# INDUCTIVELY COUPLED, COMPACT HOM DAMPER FOR THE ADVANCED PHOTON SOURCE*

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*Abstract*

The Advanced Photon Source (APS) requires damping of higher-order modes in the storage ring rf cavities in order to prevent beam instability at beam currents up to 200 mA. Due to constraints imposed by available space in the APS and by existing 35-mm pick-up ports on the 352-MHz cavities, a compact design has been analyzed with a quarter-wave rejection filter. Separate low-frequency and high-frequency broadband dampers are utilized to span the frequency range from 500 MHz to 1500 MHz. The low-frequency dampers discussed in this paper have been designed to reject the fundamental cavity mode, couple strongly to HOMs, utilize an external rf load, minimize the overall size, and incorporate rf diagnostics. In addition, the mechanical design has been optimized to simplify construction, improve mechanical stability, and reduce thermally induced stresses.

## INTRODUCTION

Capacitively coupled probe dampers with lossy ceramic loads are currently installed in the APS storage ring. They have successfully increased the beam current stability threshold by approximately 50% by reducing instabilities caused by the $TM_{011}$ monopole mode at 535 MHz [1]. However, their functionality has been limited due to the absence of a fundamental mode filter and lack of diagnostic capability.

Broadband dampers will be required in order to produce stable operation for up to 200-mA beam current. In addition, the dampers are restricted to 35-mm-diameter access ports on the storage ring cavities. As a result, a compact design has been investigated based on [2] that incorporates a reduced-length, quarter-wave fundamental mode filter, an external load, and rf diagnostics.

## DAMPER OVERVIEW

The damper geometry consists of two concentric coaxial transmission lines as shown in Fig. 1. The outer coaxial line functions as the fundamental mode rejection filter. A stepped-impedance design was incorporated into the filter to reduce its overall length by 35% and to reduce the rf-induced power density at the shorting plane to alleviate stresses.

The inner coaxial line functions as a transmission line leading to an rf load and diagnostics. The first ceramic window serves as a vacuum barrier, while each of them function as a thermal sink for the mid conductor. The mid conductor is thermally isolated from the damper copper body except at the filter shorting plane, so it is dependent upon the thermal properties of the ceramic material to dissipate the rf thermal loading into the water-cooled inner conductor. As a result, a high thermally conductive ceramic, either enhanced AlN or BeO has been pursued as opposed to standard $Al_2O_3$ ceramics.

The practical magnitude of the HOM damping depends upon the efficiency of the cooling scheme to reduce peak thermal stresses in the inner conductor coupling loop, the mid conductor, and the rf windows. Since a tube insert in the inner conductor was deemed too insubstantial due to the heat loads, the inner conductor has been designed with a water tee as shown in Fig. 1. The introduction of the water tee modifies the impedance of the transmission line and, as a result, is a factor in the frequency response of the damper.

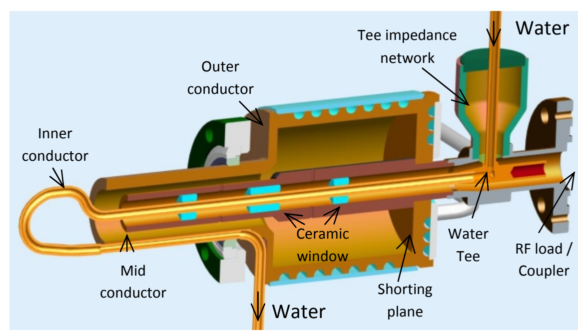


Figure 1: Cross section of damper geometry with capacitive ceramic elements.

## DAMPER RF DESIGN

The current damper installed at the APS utilizes a vacuum-compatible damper material that offers greater rf bandwidth, improved surface area for thermal mitigation, straight forward cooling, and no need for a vacuum barrier. However, it does not include a fundamental-mode rejection filter, eliminates the possibility of rf diagnostics for current and experimental bunch patterns, and is susceptible to the possibility of multipacting.

Various damper designs were evaluated to replace the existing design while optimizing their available bandwidth since the utilization of a vacuum window necessarily reduces the bandwidth of the device. This is especially true since the thickness of the window is maximized in order to serve the dual function as a thermal sink for the mid conductor. As a result, the transmission line leading to the rf load is designed as a low-pass filter matching network that incorporates the rf windows as elements of the filter.

Additionally, the water tee, which is represented as a shorted quarter-wave stub, is a narrowband circuit that

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restricts the usable frequency range of a given damper design. However, the stepped-impedance water tee shown in Fig. 1, has been shown to double the 10-dB bandwidth. The water tee was additionally optimized to incorporate a notch at 1.2 GHz in the frequency response of the low-frequency damper at the location of a high-impedance HOM that is suspected of creating instabilities at higher beam currents at the APS.

