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# DUAL-RIDGE WAVEGUIDE LOAD DESIGN FOR eRHIC*

P. Kolb†1, Y. Gao[1,2], C. Pai[1], R. Porqueddu[1], K. Smith[1], and W. Xu[1]
[1]Collider-Accelerator Department, Brookhaven National Laborarory, Upton, NY 11973, USA
[2]Institute of Heavy Ion Physics, School of Physics, Peking University, Beijing 100871, China

## *Abstract*

To increase the real estate gradient in the eRHIC electron accelerator waveguide HOM couplers are being considered. These significantly reduce the length of individual cavities and address inter-cavity trapped modes, allowing for an increased number of cavities per cryomodule, which would increase the real estate gradient. The choice of waveguide went to a dual ridge waveguide due to a smaller size compared to rectangular waveguides.

The waveguide termination, to convert the RF energy into thermal energy, is a custom designed load based on a silicon carbide dielectric that is already being used in beamline absorbers. Simulations of the RF properties of the load are presented as well as first measurements on a prototype.

## INTRODUCTION

The eRHIC LINAC-Ring design [1] consists of one of the already existing ion-rings and a new electron accelerator based on the energy recovery LINAC (ERL) principle. In multiple turns the electron beam is accelerated to 18 Gev and after collision with the ion beam decelerated in the RF cavities to transfer the beam energy into electromagnetic field energy inside the cavity to accelerate further bunches. A limitation for the electron accelerator is the overall accelerator length as straight sections in the existing RHIC tunnel are limited to 200 m. As accelerating cavity, a five cell 647 MHz cavity operating at 16.2 MV/m is under consideration. To keep the real estate gradient high and keep the accelerator short enough to fit into the tunnel, waveguide higher order mode (HOM) couplers are proposed to take care of most of the HOM power generated by the beam. Beam line absorbers will take care of HOMs traveling between cryomodules. The current cavity design has six HOM waveguide ports as shown in Fig. 1, three on each side of the cavity at 120deg rotated to each other. The two sides are rotated by 30deg with respect to each other. For compactness, dual ridge waveguides (DRWG) will be used. This waveguide geometry is more compact than a rectangular waveguide at the same cut-off frequency. This will not only help with shortening the cavity length, but also reduce the thermal load to the cryogenic system. The waveguide geometry is chosen for a cut-off frequency for the fundametal waveguide mode of 770 MHz: significantly above the operating frequency but low enough for the HOMs to propagate into it. A cross section with dimensions is shown in Fig. 2.

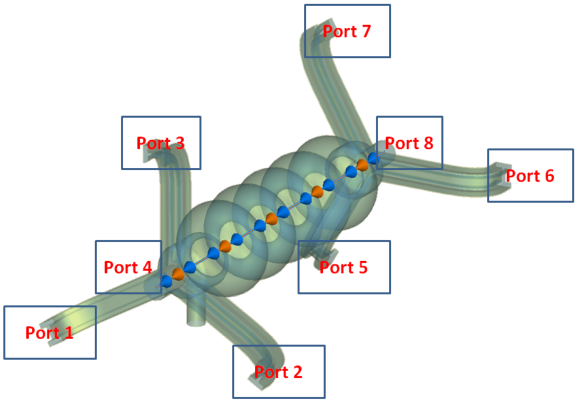

Figure 1: Simulation model of the 650 MHz cavity with six dual ridge waveguides for eRHIC.

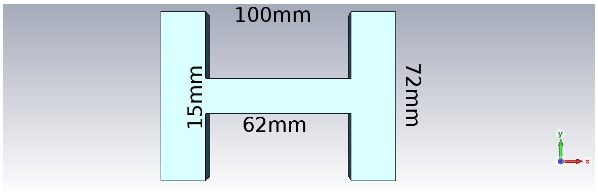

Figure 2: Cross-section view with dimensions of the DRWG with a cut-off frequency of 770 MHz.

These waveguides will terminate at loads at room temperature with water cooling. Due to multiple kW of HOM power on each load, cryogenic cooling would be unfeasible.

## HOM POWER

To determine the generated HOM power it is necessary to estimate the cavity impedance. Since the electron bunches are short with $\sigma_z$=3 mm, the impedance spectrum needs to be considered up to 40 GHz. The termination of the waveguide has to accommodate this broadband requirement. At low frequencies, up to 2 GHz, the impedance is calculated by eigenmode simulations. At higher frequencies wakefield simulations are used to calculate the cavity impedance. Another part to calculating the HOM power is the beam spectrum. This is dominated by the bunch train repetition frequency of 9.38 MHz but can be tuned with the bunch spacing and the timing between the accelerating and decelerating bunch train. Calculations on different combinations of bunch spacing showed some impact on the overall HOM power. Details of the HOM calculations can be found in [2]. In total, about 10 kW of HOM power per cavity is estimated based on the calculated eigenmode frequencies and impedance.

