FIVE PROJECTS OF HIGH RF POWER INPUT COUPLERS & WINDOWS FOR SRF ACCELERATORS*

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Abstract

Various novel high RF power input windows and couplers were developed and designed by AMAC to reliably operate at an average power level of 50kW to over 300 kW. These projects include: (1) Two waveguide windows for Jefferson Lab FEL upgrade; (2) Three co-axial window-couplers with compression ring to reduce the tensile force on ceramic; (3) Three SNS prototype high RF power windows with center conductors; (4) Two RIA prototype high RF power windows with center conductors; (5) Two cost effective TESLA RF power couplers. Couplers 2 to 4 were manufactured by CPI. Couplers 1 to 4 were high power tested by Jefferson Lab. TESLA couplers will be tested by Orsay (France) through DESY (Germany). During the R&D phase, extensive calculations were performed to optimize window designs using MAFIA, HFSS, ANSYS, multipacting program. Based on the above efforts, an innovative RF surfaces design (AMAC-2) was developed to remove the chocks used in AMAC-1 and provided the following advantages: better vacuum, easier cleaning, and less secondary electron-multipacting.

INTRODUCTION

The RF window problem has grown as the power required for waveguide and coaxial operating systems has exceeded prior design margins. Failures of windows generally occur in three categories: (1) excessive heating, (2) arcing, and (3) weak mechanical designs.

AMAC was awarded by the US Department of Energy grants to develop the innovative high RF power input couplers to resolve some of these challenges. AMAC-2 aims to replace the AMAC-1 design to improve the multipacting characteristics, vacuum properties, and to allow for easier cleaning and fabrication procedures. After extensive RF calculations, using MAFIA and HFSS programs, the design was further analyzed for multipacting resonances with a program implemented at the University of Helsinki. The calculation results support the selection of this design for 200 kW average RF power operation. An innovative feature consisting of a compression ring was incorporated to reduce the tensile forces on the ceramic by pre-stressing the ceramic and increase the reliability of the ceramic window. Water-cooling is used to remove the dissipated power at the window and the antenna.

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HIGH RF POWER COUPLER WITH COMPRESSION RING & BETTER RF SURFACE CONFIGURATIONS

We chose a typical door-knob design for the waveguide-co-axial transition. The coupler RF geometry was modeled using the HFSS program. Figures 1 to 3 show the calculated electric fields, the geometry of the window area, and a complete assembly. Figures 4 and 5 show the electric and magnetic field distributions, and the losses in the ceramic window.

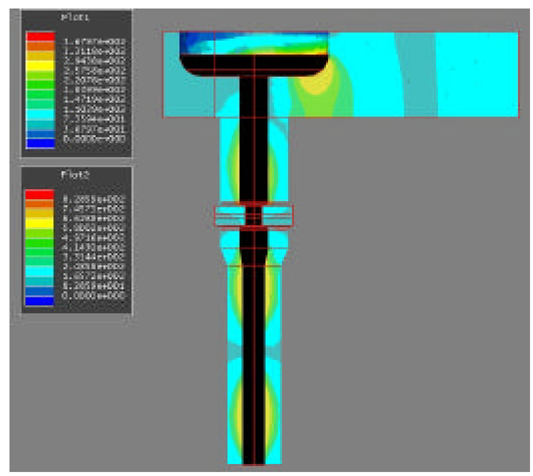


Fig. 1: AMAC -2 Coupler, Electric Fields (V/m for 1W average power)

