# TEST CAVITY AND IRIS-TO-COAX TRANSITION FOR TUNING AND HIGH-POWER VERIFICATION OF SNS DTL IRIS COUPLERS *

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*Abstract*

The Spallation Neutron Source (SNS) Drift Tube Linac (DTL) employs iris couplers to efficiently deliver RF power into the accelerating structure. To support the development, tuning, and high-power conditioning of these couplers prior to installation in the actual DTLs, a dedicated test cavity and an iris-to-coaxial transition structure have been designed. This work presents the electromagnetic design, simulation, and optimization of the test setup, enabling precise characterization of the iris coupler's performance. The transition structure allows for tuning of the iris opening dimensions without requiring a waveguide taper or full-size waveguide transitions, while maintaining impedance matching between the coaxial feed and the iris geometry to minimize reflection and power loss. During low-power tests, the iris opening dimensions can be evaluated using the iris-to-coax transition attached to the test cavity. For high-power conditioning, full-size waveguides with ceramic vacuum windows are connected to the test cavity to replicate operational conditions. Key design parameters were optimized using computer-aided simulation, and sensitivity studies were conducted to assess the impact of mechanical tolerances on RF performance. The resulting test platform provides a reliable and efficient means for tuning and validating iris couplers, contributing to improved operational stability in the SNS DTL.

## INTRODUCTION

The SNS DTL comprises six normal-conducting tanks operating at 402.5 MHz, each fed by a tapered double-ridge waveguide iris coupler through a ceramic vacuum window [1]. As hardware ages and availability requirements grow, the facility must maintain spare iris couplers conditioned off-line to reduce installation risk and shorten commissioning time. This is challenging since pre-tuning and conditioning require connection to the actual DTL tanks, or identical cavities, to quantify coupling and transfer RF power through the coupler.

To address this, a single-cell test cavity and iris-to-coax transition were developed for low-power iris coupling characterization and tuning. A cold-model iris coupler was fabricated in two sections: an iris section and a waveguide taper section. The iris-to-coax transition decouples low-power bench measurements from bulky waveguide hardware by providing a traveling-wave passband near the operating frequency and high measurement fidelity to small changes in iris opening dimensions. The test cavity incorporates inductive and capacitive tuners for frequency tunability across the range of iris opening dimensions under characterization.

The same RF design concept, extended with cooling and vacuum system integration, is intended to support high-power RF conditioning without requiring full-scale DTL tanks. The regular copper iris coupler will be connected to a waveguide ceramic window and to the high-power RF system via WR2100 waveguide, providing an input match and transmitting most of the power with modest dissipation without enlarging the iris opening solely to achieve single-port match during testing. Electromagnetic design studies validated the RF design and established allowable iris geometry ranges. The resulting workflow demonstrates a path toward practical off-line pre-conditioning of SNS DTL iris couplers.

## IRIS-TO-COAX TRANSITION

The test platform enables low-power characterization and tuning of the iris using standard coaxial instrumentation through a compact transition, such that iris geometry changes are directly reflected in the measured coupling factor.

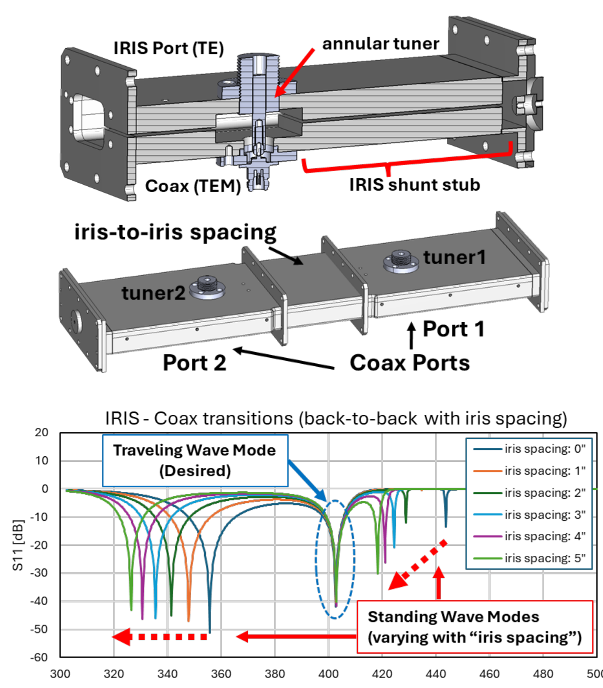


Figure 1: Iris-to-coax transition with annular tuner and iris shunt stub (top), back-to-back through fixture with varying iris-to-iris spacing (middle), and simulated S-parameter responses confirming traveling-wave operation (bottom).