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† pkolb@bnl.gov

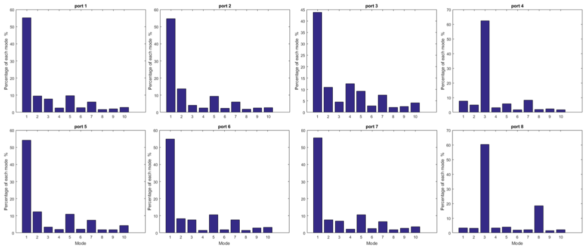

Figure 3: Distribution of HOM power over the first 10 waveguide modes in each port. The waveguide ports (1-3,5-7) show high power in the fundamental mode while the beam pipe ports transmit power in the TM01 mode.

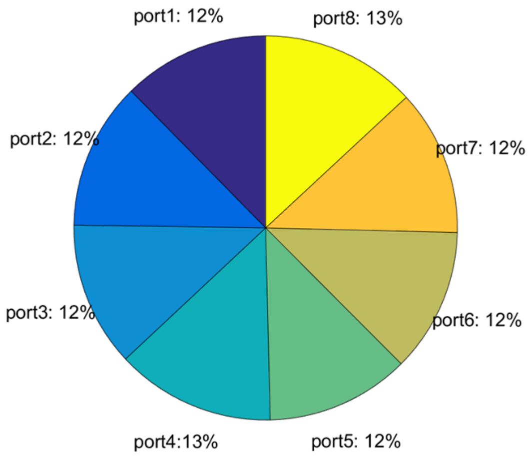

Figure 4: Fractional HOM power distribtion in each port. The HOM power is distributed evenly along all ports.

This can be significantly higher if the HOM frequency matches an integer multiple of the train repetition frequency of 9.38 MHz. As a precaution, the design HOM power is increased to 15 kW per cavity or 2.5 kW per waveguide. Wakefield and eigenmode simulations showed that a significant part of the HOM power is generated from an eigenmode around 1.22 GHz. It has also been determined that most of the HOM fields will leave the cavity in the first waveguide mode as can be seen in Fig. 3. In addition, the HOM power distributes over the six waveguides evenly in first order approximation as shown in Fig. 4, so that all waveguides can operate with the same load design.

### *Load Design*

The design was guided to minimize the RF reflection of the RF wave primarily in the fundamental waveguide mode by using silicon carbite (SiC) as a dielectric load. SiCs such as SC-35 from Coorstek have been successfully tested in beam line absorbers and waveguide loads [3–5]. The electrical characteristics of it are documented in [6] and will be used for the RF simulations. As simulation software the CST Studio Suite is used. The load consists of to identical pieces made out of SiC as can be seen in Fig. 5a, a top and a bottom piece which fit into the waveguide. Each piece is split into tiles (fig. 5b) that will be brazed to the load body individually. While the majority of the HOM power will be in the fundamental waveguide mode, the load covers also higher modes that have field in the vertical sides of the waveguide. Both the tiles in the vertical section and the horizontal section taper towards the center to create a smooth impedance matching to the incoming RF wave. Simulations have been carried out with solid dielectric pieces and with the tiles with gaps in between and no significant changes have been found.

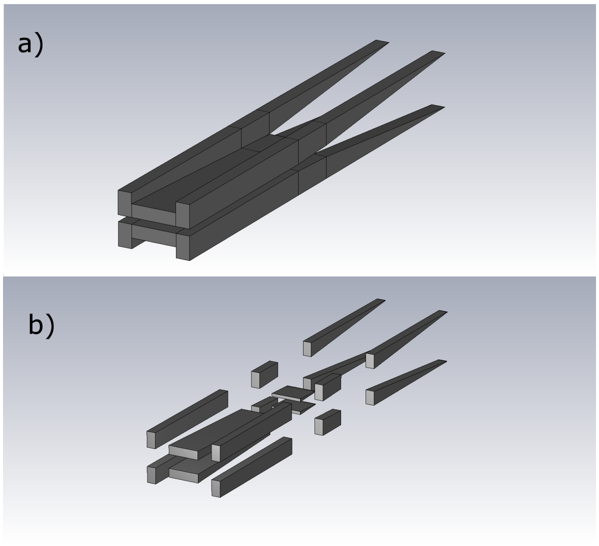

Figure 5: a) View of two identical halves of the dielectric load; b) exploded view of individual tiles of the load.

