DESIGN OF 162.5 MHZ CW MAIN COUPLER FOR RFQ*

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Abstract

Project X Injector Experiment (PXIE) at Fermilab will utilize a 162.5 MHZ CW RFQ accelerating cavity. The design of a new main coupler for PXIE RFQ is reported. Two identical couplers will deliver approximately 100 kW total CW RF power to RFQ. A unique feature of the coupler allows the application of a DC bias for multipactor suppression. Results of RF and thermal simulations, along with mechanical design, are presented.

INTRODUCTION

A multi-MW proton facility (PIP-II) has been proposed at Fermilab. A prototype of the PIP-II front end, PXIE, is planned to validate the conceptual design. PXIE will supply a 25 MeV 50 kW beam, and will include an H- ion source, a CW RFQ and two superconducting RF cryomodules providing up to 25 MeV energy gain at an average beam current of 1 mA (upgradable to 2 mA) [1]. The ion source will deliver up to 10 mA of H- at 30 keV to the RFQ. The 162.5 MHz RFQ (Fig. 1) accepts and accelerates this beam to 2.1 MeV. The RFQ is designed to dissipate ~80 kW of RF power under nominal operating conditions. To reduce coupler power demands, two power couplers will be integrated with the RFQ [2].

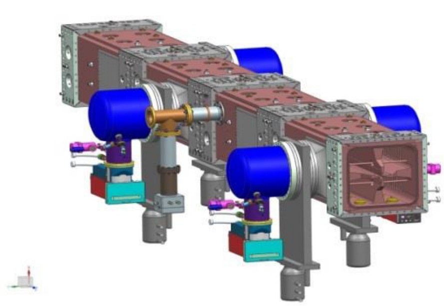

Figure 1: CAD view of RFQ

Table 1: RFQ Parameters

Parameter	Value
Ion type	H-
Beam current	1-10 mA
Beam energy	0.03-2.1 MeV
Frequency	162.5 MHz
Duty factor (CW)	100%
Total RF power	≤ 130 kW
Number of couplers	2

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RFQ COUPLER

Requirements

Parameters of the RFQ (Table 1) define requirements for the two couplers. They are listed in Table 2.

Table 2: Coupler Requirements

Parameter	Value
Frequency	162.5 MHz
Operating power	75 kW
Coupling type	Loop
Output port diameter	~3"
Input impedance	50 Ohm

Coupler Structure

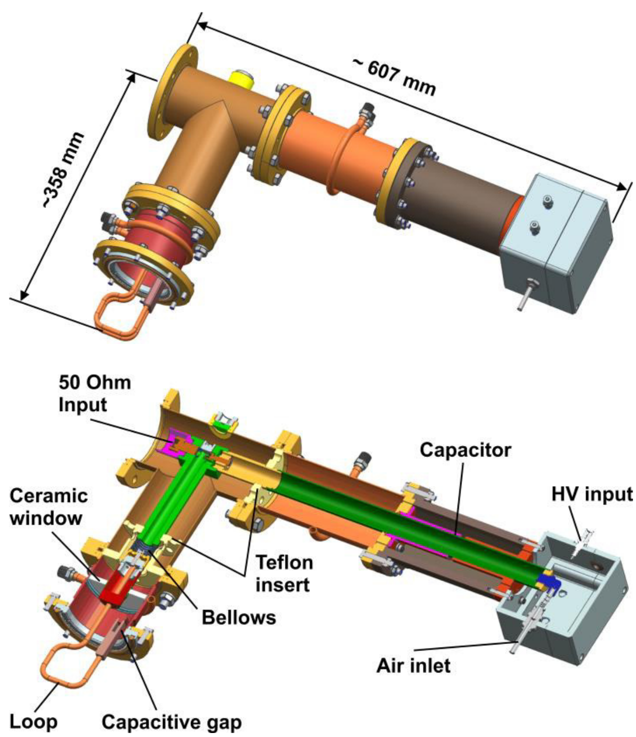

Figure 2: Main dimensions and internal structure of RFQ coupler.

Fig. 2 presents a schematic of the coupler, showing its main dimensions and internal structure. The coupler includes an alumina ceramic window with 77 mm outer diameter, 28.6 mm inner diameter and 6 mm thickness. The coupling loop consists of two parallel 1/4" copper pipes through which cooling air flows. The loop is not grounded (not connected to the outer conductor). It allows application of a high voltage (HV) bias to the inner conductor and loop to suppress multipacting. Standard, commercially available components were used when possible to reduce costs. The outer conductor is a standard 3-1/8" size. The coupler has 50 Ohm input impedance. It is assumed that the coupler will be connected to a larger size feed line by means of an adapter.

RF Properties of Coupler

The RF structure of the coupler is simple and is shown in Fig. 3. It is a coaxial line with ~1/4 λ coaxial support. Support is necessary to provide cooling air and to apply a HV bias to the inner conductor and a loop. As shown in the graph in Fig. 4, the coupler has a rather wide passband of ~25MHz, ~15.4%, (S11 < 0.1). This indicates that high precision is not required during manufacture of the coupler components.

