

# PROGRESS OF THE MODULATED 325 MHz LADDER RFQ

M. Schuett\*, U. Ratzinger and M. Syha  
Institute for Applied Physics, Goethe University, Frankfurt, Germany

## Abstract

Based on the positive results of the unmodulated 325 MHz Ladder-RFQ prototype from 2013 to 2016 [1], we developed and designed a modulated 3.3 m Ladder-RFQ. The idea of the Ladder type RFQ firstly came up in the late eighties [2,3] and was realized successfully for the CERN Linac3 operating at 101 MHz [4] and for the CERN antiproton decelerator ASACUSA at 202 MHz [5].

The unmodulated Ladder-RFQ features a very constant voltage along the axis. The RFQ was high power tested at the GSI test stand [6]. It accepted 3 times the RF power level needed in operation [7]. The highest level corresponds to a Kilpatrick factor of 3.1 with a pulse length of 200  $\mu$ s. The 325 MHz RFQ is designed to accelerate protons from 95 keV to 3.0 MeV according to the design parameters of the proton linac within the FAIR project. This particular high frequency creates difficulties for a 4-ROD type RFQ, which triggered the development of a Ladder RFQ with its higher symmetry. The results of the unmodulated prototype have shown, that the Ladder-RFQ is a suitable candidate for that frequency. For the present design duty cycles are feasible up to 5%. The basic design and tendering of the RFQ has been successfully completed in 2016 [8]. Manufacturing will be completed until May 2018. In this paper we present the latest results of manufacturing and beam dynamics simulations for the matching between LEBT and RFQ.

Table 1: Main RF and Geometric Parameters of the Modulated Prototype Ladder RFQ

No. of RF cells	55
Q-Value (simulated)	6800
Loss (with sim. Q)	675 kW
Shunt Impedance (sim.)	45 k $\Omega$ m
Vane-Vane Voltage	89 kV
Frequency	325.224 MHz
Repetition Rate	4 Hz
Pulse Duration	200 $\mu$ s
Total Length	3410 mm
Cell Length	40 mm
Spoke Height	280 mm
Spoke Width	150 mm
Electrode Length	3327 mm

## DESIGN AND MANUFACTURING

The mechanical design consists of an inner copper ladder structure mounted into an outer stainless steel tank. The tank is divided into three parts - the lower and upper shells and a middle frame.

\* schuett@iap.uni-frankfurt.de



Figure 1: Upper tank shell of the Ladder RFQ after finishing of polishing ready for copper-plating.

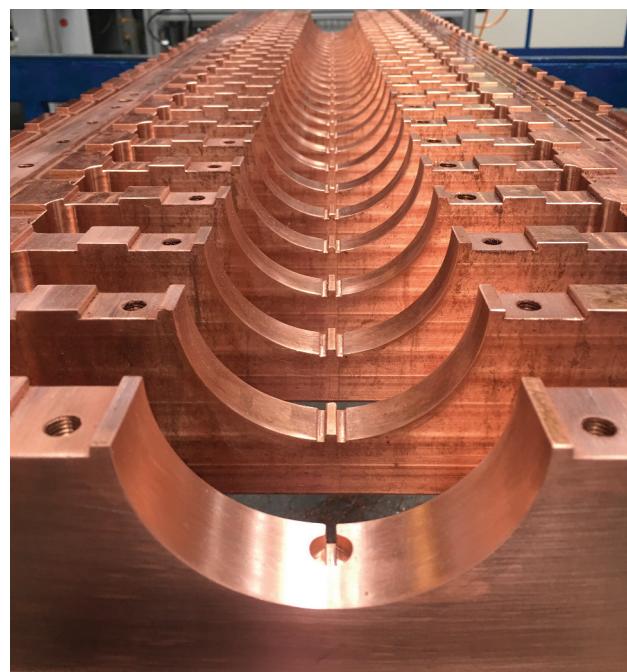


Figure 2: Lower half-ladder structure during the final finishing process.