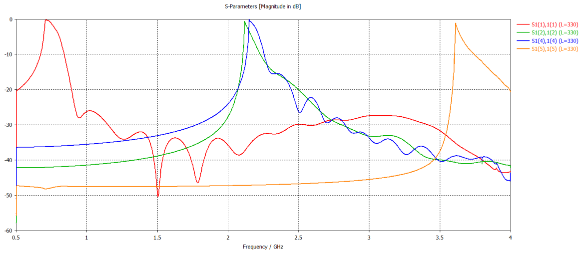

Figure 6: Reflection spectrum of the DRWG load for the first five waveguide modes (modes 2 and 3 are the same mode just polarized) up to 4 GHz. For all modes the reflection is below -20 dB shortly after the cut-off frequency.

Figure 6 shows the reflection coefficient S11 for the first five waveguide modes (modes 2 and 3 are symmetric in the waveguide and therefore have very similar reflections). As can be seen, the reflection is below -20 dB shortly after the cutoff frequency of each mode and below -30 dB for higher frequencies. Noteworthy is the first waveguide mode at 1.2 GHz. As mentioned earlier, a cavity mode at this frequency generates most of the HOM power. For this mode, the S11 parameter is below -30dB, so only a minimal fraction of the incoming wave is reflected. A prototype of the mechanical housing for the SiC has been designed (see. Fig. 7. This particular design is meant for a low power

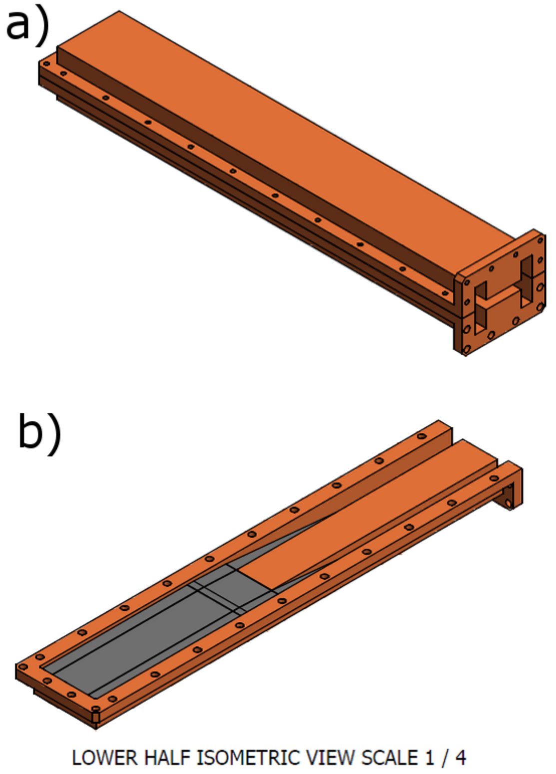

Figure 7: a) Assembled waveguide termination; b) lower half of waveguide termination with SiC visible.

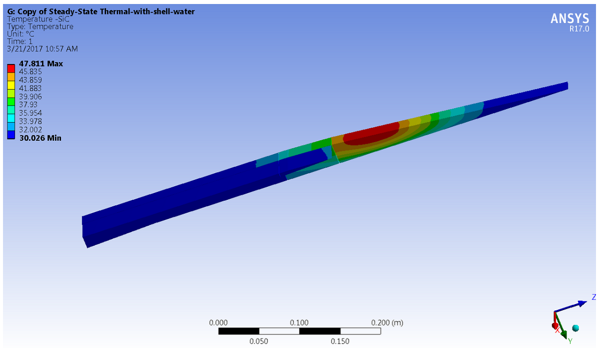

Figure 8: Ansys heat distribution simulation on the SiC dielectric for 1 kW of RF power at 1.2 GHz. The maximum temperature difference is 18C with watercooling on the housing of the load.

tests in air. For a full power, vacuum-tight model, the bolt pattern will be changed to a weld to connect the two halves together. Based on this prototype and the loss density calculated by CST Microwave studio at 1.2 GHz (frequency of the HOM with highest power) a thermal analysis was conducted. These thermal calculations showed a maximum temperature of 48 C in the SiC with 1 kW of RF power coming in as can be seen in Fig. 8. This is with water cooling on the outside of the housing. The tensile stress analysis showed reasonable performance with enough safety margins.

## FURTHER DEVELOPMENTS

There are certain challenges with the current design. For once, the load is 60 cm long, which could cause spacial issues in the RHIC tunnel and will be expensive to manufacture. As an alternative to the H-shaped dual ridge waveguide, a B-shaped waveguide was developed to avoid multipacting and provide better coupling to HOMs. A broadband load has to be designed at the time of writing. Further details on this can be found in [7].

## CONCLUSIONS

A broadband waveguide termination has been developed for a double-ridge waveguide with a cutoff frequency of 770 MHz. This will be used in a 650 MHz SRF cavity, which has six of those waveguides to extract HOM power. The termination has a reflection parameter of -20 dB or less on a broad frequency spectrum. A thermal and stress analysis of the termination showed a temperature increase of 18 K at 1 kW of RF power with reasonable stresses in the SiC.

## ACKNOWLEDGMENTS

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