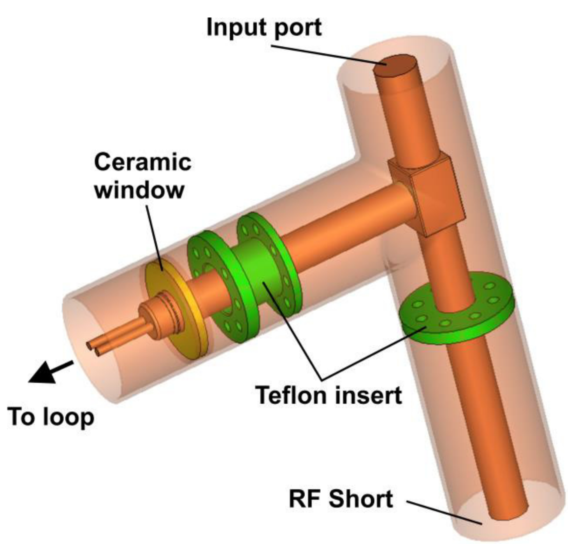

Figure 3: RF structure of RFQ coupler.

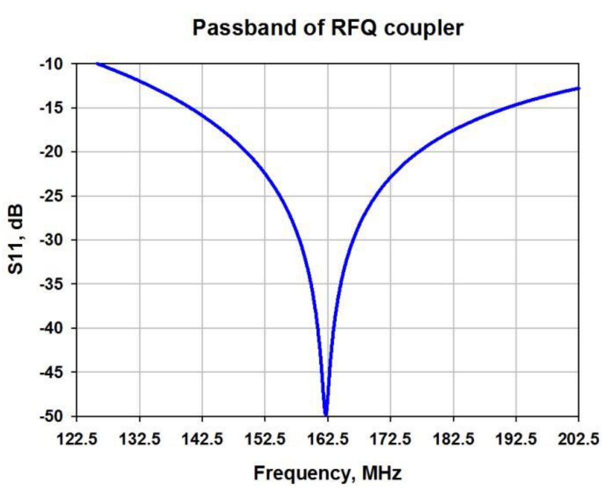

Figure 4: Passband of RFQ coupler.

Fig. 5 shows the position of the coupling loop inside the RFQ cavity. The loop can be rotated without changing the orientation of the input port. The design loop orientation is 45° relative to the position of max/min coupling. This allows the coupler to be tuned to compensate for both simulation and manufacturing inaccuracies.

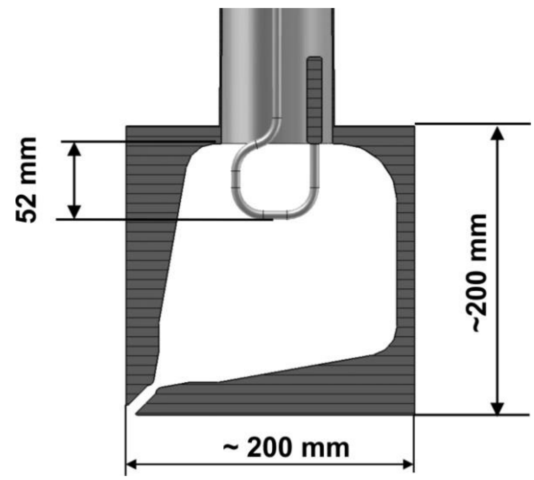

Figure 5: Loop position inside RFQ cavity.

Air Cooling and Thermal Simulations

The largest power losses in the coupler occur in the loop. Loop losses are due mostly to the magnetic field of the RFQ cavity and are about 130W under operating conditions. The loop must be cooled internally. Air was chosen as the cooling medium for several reasons: simplicity, the ability to apply HV bias, and less severe consequences in the case of a leak. Simulations indicate that an air flow rate of 3g/s is enough to provide acceptable cooling. The expected pressure drop is ~0.6 bar and maximum air flow speed in the loop tubes is ~140 m/s. Figure 6 shows of example of thermal simulations for 80 kW input power.

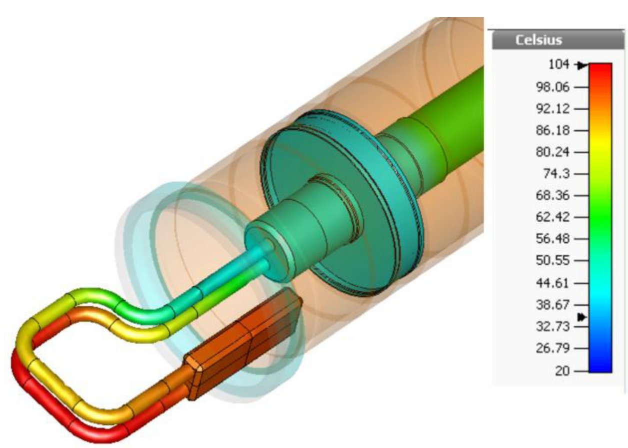

Figure 6: Example of thermal simulations. Input power is 80 kW, air flow rate 3 g/s.

