# RF COUPLER DESIGN FOR THE TRIUMF ISAC-II SUPERCONDUCTING QUARTER WAVE RESONATOR

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*Abstract*

An rf Coupler for the ISAC-II medium beta (β=0.064 and 0.074) superconducting quarter wave resonators was designed and tested at TRIUMF. The main goal of this development was to achieve stable operation of superconducting cavities at high acceleration gradients and low thermal load to the helium refrigeration system. The cavities will operate at a 6 MV/m acceleration gradient in overcoupled mode at a forward power of 200 watts at 106 MHz. The overcoupling provides ±20 Hz cavity bandwidth, which improves the stability of the rf control system for fast helium pressure fluctuations, microphonics and environmental noise. Choice of materials, cooling with liquid nitrogen, aluminum nitride rf window and thermal shields insures a small thermal load on the helium refrigeration system by the Coupler. An rf finger contact, which caused micro dust in the coupler housing, was eliminated without any degradation of the coupler performance. Rf and thermal calculations, design and test results on the coupler are presented in this paper.

## INTRODUCTION

The ISAC II [1] medium beta cavities have a design gradient of 6 MV/m. This corresponds to a peak surface fields of ~ 30 MV/m and ~60mT, and a stored energy of U=3.2 J. This is a significant increase over other operating heavy ion facilities. To achieve stable phase and amplitude control the natural bandwidth of +/- 0.1 Hz is broadened by overcoupling to accommodate detuning by microphonic noise and helium pressure fluctuations (~1-2 Hz/Torr). The ISAC II medium beta cavities are outfitted with a passive mechanical damper [2] and the microphonics are not expected to be more than a few hertz RMS. The chosen tuning bandwidth of +/- 20 Hz demands a cw forward power of 200 watts and a peak power capability of 400 watts to be delivered to the coupling loop at the cavity.

The various prototypes of the coupler design are reported in [3]. We started with a copy of an INFN-Legnaro design for gradients of 3-4 MV/m and forward power of 50 W, which we identified as Mark I. In the Mark II design we changed the loop assembly materials and added LN2 cooling. We initially tried to cool the outer conductor of the cable with an LN2 cooling loop as well but opted to add a thermal shield inside the cryostat along the rf drive cable which performed a more efficient job in reducing the added thermal load on the helium system. The thermal shield is connected to the LN2 shield of the cryostat and restricts heat radiation flux from the coupler rf cable to the helium system. In the Mark III version we added a 1-inch long split ring piece of Aluminum Nitride (AIN) dielectric to thermally connect the inner and outer conductors of the loop near the heat exchange block to reduce inner conductor heating. In the Mark IV prototype shown in Fig.1, the outer conductor and heat exchange block are formed from a solid piece of copper and a cooling channel running through the block allows direct cooling with LN2. All of these modifications allowed us to reach our design goal of 200 watts forward power at the coupling loop with less than 1 watt of power being added to the helium load. The Mark V (Fig.2 and Fig.6) is the final design for the cryomodule and differs from the Mark IV only by the heat exchange block design, which is adapted for the cryomodule assembly. The thermal shield and heat exchange block are cooled with the same LN2 flux.

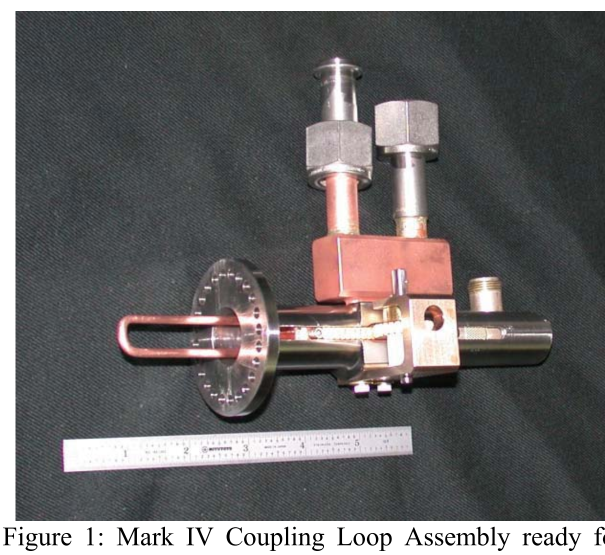

Figure 1: Mark IV Coupling Loop Assembly ready for installation into the cavity.

## RF COUPLER

### *Coupling Loop Assembly*

The housing of the coupling loop is made from thin stainless steel for thermal isolation from the cavity. The inner and outer conductors of the coupling loop assembly are made of copper. The outer conductor, which includes an integrated heat exchange block, is driven in and out through a rotating shaft attached to a stepping motor on the cryostat lid via a rack and pinion mechanism on the loop housing. The position of the AIN dielectric and the

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LN2 cooling circuit is shown in a cut-away rendering of the Mark V coupling loop assembly in Fig. 2.