A dielectric-loaded low-frequency damper design with water tee is shown in Fig. 2. The design uses block ceramics that serve as a thermal sink where the first ceramic also serves as a vacuum barrier. The dielectric-loaded damper transmission line is designed as a low-pass filter with parameter values determined from [3] for a 5-element Tchebychev filter with 0.2-dB ripple consisting of shunt-capacitive and series-inductive elements. The chosen parameter values offer a compromise between a flat broadband frequency response and maximal length of the ceramic elements to assist as a thermal sink for the mid conductor. Distributed transmission line elements, including the capacitive ceramic and inductive coaxial length, were used to approximate the lumped-element values using Richard's transformation techniques [4].

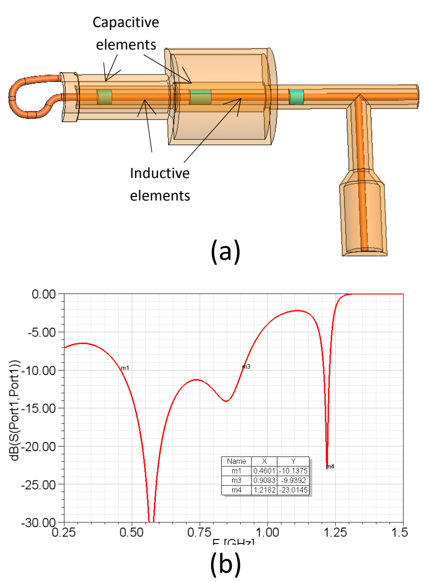



Figure 2: Low-frequency damper with a 5-element, capacitively loaded Tchebychev filter: (a) low-frequency damper with capacitive ceramic elements, and (b) broadband frequency response.

Figure 2(b) shows the broadband response of the 5-element low-pass filtering with the water tee. The effective 10-dB bandwidth of the damping transmission line is from 460 – 910 MHz. It is important to note that the frequency response in Fig. 2(b) does not incorporate effects due to coupling of the damper to the cavity, which depend upon the orientation and insertion depth of the coupling loop. HOMs with less than a 10-dB return loss, as shown in Fig. 2(b), couple less strongly to the damper and are considered outside of the damper bandwidth. As a result, to ensure strong deQing of modes suspected of being the most dangerous to beam stability, a return loss of 20 dB is preferred.

The dielectric-loaded damper design provides good rf performance. However, it presents difficulties in brazing of the assembly and maintaining the integrity of the ceramic braze due to multiple furnace runs. An alternate design with simplified assembly requirements is shown in Fig. 3(a). The design consists of a 3-element Tchebychev filter with 0.5-dB ripple and impedance steps in the diameter of the inner conductor to create the filter element values. The performance of the low-pass filtering with the addition of the water tee is shown in Fig. 3(b) which exhibits a reduced bandwidth compared with Fig. 2(b). The total length of the Tchebychev filter was restricted to not exceed the length of the fundamental mode filter in order to maintain a compact overall damper length. As a result, only a third-order Tchebychev filter was possible. However, the filter design and construction is simplified with the inner conductor producing the elemental values and only a single ceramic required.