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For 80 kW transmitted RF power, power lost in the ceramic window will be 185W and 212W for loss tangents of 10^{-4} and 10^{-3} respectively. Figure 7 shows temperature distribution at the ceramic window for loss tangents 10^{-4} and 10^{-3}.

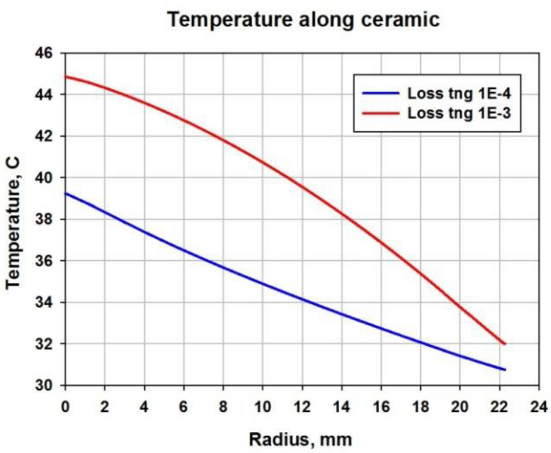

Figure 7: Temperature distribution at the ceramic window. Input power 80 kW, air flow rate 3 g/s.

Multipacting Suppression

Simulations show that multipacting is possible in a power range close to the operational level. Multipacting occurs in the coaxial part of the cavity input port. However, multipacting can be effectively suppressed by applying a high voltage (HV) bias. Simulations show that a +4kV bias suppresses multipacting in all power ranges. Additionally, the surface of the ceramic will be coated with TiN to reduce secondary emission.

DC BLOCK

To apply a HV bias to the internal conductor of the coupler, it must be isolated from the power amplifier. For this purpose, a "DC block" was designed. The structure of the DC block is presented in Figure 8.

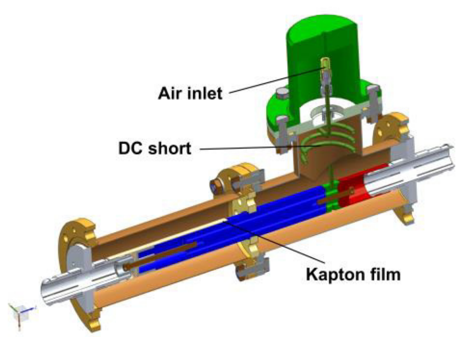

Figure 8: Structure of DC block.

The input and output of DC block are standard 3-1/8 inch, 50 Ohm coaxial waveguide. Two pieces of the central conductor overlap with a thin kapton film between them. This forms capacitor which passes RF power and blocks direct current (DC) high voltage . To protect the RF source in case of kapton breakdown, a DC short is installed at RF source side. This DC short is spiral shaped and transparent for 162.5 MHz RF power. The spiral is cooled by air. The passband of the DC block is ~100 MHz (S11 < -20 dB) and is presented in Figure 10. DC blocks and couplers were tested with HV up to 5.5 kV. Expected operating voltage is 4 kV.

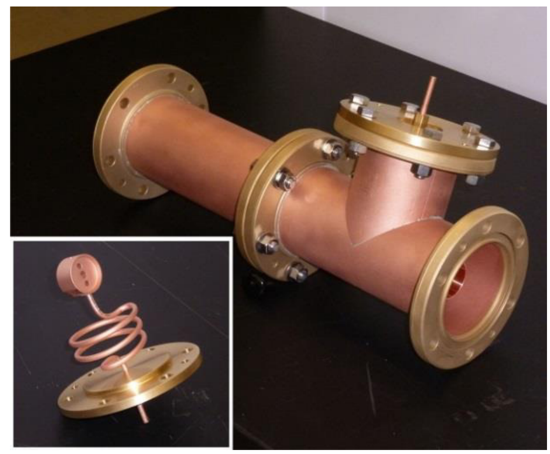

Figure 9: DC block. Tested up to 5.5 kV DC HV.

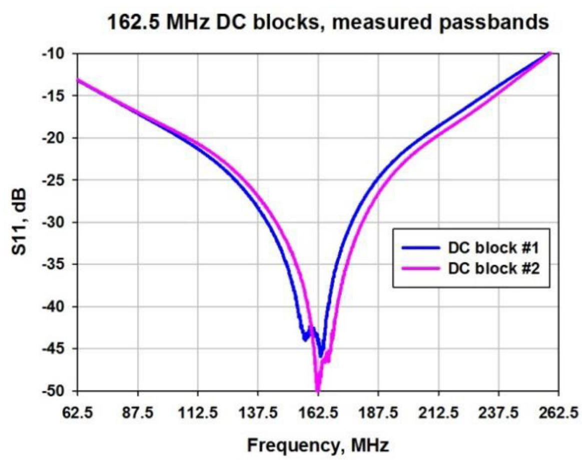

Figure 10: Measured passbands of 162.5 MHz DC blocks.

CONCLUSIONS

162.5 MHz coupler for ~75 kW, CW power has been designed. Currently two couplers are under fabrication.

REFERENCES

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