

PROJECT DESCRIPTION
FY2006 ILC University Accelerator R&D

Circular Waveguide Power Coupler and HOM Damper for the ILC

Personnel and Institution(s) Requesting Funding

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Project Overview

We propose a novel power coupler and higher-order-mode (HOM) damper system that should reduce both the cost and the technical risk compared to the baseline design.

CONCEPT

The baseline design for the International Linear Collider (ILC) superconducting radio frequency (SRF) cavity's power coupler and higher-order-mode (HOM) damper is complicated, expensive and a reliability issue. The baseline power coupler uses a coaxial transmission line with two ceramic windows. The outer conductor is rigid and the center conductor is adjustable to vary the coupling strength. The HOM damping is accomplished with two couplers consisting of niobium lumped-circuit notch filters with cold low power ceramic feed-throughs and coaxial cables that transmit the HOM power to room temperature loads.

We propose a radically different approach of using a single, circular waveguide with a ceramic disc vacuum window as both the input power coupler for the fundamental accelerating mode, and as the output coupler for all HOMs. This would significantly simplify the power coupler, HOM damper, cavity and cryomodule assembly.

Figure 1 shows the cavity with the circular waveguide coupler. The top view shows the electric field profile of the TE_{11} mode that is transmitted through the waveguide to the cavity where it is coupled to the axial electric field of the cavity's TM_{010} mode. The circular coupler can be an integral part of the cavity or separated via a beam pipe flange as is shown in the figure.

The pickup or transmission probe that monitors the field amplitude can be placed at a null of the input coupler's TE_{11} mode and still monitor the evanescent wave of the cavity TM_{01} mode as shown in Figure 1. This will further simplify the cavity so the waveguide coupler and pickup are on the same end of the cavity and the tuner and its associated components can occupy the other end of the cavity.

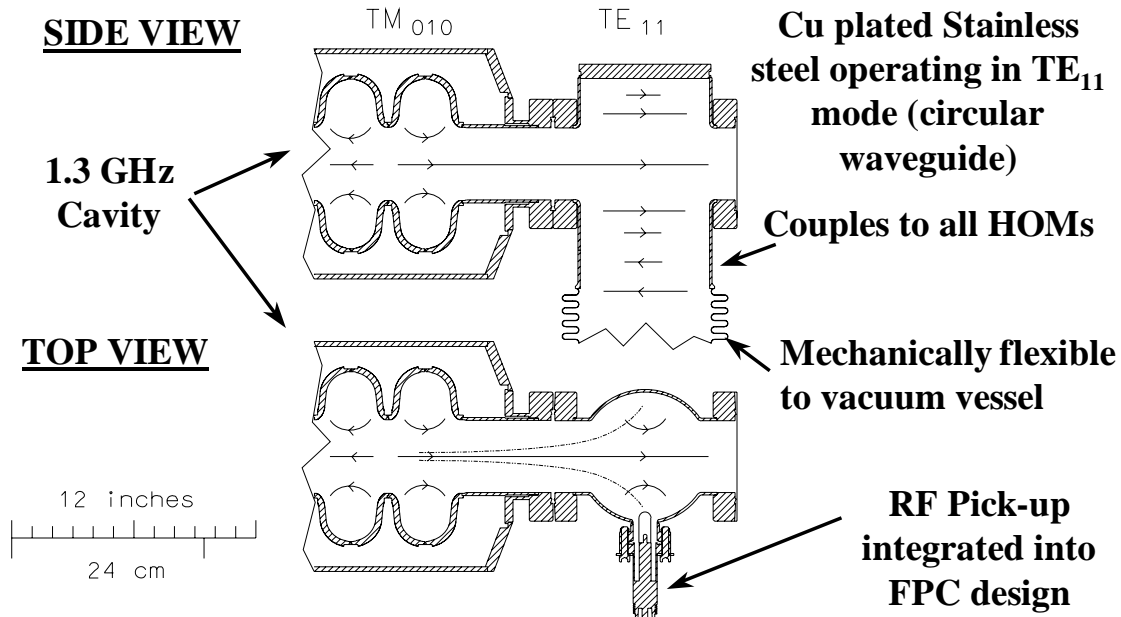


Figure 1. Circular waveguide power coupler and HOM damper, side view (above) and top view (below).

The transverse dimension of the circular waveguide must be large enough to have the TE_{11} mode cutoff frequency below 1.3 GHz. The relatively large dimension makes the waveguide coupler inherently capable of high pulsed and cw power. Also, it allows HOMs to couple to different TE and TM modes of the circular waveguide so it is anticipated that all HOMs can be adequately damped using additional loads on the air-side of the ceramic window.