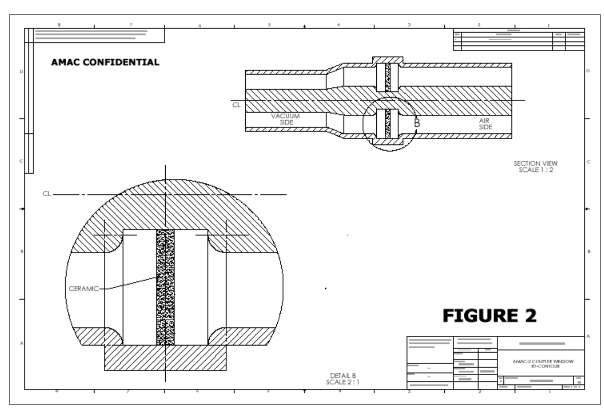


Fig. 2: Window Geometry

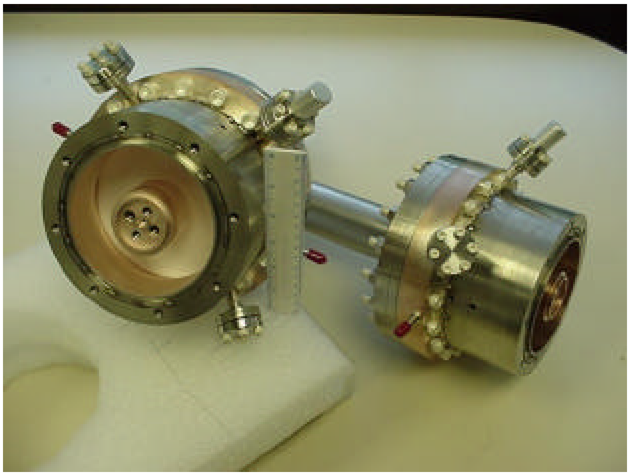


Fig. 3: Coaxial coupler assembly with AMAC-2 (with compression ring) window design

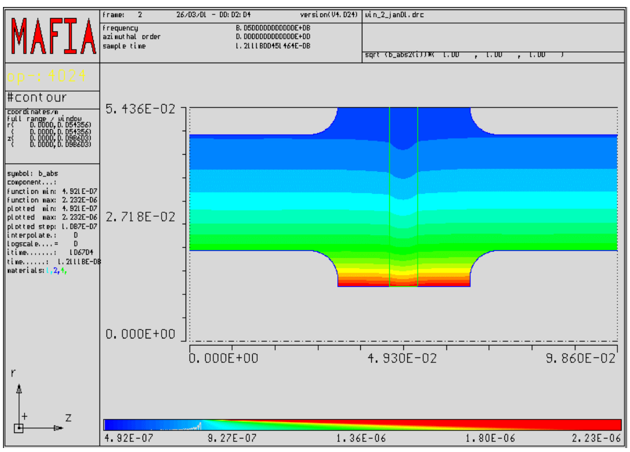


Fig. 4: Contour plot of magnetic field in AMAC-2

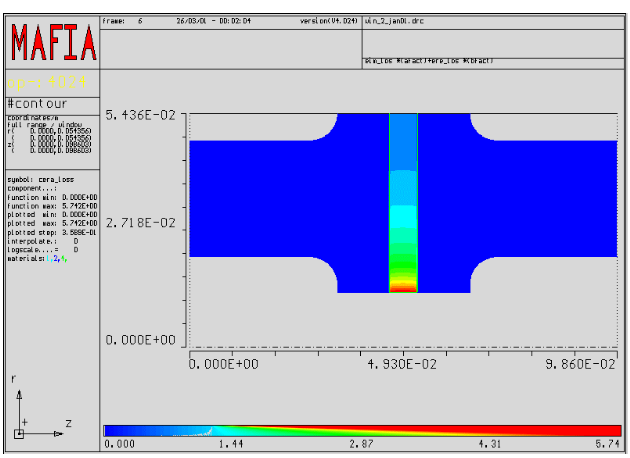


Fig. 5: Contour plot of dielectric loss of ceramic in AMAC-2

Multipacting calculations were performed at the University of Helsinki using a program that tracks electron trajectories in various wave reflection conditions and determines their enhancement possibility for different power levels.

As illustrated in Fig. 6, the results show low multipacting activity at several phase angle positions. It is evident from the comparative results for up to 4 MW peak power levels (104 kW average power), that the AMAC-2 version shows a much lower multipacting activity than the AMAC-1 version in all reflection and power level conditions.