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The transition converts a standard coaxial TEM port into the ridge-loaded iris TE waveguide, as shown in Fig. 1 (top). The iris section is treated as a transmission line. At the coax–iris junction, an iris shunt stub is used to provide reactive compensation that minimizes reflection and transmission loss at 402.5 MHz. An annular tuner at the junction provides fine frequency correction to accommodate fabrication tolerances and suppress parasitic resonances. Properly tuned, the transition excites the desired mode in the iris line and rejects nearby standing-wave modes, enabling stable and repeatable low-power measurements with standard coax adapters. To identify and verify traveling-wave operation, two identical transitions are connected coax-iris-coax to form a through fixture with varying iris-to-iris spacing, as shown in Fig. 1 (middle). S-parameters at the coax ports are obtained from RF simulation. If propagation in the iris section is traveling-wave, changing the spacing alters only the electrical length, so the passband center remains fixed at 402.5 MHz with transmission $S_{21}$ better than -0.1 dB. If the response is dominated by a standing-wave resonance, the resonance frequency shifts with iris spacing. As shown in Fig. 1 (bottom), the passband at 402.5 MHz remains fixed across all iris spacings while the standing-wave resonances shift with spacing, confirming traveling-wave operation of the transition and the iris section.

## IRIS TEST CAVITY DESIGN

Two single-cell cavity topologies were numerically evaluated for efficient coupler testing and tuning, as shown in Fig. 2. A pillbox cavity produces a uniform azimuthal magnetic field along the cavity length and a lower peak electric field for a given transmitted power but may require larger iris openings to achieve the desired coupling factor.

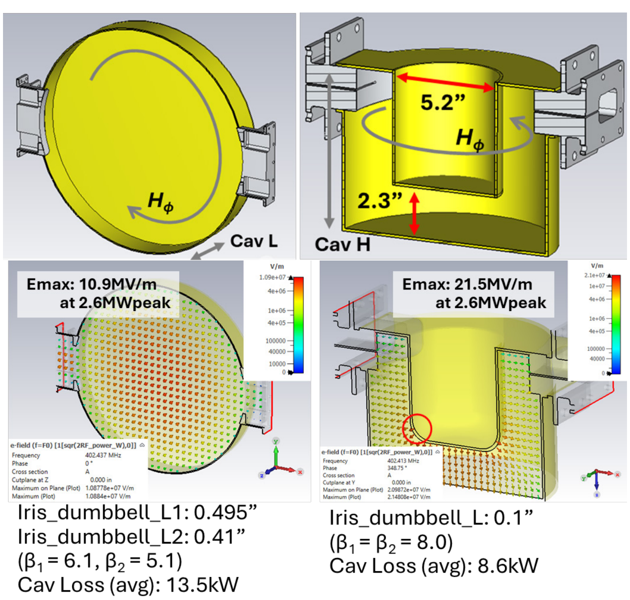



Figure 2: Two single-cell cavities with two iris ports used as two-port bridges: pillbox (more uniform fields, lower peak electric field) and re-entrant (fields concentrated near the irises, strong coupling with smaller openings)

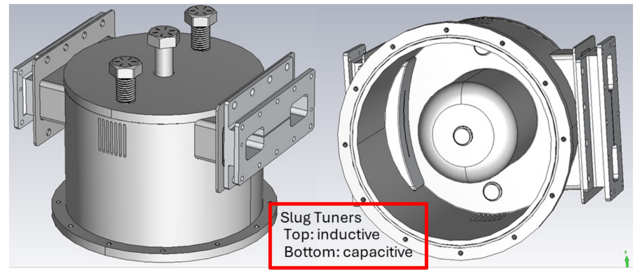



Figure 3: Low-power iris test cavity with slug tuners: two inductive near the iris and one capacitive near the re-entrant gap. A blank shorting plate enables 1-port operation; irises on both ports enable 2-port operation.