The klystron power with circulators and directional couplers is transmitted to the cavity via standard WR-650 rectangular waveguide. A conventional mode converter will transform the rectangular TE_{10} waveguide mode to a circular TE_{11} waveguide mode. A tuning stub can be made part of the mode converter to change the coupler's external quality factor, Q_{ext} .

By setting up a standing wave in the circular waveguide to the cavity, the coupling strength or Q_{ext} can be varied. The ceramic window can be placed at a null in the electric field so minimal heating occurs. The circular waveguide is compatible with high power so cw applications and standing waves are appropriate.

Figure 2 shows the cavity with hermetically sealed coupler that is accomplished with a room temperature ceramic window. The power coupler is simpler than the baseline design while maintaining the ability to adjust coupling strength. The connection to the vacuum vessel is flexible and can allow axial motion of the cavity during cool down which can significantly simplify the cryomodule design. The HOMs can be individually damped with loads on the air-side of the ceramic window that are specifically tuned for dangerous modes.

Waveguide couplers have been used for previous applications including the 1500 MHz CEBAF multi-cell cavities and the 500 MHz Cornell single-cell cavities [1]. For these cases a rectangular cross section is used. The proposed circular cross section is much simpler and less expensive since standard stainless steel pipes, bellows and Conflat flanges with copper plating can be used. Also, the circular ceramic vacuum window is better matched to the waveguide for the fundamental mode as well as the HOMs.

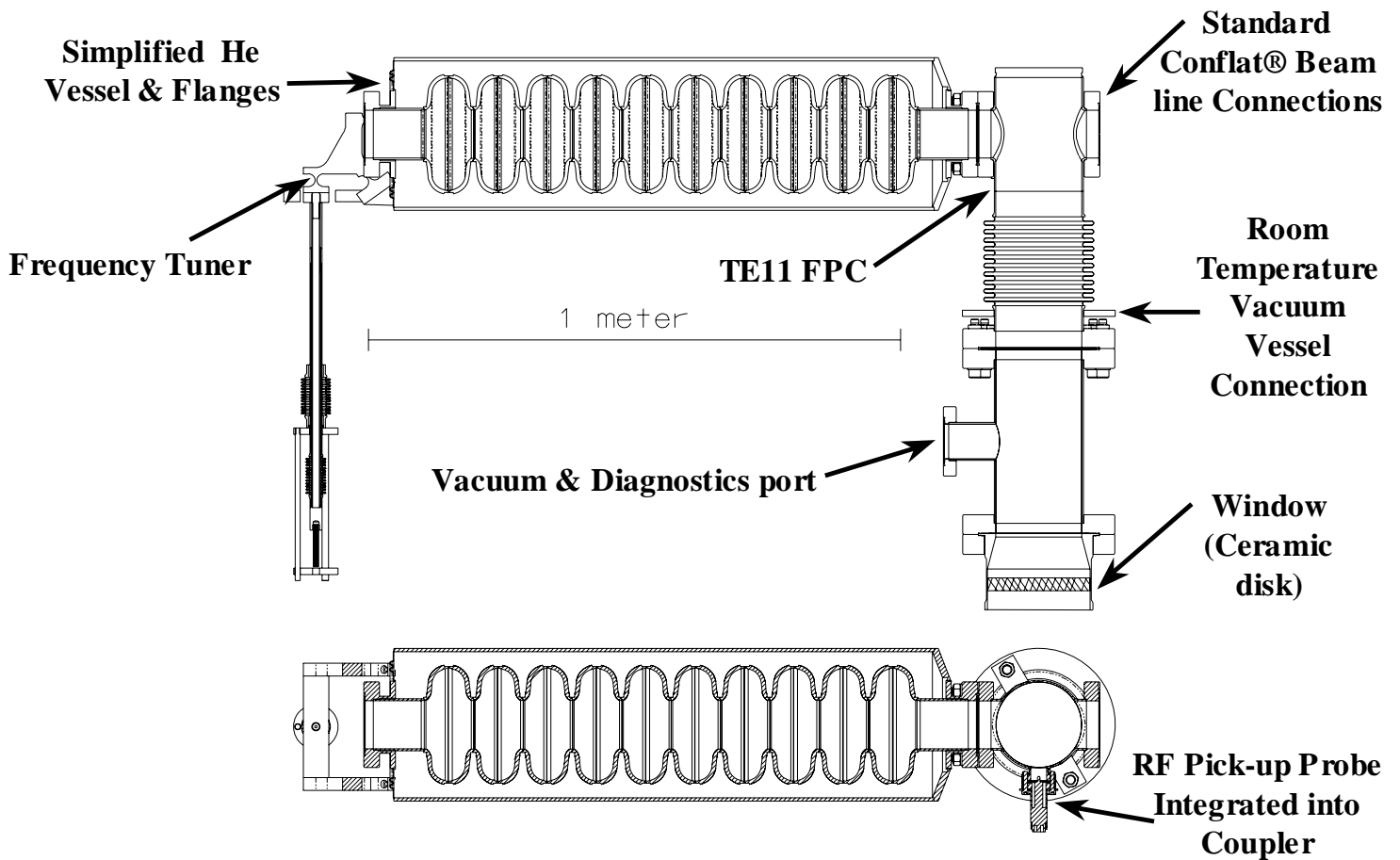


Figure 2. Circular waveguide coupler and ceramic disc window with vacuum vessel connection point. Note that the axial position of the room temperature part of the coupler is adjustable, as needed to accommodate the contraction of the cavity during cooldown.