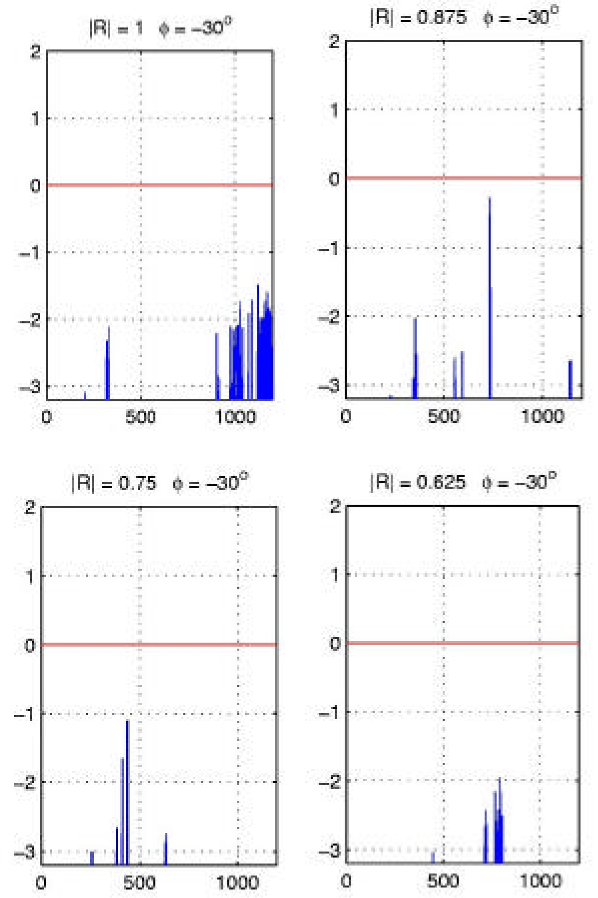


Fig. 6: Relative Enhanced Counter Function (348 kW average, 4 MW peak power)

The antenna and the inner and outer edges are water-cooled. The circuit is designed for up150 psi water pressure and the water circuits are not in direct contact with the thin copper cylinders attached to the ceramic to avoid the risk leaks into the vacuum system in case of eventual corrosion. The water velocity was limited to less than 1.2 m/s also to reduce the possibility of radiolitic corrosion. The maximum calculated temperature difference on the ceramic along the surface is 15^{o}C for 200 kW average power and loss tangent value 0.0006.

A stainless steel compression ring was added to AMAC-2 to reduce the thermal tensile stresses in the ceramic during high power operation. For a case of 500 kW input power with symmetric cooling, the compression ring reduces the maximum tensile stress in the ceramic to 2.7 kpsi (the maximum stress occurs at the outer brazing edges). This is only 47% of the corresponding stress without the compression ring. Figure 7 shows the distribution of 1st principal stress in the window.

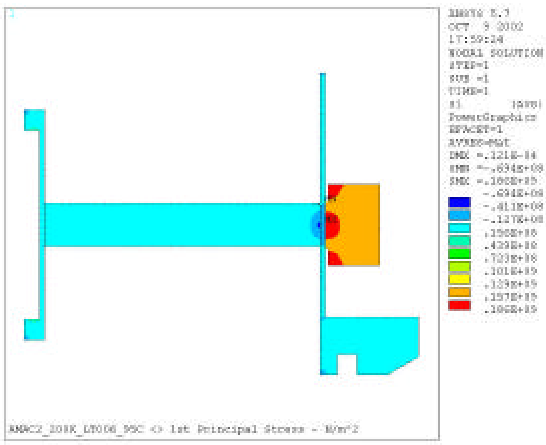


Fig. 7: 1st Principal Stress distribution

In TW mode up to 1 MW (1 ms, 30 Hz), test "CW" at 800 kW for about 100 minutes O.K. In TW mode CW test at 400 kW (1 ms, 40 Hz - due RF system limitations) for 3 hours. In SW mode up to 800 kW local peak power. Tests stopped due to klystron problems.

SNS PROTOTYPE COUPLERS

AMAC and CPI (subcontractor) were awarded a contract to produce three prototype SNS high RF input power coupler windows. They were delivered; high RF power tested, and qualified to meet the SNS technical requirements. The SNS technical requirement are briefly listed in the following:

VSWR: 1.05 or lower at 805 MHz
Power input: 550 kW peak traveling wave
RF on pulse length: 1.3 ms
Pulse repetition rate: 60 Hz
Standing wave in full reflection: 4 MW (up to 150 µs)
Average power: 53 kW (with 10% margin)
Maximum radiative heat loss to 2.1K circuit: 1 W

Figures 8 and 9 show a general window geometry and a picture of AMAC-1 SNS high RF Input Power window.