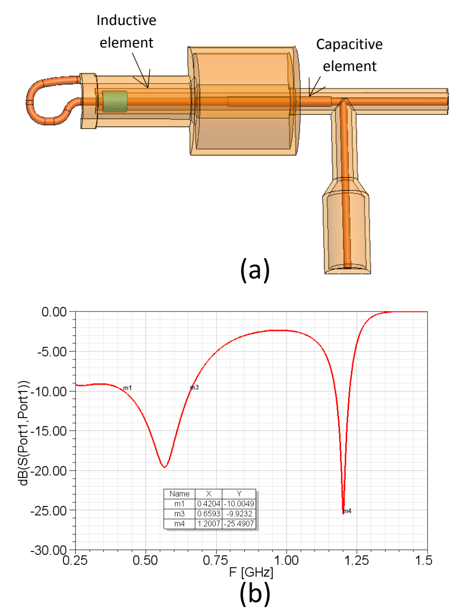


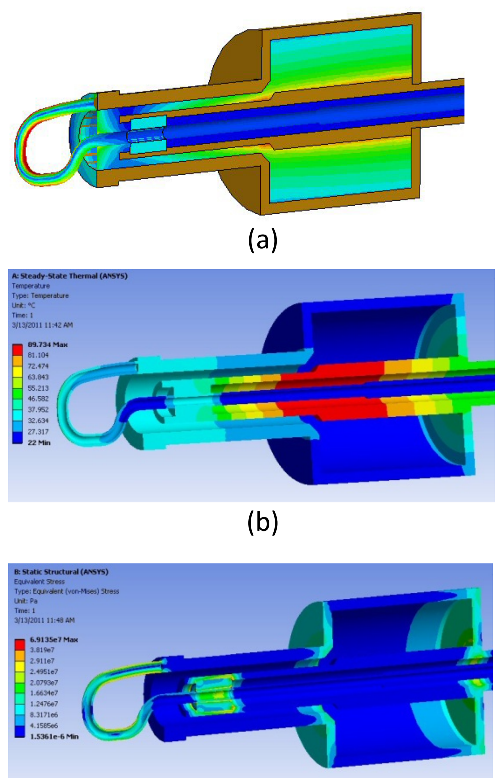

Figure 3: Low-frequency damper with a 3-element, stepped-impedance Tchebychev filter: (a) low-frequency damper with water tee, and (b) broadband frequency response.

## PERFORMANCE

The HOM damping performance for modes that are most responsible for creating longitudinal beam instabilities at higher beam currents is shown in Table 1. The fundamental-mode filter is expected to produce up to 50-dB rejection. The rf loading due to fields at 352 MHz and the resultant mechanical simulation results for the stepped impedance damper design are shown in Fig. 4. For a 1-MV accelerating voltage, the power deposition in the coupling loop, mid conductor, and outer conductor are 160 W, 200 W, and 145 W, respectively. The thermal profile is shown in Fig. 4(b). The circumference of the outer conductor near the shorting plane is cooled, in addition to the inner conducto,r which is internally cooled with turbulent flow producing a film coefficient of 2W/cm$^2$/$^o$C. The peak temperature gradient is in the mid conductor, as expected, due to its isolation from a thermal sink. The equivalent Von Mises stress is shown in Fig. 4(c) where the peak stress is 70 MPa in the ceramic where it interfaces with the mid conductor.

Table 1: Damping levels for modes producing longitudinal beam instabilities in the APS cavities.

| | 533 MHz (k) | 921 MHz (k) | 1200 MHz (k) |
|---|---|---|---|
| $Q_u$ | 43 | 110 | 105 |
| $Q_{ext}$ (3-element) | 9.4 | 160 | 9.3 |
| $Q_{ext}$ (5-element) | 9.2 | 20 | 8.3 |



(a) (b) (c)

Figure 4: Rf and mechanical simulation results for the low-frequency stepped-impedance damper: (a) magnetic field magnitude, (b) thermal distribution, and (c) Von Mises stress.

## PROTOTYPE

A prototype is currently being constructed of the dielectric loaded damper using Glidcop AL-15 for the inner, mid, and outer conductors. Glipcop was chosen in order to increase the structural strength of the damper, especially in the 4.8-mm-diameter coupling loop and high-stress areas in the mid conductor. Testing has been concluded to demonstrate that the Glidcop coupling loop can be machined, formed, and brazed into the outer conductor, see Fig. 5.

Manufacturing will include multiple braze cycles using 35/65 gold/copper and 50/50 gold/copper braze alloys. During prototyping, several test brazes will be run to determine the process and feasibility of brazing the ceramics to Glidcop, pass these joints through multiple braze cycles, and maintain hermetic and water-tight joints. Methodologies for constructing the stepped-impedance damper design are also being pursued as an alternate possibility.

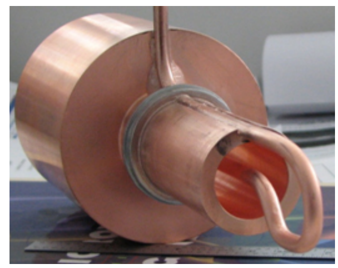


Figure 5: Prototype damper coupling loop and outer conductor after Glidcop brazing.

## CONCLUSION

An inductively coupled HOM damper has been presented in order to produce stable operation for up to 200-mA beam current in the APS storage ring. The damper incorporates a fundamental-mode rejection filter, external rf load, and rf diagnostic capabilities.

Low-frequency damper designs have been discussed that address rf and mechanical concerns due to external rf loads and diagnostics, space limitations, and thermal loading. Designs were based on a 5-element dielectric-loaded Tchebychev low-pass filter and a 3-element stepped-impedance filter. The performance of each of the filters was optimized at HOM frequencies of 535 MHz and also at 1.2 GHz by creating a notch filter using the water tee shorting stub.

## REFERENCES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