If a secondary vacuum barrier on the coupler is desired, then a second room temperature window can be used with its own vacuum or helium pressurized volume that is monitored and interlocked. The secondary window would not require ultrahigh vacuum and therefore could be made of other materials such as plastic with O-ring seals.

DESIGN

This two year plan will design, fabricate and test a circular waveguide coupler that is used as both the input power coupler and the output HOM coupler. A low power prototype will be fabricated to confirm coupling strengths and field levels of all cavity modes. Finally, a high power prototype will be fabricated and conditioned to full power to demonstrate that the circular waveguide coupler can be used for the ILC.

The mechanical design will need to take into account many competing requirements. The coupler diameter will be based on available stainless tubing and formed bellows, and the need to be above the cutoff frequency. The location of vacuum flanges and transition from niobium to copper plated stainless steel will influence the cryogenic load. The thickness and length of the copper plated stainless steel and location of thermal intercepts will determine the static cryogenic load. The short at the cryogenic end of the circular waveguide will change the coupling strength of the fundamental mode and the other HOMs.

The location of the brazed alumina window will determine the radial extent of the coupler, and will influence the cryomodule assembly procedures. Since there will likely be a standing wave on the circular waveguide, it may be desirable to place the window at a null in the electric field to reduce dielectric heating and the risk of discharge due to field emission or multipacting associated with the window.

The HOMs will couple to different TE and TM modes of the circular waveguide and it must be confirmed that adequate coupling strength to room temperature loads is obtained. The coupling strength of the fundamental mode and the HOMs can be changed independently using the shape of the short and by using waveguides with cutoff frequencies above 1.3 GHz on the room temperature, air-side of the coupler.

Once the mechanical design exists, an electromagnetic analysis can be done to calculate the field levels and coupling strength, Q_{ext} [2]. The Q_{ext} values of the fundamental mode and many of the HOMs will be determined. The field levels on the surface of the conductors and in the ceramics can be used to calculate the cryogenic thermal load.

Thermal analysis will determine the temperature profile along the coupler as well as the static and dynamic loads. The static and dynamic loads are the power conducted to the cryogenics due to conduction from higher temperature and due to the rf heating on the surface, respectively.

The mechanical design of the coupler will be completed in the first 6 months of the two year program, except for the HOM analysis which will take an additional 3 months.

PROTOTYPE R&D

The low power prototype, which does not include a brazed ceramic window, will be fabricated and tested during the second half of year one. Also during this time the mechanical drawings and fabrication plans of the high power coupler will be finalized. The National Superconducting Cyclotron Lab at Michigan State University has a hydrogen oven for brazing alumina windows to the copper waveguide. This oven is used extensively for the 100-250 kW power couplers for the superconducting cyclotrons. A thin layer of TiN can be added to the vacuum side of the ceramic to lower the secondary electron coefficient if discharging or multipacting are problematic.

In the first half of year two the power couplers and high power conditioning system will be fabricated. High power conditioning will take place during the last 6 months of the project. Also during the last year there will be detailed HOM measurements using the actual power couplers and a copper multi-cell TESLA cavity to verify that the coupler can handle both the input power and HOM damping requirements.

REFERENCES

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- [2] T.L. Grimm, W. Hartung, F. Marti, H. Podlech, R.C. York, J. Popielarski, C. Wiess, L. Kempel, G. Ciovati and P. Kneisel, "Input Coupling and Higher-order Mode Analysis of Superconducting Axisymmetric Cavities for the Rare Isotope Accelerator", Proc. of the 8th European Accelerator Conference, Paris (2002).
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Broader Impact

In addition to advancing the ILC as explained above, the circular waveguide coupler is ideally suited to two other applications of SRF cavities:

1. cw applications such as next generation x-ray light sources
2. High current applications such as energy recovery linacs, proton drivers and pulsed spallation neutron sources.

Since the circular waveguide coupler can handle higher average power and higher current, it can be adopted by multiple projects (including the ILC). Hence the R&D can be pursued with additional resources to advance the concept and ultimately industrialize production, which is needed to reduce the ILC linac cost.