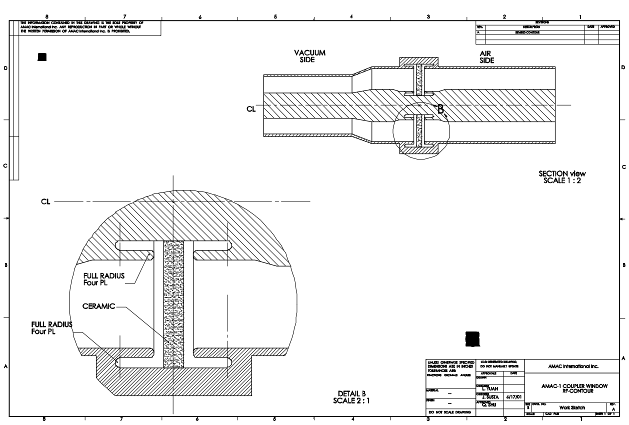


Fig. 8: Window Geometry

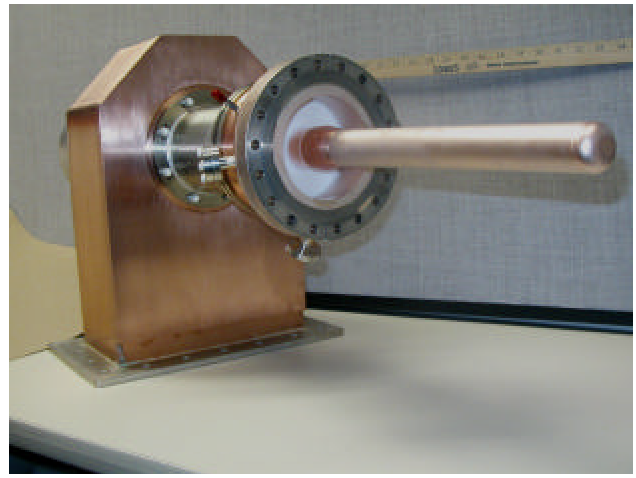


Fig. 9: AMAC-1 SNS coupler

AMAC-1 is a coaxial type of coupler with a planar ceramic window separating the vacuum side from the air side. In the HFSS simulation, the inner and outer conductor are treated as conductor boundary with finite conductivity (5.8E+7 siemens/m). The loss tangent is taken as 0.0002, and the permittivity value is 9.6.

The RF calculations show that for a 53 kW average power window assembly:

S11: 0.00864
S12: 0.99939
VSWR: 1.0174
Power Loss in the Ceramic: 6.5 W (LT=0.0002)
Power Loss at the Copper Surface: 54 W
Peak Electric Field: 27.5 kV/m (at the choke corner)
Peak Magnetic Field: 91.4×10^{-6} Tesla (at the ceramic inner boundary)
Insertion Loss: -0.0053 dB

The coupler windows have been conditioned and successfully RF tested at the Jefferson Laboratory to meet the SNS specifications. Figure 10 shows the high RF power test fixture of AMAC-1 SNS coupler.

AMAC-1 Coupler was on the klystron side, AMAC-2 coupler on the RF terminating load (Short circuit).

Electron activity (about 20 nA) started to manifest during long constant RF power test (525 kW, pulse duration 1.15 ms, repetition 60 Hz). No bias voltage was applied during all these tests. The major findings from the test are:

- In TW mode up to 1 MW (1 ms, 30 Hz), test "CW" at 1 MW for about 60 minutes O.K.
- In TW mode, 2 × 12 hours constant power test at 550 kW (1.15 ms, 60 Hz)
- In SW mode up to 2.8 MW local peak power (pulse duration 0.15 ms, repetition rate 60 Hz).