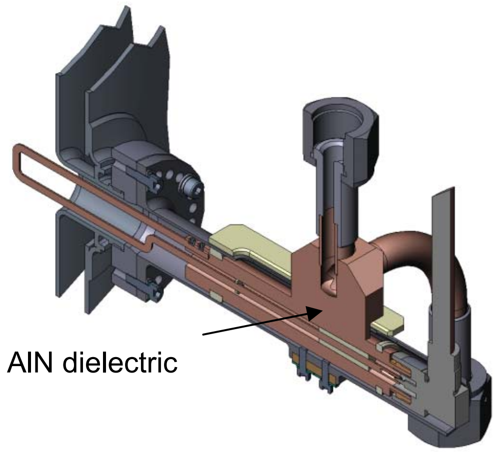


Figure 2: A cut-away rendering of the Mark V coupling loop assembly showing the position of the AlN dielectric and the LN2 cooling block.

## *Internal Coaxial Cable*

In the initial rf tests we used Flexco FC445 coaxial cable which did the job but was very expensive. We are now using an Andrews ETS50 coaxial cable, which is less expensive and has better thermal conduction from the inner conductor to the outer conductor of the cable, even though the attenuation is bit more and the maximum power rating is less. The comparison is shown in Table 1.

Table 1: Comparison of coaxial cables for use inside the cryostat at 106 MHz

| | FC445 | ETS50 | Comparison* |
|---|---|---|---|
| Maximum Power, W | 9.6 | 6.0 | 37% less |
| Attenuation, dB/m | 0.037 | 0.041 | 10% more |
| Velocity of propagation, % | 84 | 83 | |
| Transverse thermal conductivity of dielectric, W/(m*K) | 0.27 | 0.50 | 84% more |
| Price, $/m | 250 | 120 | 53% less |

*Parameters of Andrew ETS50 cable in comparison with Flexco FC445.

In the test cryostat the length of coaxial cable required from the coupling loop assembly to the top feed through flange is 1.65 meters. This turns out to be an unfortunate length for a cable at this frequency with a VSWR, which positions a current maximum at the flange connection. However for the cryomodule the length of the cable is reduced to 1.25 meters, which greatly reduces the current density and the consequent heating problem at the flange (see Fig.3). The peak current at the flange for the cryomodule is 1.9 amps compared to 5.4 amps for the test cryostat.

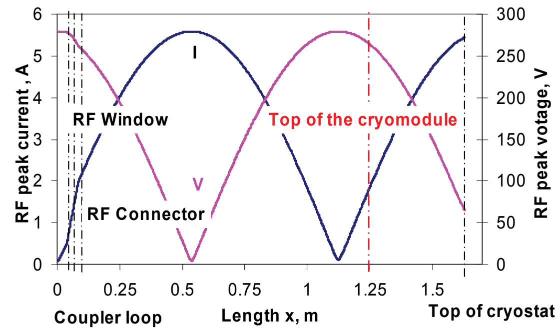


Figure 3: The voltage and current distribution along the coupler line inside of the test cryostat at nominal operating parameters (Ea=6 MV/m, Pf=200 W).

## *Thermal Measurements*

Thermal measurements are done by first measuring the static heat loss based on the helium boil-off rate after full thermalization. The cavity is then powered until thermal equilibrium is reached and the new static heat load is measured. Several sensors during power on and power off cycles monitor the temperatures of the loop assembly. The position of the sensors on Mark IV design are shown schematically in Fig.4 and table 2 is the temperature of the sensors with rf off after full thermalization of the He cooling system and with rf on after thermal equilibrium is reached. TS8 is mounted on the heat shield and although it is showing a high temperature in the table, it was found that this was mostly due to a poor thermal contact of the thermal shield with the LN2 shield.

The measurements were taken with a forward power at the loop of 250 watts and a gradient (Ea) in the cavity of 6 MV/m. Under these conditions the loop heating caused approximately an extra 0.5 watts to the helium static load.

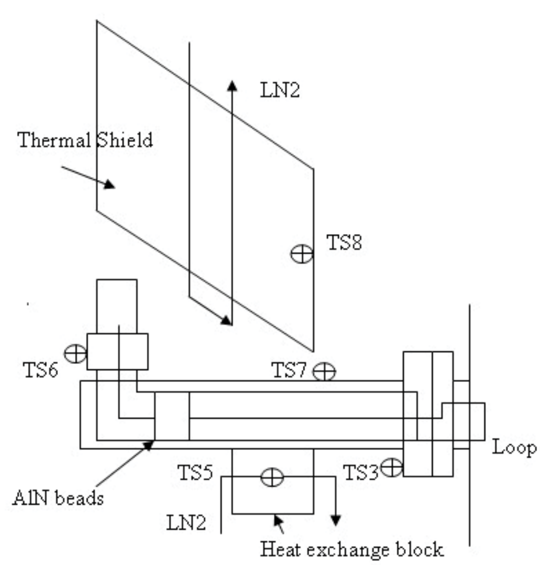


Figure 4: Schematic presentation of the temperature sensors on the coupling loop assembly.

