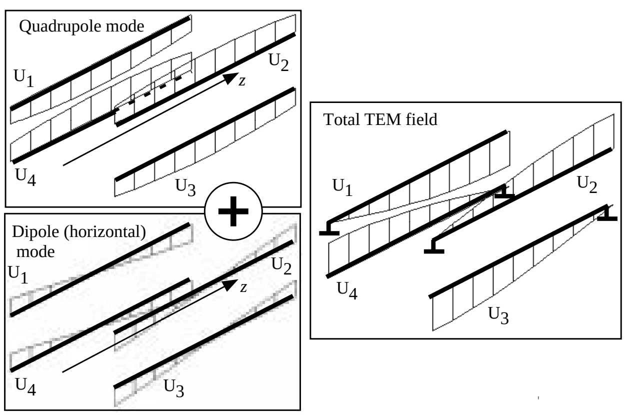


Figure 8: The superposition of quadrupole and dipole modes shifted by $\lambda/4$ to each other.

For the case of MB-RFQ, this combination is extended to the superposition of quadrupole mode of type 1 and dipole mode of type 2 (see Fig.4). For a real configuration of MB-RFQ resonator, the boundary conditions on all tank walls must correspond to a perfect conductor. The dipole mode of type 2 is replaced by the dipole mode of type 1 (see Fig. 2). In contrast to the dipole mode of type 2, potentials of electrodes surrounding RFQ-channels for the dipole mode of type 1 deviate from a correct dipole field (see Fig.4). As the result, a total field in the MB-resonator is distorted.

A difference between dipole modes of type 1 and type 2 is appeared as different boundary conditions on the shield for the upper and lower rows of 4-rod unit cells. Free frequencies of the outer cells deviate from their values for cells in the middle rows of MB-resonator. The free frequencies of the outer cells should be tuned. The free frequency of a 4-rod unit cell depends on an electrical length of conductors. For the MB-resonator shown in Fig.7, the length of conductors in the middle rows is less than the length in the outer cells on the value, *d*.

Fig. 9 shows the distributions of the quadrupole and dipole voltages in separate channels calculated with MAFIA code. The quadrupole voltage $V_{ij}$ in the ij-channel is calculated from the voltages of electrodes surrounding the channel by the relation

$$V_{i,j} = (U_{i,j} - U_{i,j+1} + U_{i+1,j+1} - U_{i+1,j})/2$$

The voltages of horizontal and vertical dipole modes, $Dh_{ij}$ and $Dv_{ij}$ are defined by the following formulas:

$$Dh_{i,j} = (U_{i,j} - U_{i,j+1} - U_{i+1,j+1} + U_{i+1,j})/2$$

$$Dv_{i,j} = (U_{i,j} + U_{i,j+1} - U_{i+1,j+1} - U_{i+1,j})/2$$

For the case of *d*=0, the values of quadupole voltage, $V_{ij}$ are different for the middle and outer channels. The phase shift between quadrupole and dipole voltages deviates from $\lambda/4$ for outer channels. For the optimal value of *d*=1.8cm, curves of quadrupole voltages became very similar and the required phase shift of $\lambda/4$ is restored.

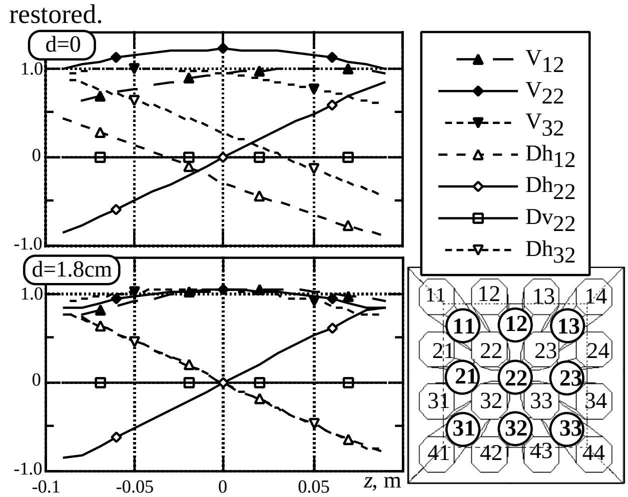


Figure 9: The distributions of the quadrupole and dipole voltages in separate channels calculated with MAFIA code.

## 3 ACKNOWLEDGEMENTS


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## 4 REFERENCES


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