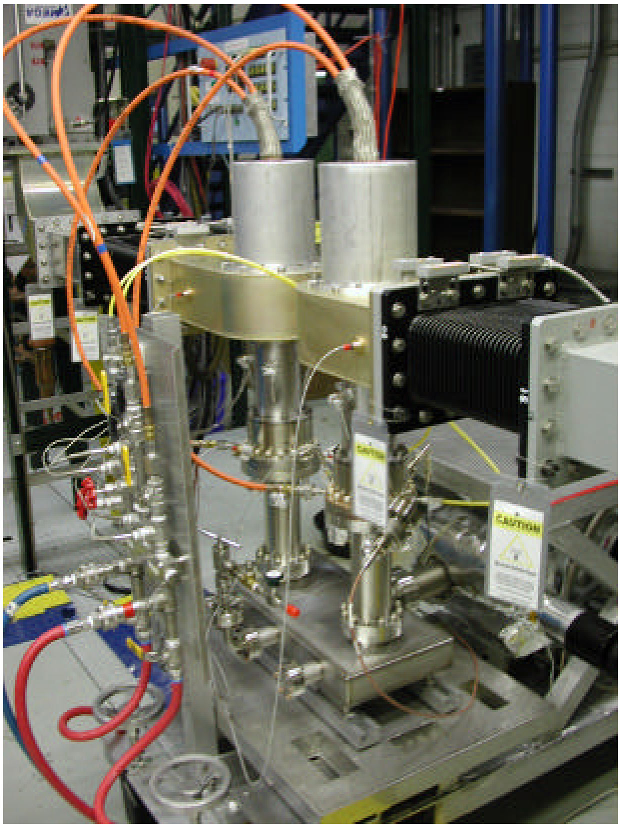


Fig. 10: Jefferson Lab Test Stand with two AMAC windows

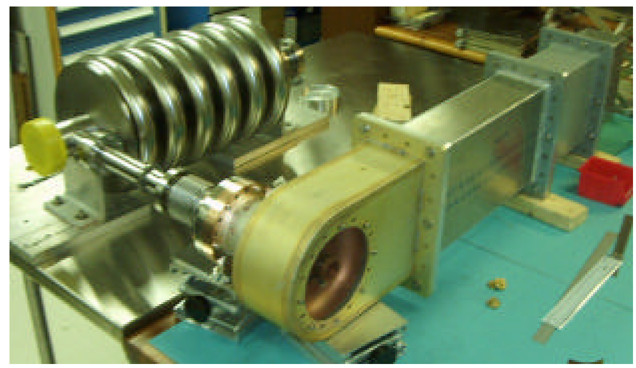
RIA PROTOTYPE COUPLERS

RIA project is on the top priority of US DOE Nuclear Physics division. AMAC and MSU designed a RF coupler window to meet the specification requirements for the proposed RIA accelerator project. CPI performed the manufacturing optimization and fabrication. The main specification parameters for RIA prototype coupler are:

VSWR: 1.05 or lower at 805 MHz
Maximum CW power: 10 kW
External Q of coupler: 2×10^7
Maximum thermal load to 2 K circuit: 2 W

Air-cooling removes the dissipated power at the window and the antenna and outer conductor are conduction cooled. The outer conductor is copper plated stainless with a 50 or 77 K thermal intercept. The RIA cryostat geometry requires a coaxial 805 MHz coupler design with a transition to standard 3-1/8" transmission line. This coupler design is similar to the AMAC SNS high power prototype couplers. The geometry incorporates chokes at the inner and outer conductor. The coupler windows have been conditioned and successfully RF tested at the Jefferson Laboratory, and meet or exceeds the RIA specifications with small temperature increases in the ceramic and no arcing. Figure 11 (a) shows the RIA coupler and Fig. 11 (b) shows the assembly of RIA SRF cavity and couplers prepared for the high RF power test at Jefferson Lab.