Table 2: Temperature readings of the sensors on the coupling loop assembly shown in Fig. 4

| | TS3, $^0$K | TS5, $^0$K | TS6, $^0$K | TS7, $^0$K | TS8, $^0$K |
|---|---|---|---|---|---|
| RF off | 7.7 | 77 | 84 | 16.8 | 87.5 |
| RF on | 12.8 | 96.5 | 169.8 | 28.5 | 130.4 |

### *Fingerstock*

RF fingerstock was initially installed in the coupling loop assembly to connect the outer conductor of the coupling loop assembly to the outer stainless steel housing. This provided an rf path to ground for any rf leakage from the cavity through the coupling loop penetration. However this also caused micro dust in the coupling loop housing and the possibility of eliminating it was investigated.

Figure 5 presents a segment of the HFSS model of the coupler for the fingerstock simulation. The total HFSS model consists of a lossless quarter wave resonator and a 50 Ohm loaded coupler set close to nominal coupling. The fingerstock plane boundary condition changes from a perfect conductor (with fingerstock) up to a minimum capacitance, of the coupler body to ground, of 20 pfd. The results from the Eigensolver calculations for resonant frequency and external quality factor with and without fingerstock was the same ($f_o$=105.941 MHz, $Q_{ext}$=3.5*10$^6$). The fingerstock could indeed be eliminated without any degradation to the coupler performance.

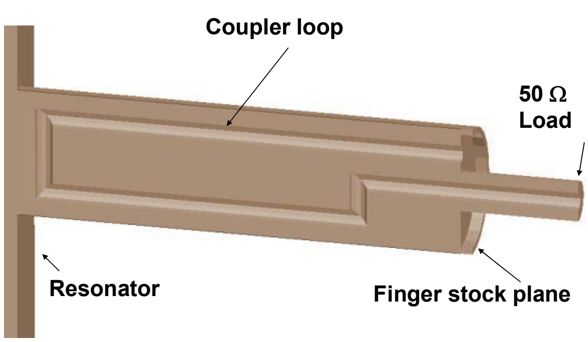


Figure 5: HFSS model for fingerstock simulation.

The only noticeable difference was an increase in the rf leakage as noted by an offset in some of the temperature sensor readings.

### *Mark V Coupler Assembly*

The cryomodule, with four medium □ cavities equipped with Mark V coupler assemblies, were successfully tested up to 700 watts of rf forward power. Fig.6 shows two of the cavities with their coupler installed and their associated heat shields. One can also see the arrangement of the LN2 cooling lines.

## CONCLUSIONS

When we started out with Mark I we could not go to higher powers without significantly heating both the cable and the loop assembly and several watts of power were added to the helium load even at low power levels. In the Mark II design the temperature of the inner conductor of the coupling loop assembly was high enough to increase the length of the coupling loop and caused an increase in the coupling beta. This increase in beta was sufficient to cause the power at the coupling loop to increase from 140 watts to 200 watts for the same field gradient in the cavity. The added heat load to the helium system for this arrangement was 4.5 watts. The addition of the heat shield around the cable and loop assembly further reduced the additional helium heat load to 2.5 watts but the temperature of the inner conductor was still high enough to increase the length of the coupling loop. In the Mark III design, the addition of the AIN dielectric reduced the temperature of the inner conductor sufficiently to prevent the length of the coupling from increasing for a more stable operation. In addition the improvement in the thermal path reduced the thermal equilibrium time from 6 hours to 2 hours. The added power to the helium load under these conditions was 1.5 watts. The Mark IV design has now allowed us to take the last step in achieving our design goal of less than 1 watt added to the helium load for 250 watts forward power at the coupling loop.

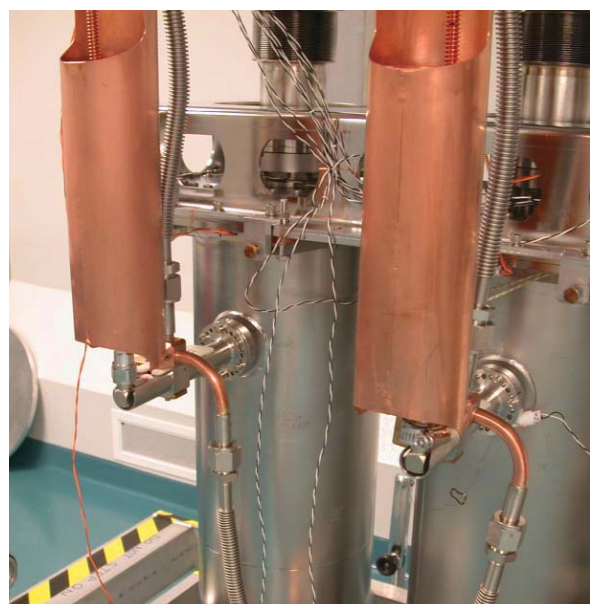

Figure 6: Mark V Coupler Loop Assembly installed on the cavity in the Cryomodule.

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[3] R.E. Laxdal, et al, A Mechanical Tuner and rf Drive Line System for the ISAC II Quarter Wave Superconducting Cavities, SRF2003