Results of Prior Research

Waveguide couplers have been used for previous applications including the 1500 MHz CEBAF multi-cell cavities and the 500 MHz Cornell single-cell cavities [1].

The principal investigator and staff at Michigan State University (MSU) developed power couplers for the Rare Isotope Accelerator (RIA). This work included HOM analysis that showed the pickup and power coupler could adequately damp the HOMs without additional HOM couplers due to the low current, cw beam [2]. The RIA couplers were fabricated by industry and processed to full power in a coupler conditioning system [3,4]. Finally, the couplers were installed in a RIA prototype cryomodule, tested and shown to exceed the design specifications [5].

The staff at MSU also designed and built the 100-250 kW power couplers for the superconducting cyclotrons. The couplers/windows are brazed in house with a hydrogen braze oven. The ceramic window is a disc of similar size to that proposed for the ILC.

Facilities, Equipment and Other Resources

This project can be completed using the existing facilities and infrastructure at the National Superconducting Cyclotron Laboratory (NSCL). The NSCL facilities include an electronics shop, fully integrated mechanical design department and machine shop, cryogenics plant (1.75 KW), computer department, welding department and fabrication and assembly group. The superconducting radio frequency group at the NSCL has additional specialized facilities to manufacture, process, and test the superconducting cavities. The infrastructure includes a class 100 and a class 10,000 clean room, ultra pure water system (>17 M Ω -cm), chemical etching facility with 500 CFM scrubber, sub atmospheric pumping system (1.5-4 K), shielded (magnetic and radiation) vertical test Dewars, and RF testing equipment. A brazing furnace is available for power coupler manufacturing, with a maximum temperature capability of 1450 °C. About 1/3 of the available power is used to reach the maximum temperature with the hydrogen gas

mixture. The temperature is controlled by a programmable ramp and soak temperature controller. A PC is used to program it for temperature vs. time, depending on the application and to monitor the progress during a run. The brazing furnace has a hot zone 9 inches in diameter by 1 foot tall.

FY2006 Project Activities and Deliverables

The FY2006 activities and deliverables are:

1. Mechanical design of coupler including cavity, cryomodule and klystron interface
2. EM analysis and Q_{ext}
3. Thermal analysis
4. HOM analysis
5. Design of brazed alumina window
6. Design of copper plated bellows
7. Design of high power conditioning system
8. Document results

FY2007 Project Activities and Deliverables

The FY2007 activities and deliverables are:

1. Fabricate low power coupler
2. Fabricate copper TESLA cavity with coupling port
3. Q_{ext} measurements
4. Fabricate high power coupler
5. Fabricate high power conditioning system
6. High power conditioning test
7. HOM measurements
8. Analyze and document results

Budget Justification

	FY06	FY07
Design		
EM analysis and Q _{ext}	0.25 FTE	
Thermal analysis	0.15 FTE	
HOM analysis	0.35 FTE	
Brazen alumina window	0.15 FTE	
Copper plated bellows	0.15 FTE	
High power conditioning system	0.25 FTE	
Prototype		
Coupler fabrication	20 k	40 k
Copper TESLA cavity with coupler	10 k	20 k
Q _{ext} measurements		0.45 FTE
High power conditioning system		50 k
High power conditioning test		0.6 FTE
HOM measurements		0.63 FTE
Analyze and document results	0.3 FTE	0.3 FTE
Materials and supplies	5 k	5 k
Travel	2 k	2 k
Subtotal manpower	1.6 FTE	1.98 FTE
Subtotal manpower	225 k	279 k
Equipment	30 k	110 k
Materials, supplies and travel	7 k	7 k
TOTAL	262 k\$	396 k\$
FY06-FY07 TOTAL = 658 k\$		

Three-year budget in then-year \$

Item	FY2006	FY2007	Total
PI/Senior Personnel	\$11,459	\$11,803	\$23,262
Other Professionals	\$67,255	\$90,836	\$158,091
Graduate Students	\$21,395	\$22,037	\$43,432
Undergrad Students	\$8,840	\$ 9,105	\$17,945
Total Salaries and Wages	\$108,949	\$133,781	\$242,730
Fringe Benefits	\$32,644	\$43,214	\$75,858
Total Salaries, Wages and Fringe Benefits	\$141,593	\$176,995	\$318,588
Equipment	\$30,000	\$110,000	\$140,000
Travel	\$2,000	\$2,000	\$4,000
Materials and Supplies	\$5,000	\$5,000	\$10,000
Other direct costs	\$7,805	\$8,429	\$16,234
Total direct costs	\$186,398	\$302,424	\$488,822
Indirect costs (1)	\$75,782	\$93,837	\$169,619
Total direct and indirect costs	\$262,180	\$396,261	\$658,441