(a)



(b)

Fig. 11: (a) RIA coupler (b) RIA SRF cavity, waveguide, and coupler assembly

NEW TESLA COUPLER

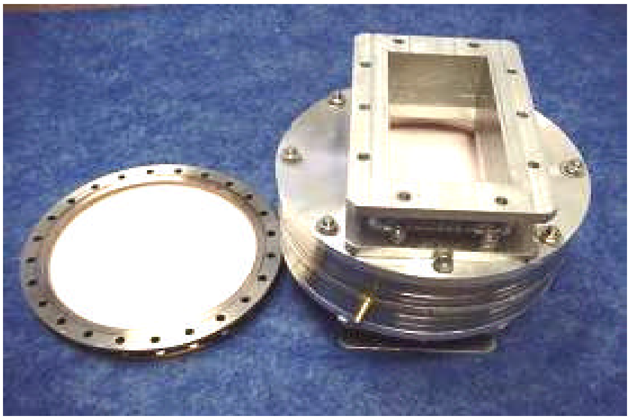
High RF power input couplers capable of carrying very high RF power to superconducting accelerating cavities are expensive and difficult to process. Based on AMAC's successful results, AMAC has signed a joint agreement with DESY to develop a reliable, low cost high power input coupler for the TESLA project, which is led by DESY, Germany. The novel DFM principles will be applied to the coupler design with unique modular sub-assembly to largely reduce the manufacturing cost.

Preliminary design has completed and been reviewed by DESY and Orsay (France). HFSS, MAFIA, ANSYS, and multipacting programs have been used to optimize the design. Engineering design will be finished and the entire coupler will be fabricated by next Spring.

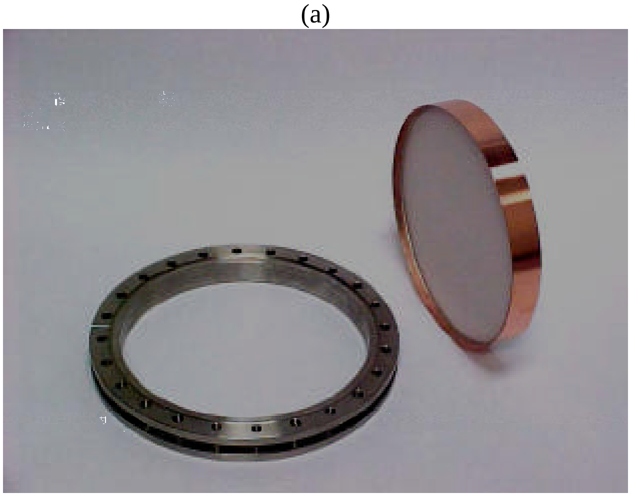
HIGH POWER WAVEGUIDE WINDOWS FOR FEL UPGRADE

Two prototype windows were constructed using the innovative compression ring & internal cooling technology, as shown in Fig. 12. A stainless steel to copper laser welded sample-ring for the final vacuum seal, and the innovative power window design was demonstrated. The RF performance of five window design-options was simulated and one design was chosen to be fabricated, cold tested (low RF power), and successfully high power tested (35-kW CW RF Power-the maximum available RF power at Jefferson Lab).

Calculations of the interference fit indicated that the window was under 15,000 psi compression at room temperatures.



(a)



(b)

Fig. 12: (a) 200-kW CW RF power waveguide window, (b) Compression ring & ceramic window

The loss in the window was calculated to be 200 watts at 200 kW, or 0.1%, by ANSYS calculations. The high power tests at 35 kW would dissipate 35 watts into the window. This was confirmed in the high power tests by the temperature rise of the window and ANSYS Calculation.

ACKNOWLEDGEMENT

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REFERENCE

[1] Q. S. Shu, J. Susta, G. F. Cheng, S. Einarson, T. A. Treado, W. C. Guss, and M. Tracy, “Design and Fabrication of Input RF Coupler Windows for the SNS,” Proc. of Workshop on High-Power Couplers for Superconducting Accelerators, Jefferson Lab, Newport News VA,October 30 - November 1, 2002.

[2] Q. S. Shu, J. Susta, G. F. Cheng, S. Einarson, T. A. Treado, W. C. Guss, M. Tracy, I. Campisi, and M. Stirbet, “Design, Fabrication and Testing of Novel High Power RF Input Couplers,” Proc. of Workshop on High-Power Couplers for Superconducting Accelerators, Jefferson Lab, Newport News, VA, October 30 - November 1, 2002.

[3] Q. S. Shu, J. Susta, G. F. Cheng, T. L. Grimm, J. Popielarski, S. Einarson, T. A. Treado, “Input RF Coupler Windows for RIA Cavities,” will be presented at this workshop.