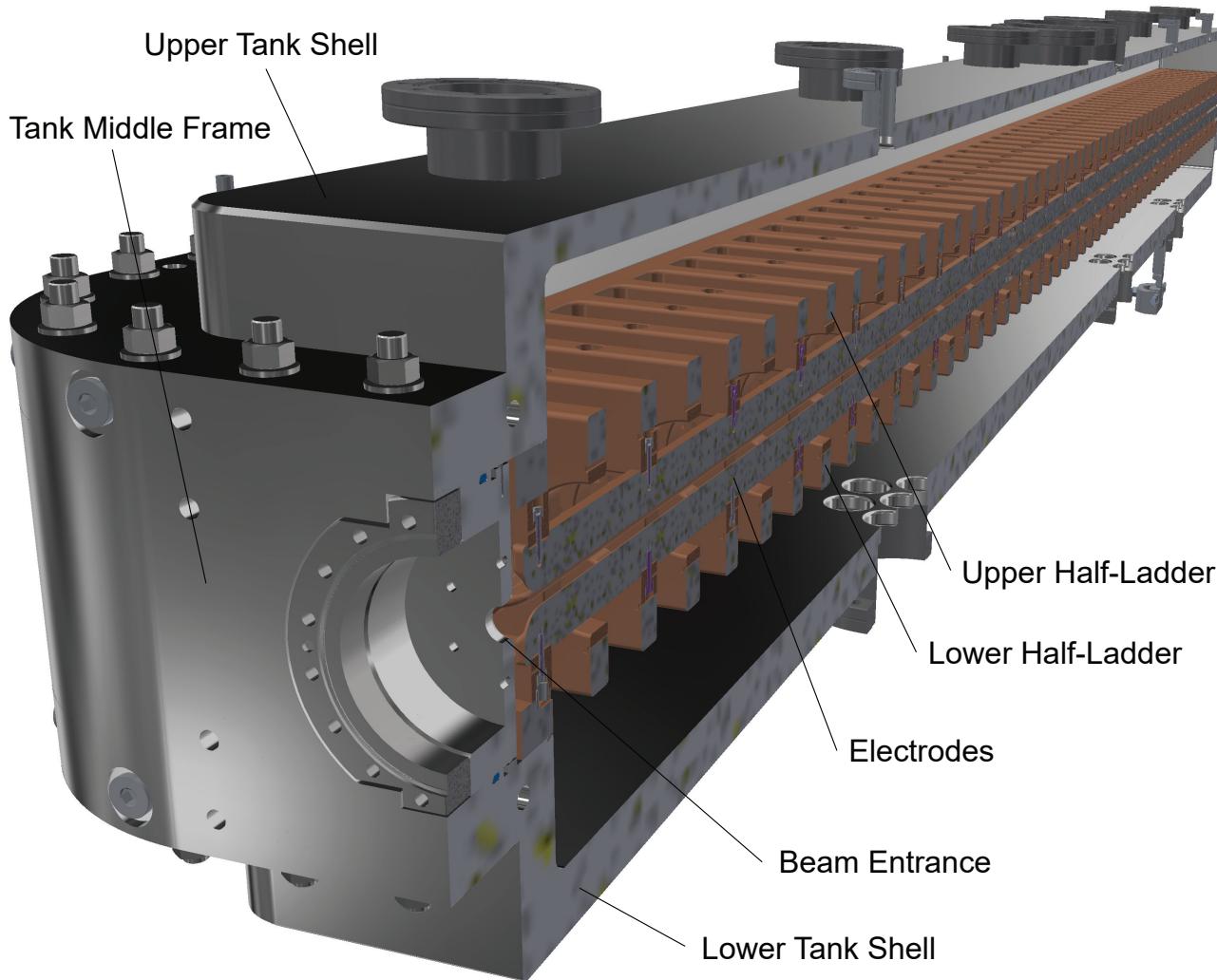


Figure 3: Isometric view of the 3.3 m modulated Ladder-RFQ prototype. Copper carrier-rings guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided for the assembly of the main components.