A re-entrant quarter-wave cavity concentrates magnetic field near the iris, achieving strong coupling at smaller iris opening dimensions - advantageous for RF pre-conditioning without enlarging the iris - and was therefore selected for this application. The re-entrant quarter-wave iris test cavity was designed for low-power measurements, coupling studies, and iris coupling characterization. The cavity can be configured as a one-port setup by installing an iris on one side and shorting the opposite port with a blank plate, providing a repeatable terminated condition for low-power iris tuning. It can also be configured as a two-port setup with irises on both ends to enable full S-parameter characterization and verify coupling factor calculations. Three slug tuners - two inductive near the iris and one capacitive near the re-entrant gap - compensate for frequency shifts due to fabrication tolerances, assembly, and iris adjustments, as shown in Fig. 3. Simulations confirm the tuners provide sufficient frequency tunability to maintain resonance at 402.5 MHz across the full range of iris opening dimensions under characterization.

The production iris coupler is machined as a single piece from GlidCop® material or copper [1] and includes the iris and ridged waveguide taper transition. For low-power bench tuning practice, a two-section aluminium cold model was fabricated - an iris section and a waveguide taper section - allowing the iris to be swapped independently for different opening dimensions. The production geometry is preserved in the cold model to ensure bench measurements reflect the actual coupler dimensions.

The iris dumbbell geometry is characterized by a fixed radius of 0.05 in. and a variable dumbbell length that controls the coupling strength. Two-port RF simulations were performed with the dumbbell length varied from 0.01 to 0.20 in. For a cavity with two symmetric couplers $\beta_1 = \beta_2$, the input coupling factor at one port with the other coupler connected is $\beta_{in} = \beta_1/(\beta_1+1) < 1$. Since $\beta_{in} < 1$, $\beta_{in} = 1/SWR_{in}$, from which the individual coupler coupling factor is derived as $\beta_1 = 1/(SWR_{in}-1)$. The resulting $SWR_{in}$ at 402.5 MHz from simulation was used to calculate $\beta_1$ for each iris opening. As shown in Fig. 4, $\beta_1$ increases monotonically from 2.09 to 5.18 over this range, confirming effective coupling control through iris geometry adjustment. Simulations were performed to estimate RF power dissipation in the re-entrant and pillbox test cavities at the SNS DTL PPU RF power level (2.6 MW peak, 6% duty cycle) [2]. The re-entrant cavity shows a peak electric field of 21.5 MV/m and average wall losses of 8.6 kW, compared with 10.9 MV/m and 13.5 kW for the pillbox cavity. This confirms the re-entrant design offers lower cavity dissipation with higher coupling efficiency.

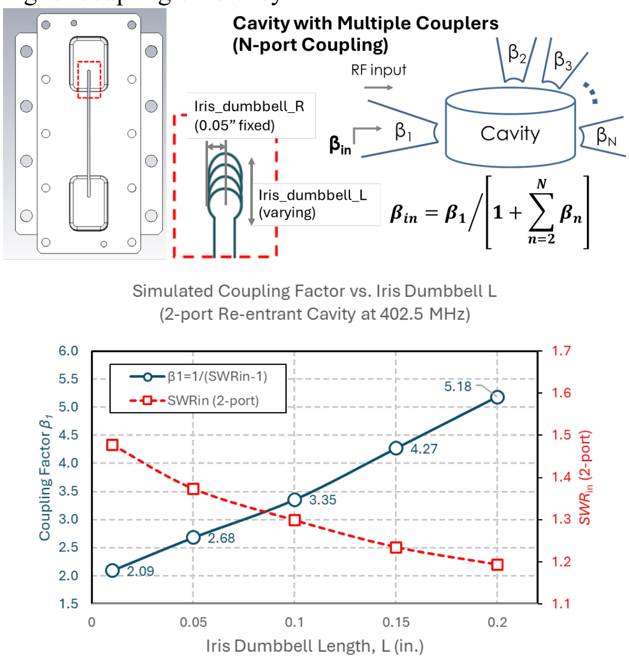



Figure 4: N-port coupling factor formulation for a cavity with multiple couplers (top), and simulated SWRin with calculated coupling factor $\beta_1$ = 1/( SWRin -1) vs. iris dumbbell length for a symmetric two-port re-entrant cavity at 402.5 MHz (bottom).