The lower shell of the tank carries and fixes the position of the inner resonating ladder structure. The ladder structure itself is machined from solid copper blocks. Due to manufacturing reasons, the ladder structure is divided into two lower and two upper half-ladder elements, which are precisely aligned via guide pins. Between the half-ladder elements the electrodes are precisely fixed via carrier-rings [9]. The carrier-rings furthermore guarantee a seamless RF connection between the electrodes and the ladder structure.

The RF features are mainly determined by the resonating structure, while the dimensions of the tank have no significant influence on the frequency. Based on the successful high power tests of the unmodulated prototype it was decided to develop a new beam dynamics with an increased electrode voltage of 89 kV [10]. The basic physical and mechanical parameters of the Ladder-RFQ results are shown in Table 1. Furthermore, the thickness of the tank walls within the entrance and exit flange of the RFQ are reduced to 10 mm within the flange radius of 100 mm (CF100). That allows an

integration of preceding and following components like a cone and steerer to reduce an emittance growth caused by an additional drift. The next step, beginning in Q3/2018, is to develop a new cone which can directly be integrated into the flange of the RFQ.

Manufacturing of the tank components, consisting of an upper tank shell, middle frame and lower tank shell started in September 2017. The middle frame has been completed in November 2017 and copper-plated by GSI in December 2017. The upper in Fig. 1 and lower tank shell followed in March and April 2018, respectively. Afterwards, copper-plating will be finished within Q2/2018. The copper structure is machined in parallel from 02-04/2018 in Fig. 2. The electrodes will also be completed in May/June 2018. The whole assembly is scheduled for end of Q2/2018. An isometric model of the Ladder RFQ components assembled in Fig. 3.

## BEAMMATCHING BETWEEN LEBT AND RFQ

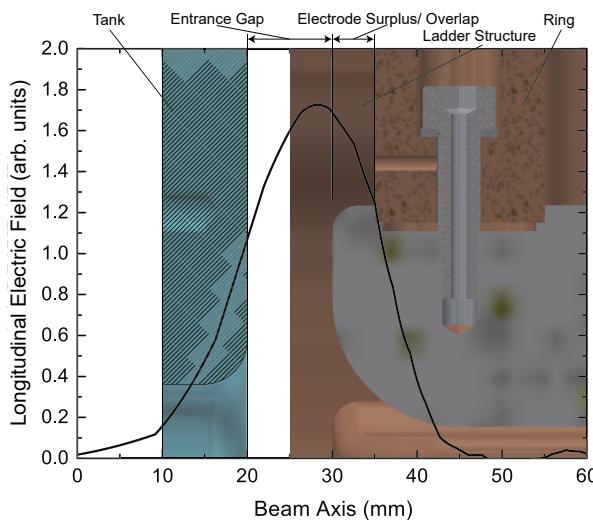


Figure 4: Longitudinal fringe field in the entrance gap/radial matching section of the RFQ.

As 4-ROD RFQ's do have an unequal potential of adjacent electrodes, there will be a non distinguishable longitudinal fringe field between the grounded tank and the net potential of the electrodes at the RFQ entrance as well as exit in Fig. 4. Depending on the distance between the walls and the electrodes as well as on the electrode potential the field may reach up to 50% of the incoming particle energy. In case of the Ladder RFQ and regarding the time-transient factor this field causes an energy modulation of up to  $\pm 2$  eV.

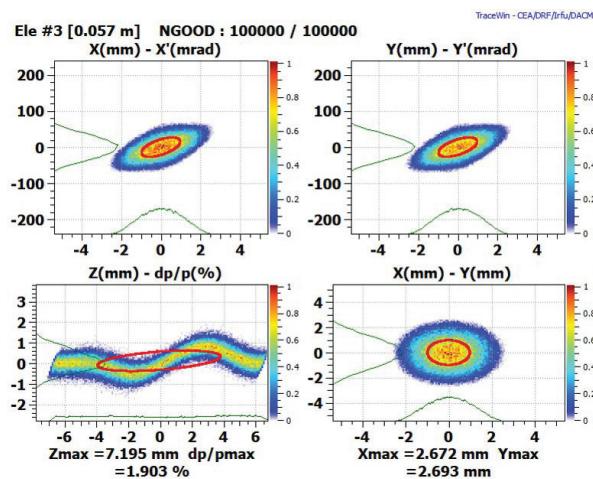


Figure 5: Beam distribution after the fringe field and radial matching section of the Ladder RFQ.

That longitudinal electric field in the entrance gap of the RFQ will now be beneficially used as a small pre-buncher of the incoming cw bunch. According to simulations the bunching is comparable to that within the first five RFQ cell after the radial matcher. Therefore, the phase of the incoming synchronous particle, which is the zero-crossing

on the rising edge of the energy modulated cw beam, has to enter the center of the first RFQ cell after the radial matcher at a phase of  $-90^\circ$ . By adding a focusing quadrupole channel, i.e. a non modulated extension of the electrodes with a constant mean aperture between the end of the radial matcher and the first modulated RFQ cell, the relative phase of the synchronous particle referred to the RF is shifted. The effect of the energy modulation is visualized in Fig. 5. After the drift through the radial matching section and the quadrupole drift the synchronous particle is centered within the phase space of  $\pm 180^\circ$ .

## ACKNOWLEDGEMENTS

We acknowledge the efficient cooperation with the GSI p-Linac team and especially Klaus Knie and Carl Kleffner. Thanks to Kress Maschinenbau GmbH for the manufacturing of the Ladder RFQ. The authors would also like to thank the galvanic workshop of GSI, Darmstadt, for copper plating the tank.

## REFERENCES

- [1] M. Schuett, U. Ratzinger, C. Zhang, "Development of a 325 MHz Ladder-RFQ of the 4-ROD-Type", Proc. of IPAC2016, Busan, Korea, p. 899.
- [2] A. Fabris, A. Massarotti, M. Vretenar, "A Model of 4-Rods-RFQ", Seminar on New Techniques for Future Accelerators, Erice, Sicily, 1986, New York, Plenum, p. 265.
- [3] M.J. Brown, G. Spalek, P.B. Friedrichs and T.C. Barts, "Studies of the Four-Rod RFQ Using the MAFIA Codes", Proceedings of LINAC88, Newport, Virginia, p. 119.
- [4] G. Bezzon, A. Lombardi, G. Parisi, A. Pisent, M. Weiss, "Construction and Commissioning of the RFQ for the CERN Lead Ion Facility", Proceedings of LINAC1994, Tsukuba, Japan, p. 722.
- [5] Y. Bylinsky, A.M. Lombardi, W. Pirk, "RFQ - a Decelerating Radiofrequency Quadrupole for the CERN Antiproton Facility", Proceedings of LINAC2000, Monterey, California, p. 554.
- [6] G. Schreiber, E. Plechov, J. Salvatore, B. Schlitt, A. Schnase, M. Vossberg, "First High Power Tests at the 325 MHz RF Test Stand at GSI", Proc. of LINAC2016, East Lansing, USA, p. 3745.
- [7] M. Schuett, M. Obermayer, U. Ratzinger, "Development and Measurements of a 325 MHz Ladder-RFQ", Proc. of LINAC2016, East Lansing, USA, p. 578.
- [8] M. Schuett, U. Ratzinger, A. Schnase, M. Syha, M. Obermayer, "Status of the modulated 3 MeV 325 MHz Ladder-RFQ", IOP Conf. Series: Journal of Physics: Conf. Series 874(2017)012048.
- [9] U. Ratzinger, K. Kaspar, E. Malwitz, S. Minaev, R. Tiede, "The GSI 36 MHz high-current IH-type RFQ and HIIF-relevant extensions", Nucl. Instrum. Meth. A 415(2018), p. 281.
- [10] M. Syha, M. Obermayer, U. Ratzinger, M. Schuett, "Beam Dynamics for a high Current 3 MeV, 325 MHz Ladder-RFQ", Proc. of IPAC2017, Copenhagen, Denmark, p. 2252.