The complete two-port iris test setup with coax-iris transitions is shown in Fig. 5, along with the simulated $S_{11}$ response at one iris port with the other iris port connected. The Smith chart confirms the impedance trajectory passes through the matched condition at resonance, with $S_{11}$ of -24.3 dB at 402.5 MHz, validating the two-port cavity design for iris coupling characterization.

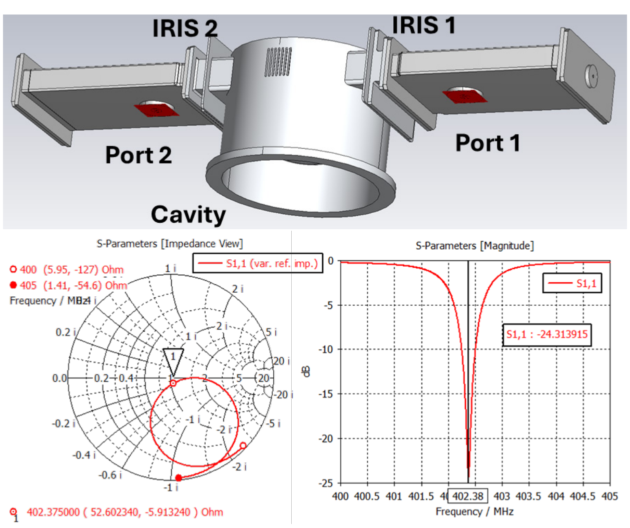
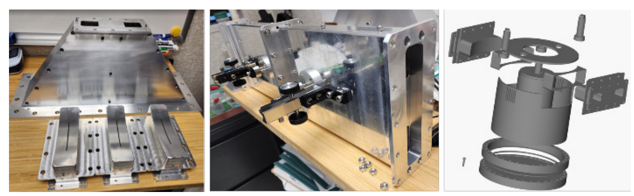



Figure 5: Two-port iris test setup with coax-iris transitions and simulated S11 response at 402.5 MHz.

## FABRICATION STATUS

Fabrication and mechanical design are progressing across all major components of the low-power test apparatus, as shown in Fig. 6. Aluminium cold models of the iris and waveguide taper sections have been completed, with four iris sections and two waveguide taper sections fabricated, as shown in Fig. 6 (a). Initial prototype bench testing of the iris cold model assembly with the iris-to-coax transition has been performed, as shown in Fig. 6 (b). The iris-to-coax transition RF design is complete; following initial prototype bench tests, modifications to the coaxial junction and annular tuner are currently in progress. The mechanical design of the re-entrant iris test cavity is complete, as shown in the exploded view in Fig. 6 (c), and the cavity is currently under fabrication. Upon completion, the full low-power test apparatus will be assembled for bench measurements to validate the iris coupling characterization workflow.



(a) (b) (c)

Figure 6: Fabrication status: aluminium cold model iris and waveguide taper sections (a), prototype bench test of iris cold model assembly with iris-to-coax transition (b), and exploded view of iris test cavity mechanical design (c).

## CONCLUSIONS AND FUTURE WORK

A low-power iris test platform has been developed to support off-line pre-conditioning and coupling characterization of SNS DTL iris couplers without requiring full-scale DTL tanks. The platform comprises a re-entrant quarter-wave test cavity and an iris-to-coax transition that decouples bench measurements from bulky waveguide hardware. Simulations confirm traveling-wave operation of the transition, effective coupling control over the full iris opening range, and sufficient frequency tunability to maintain resonance at 402.5 MHz. Fabrication of the test apparatus is underway, with bench measurements and full workflow validation planned as the next step. Upon successful low-power validation, the same RF design will be extended with water cooling and vacuum pump port integration, connected to the copper iris couplers at its ports, high-power RF windows, and the RF Test Facility (RFTF) at SNS for high-power off-line conditioning of spare iris couplers.

## REFERENCES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