Design and Optimization of a Multilayer Axial Resonator for Ar^+ Detection in the Delhi Penning Trap (DPT)

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Synopsis Resonators are widely used for the non-destructive detection of trapped ions in Penning traps through resonant image-current detection. The performance of such resonators depends strongly on their inductance, parasitic capacitance, and self-resonance frequency, which are influenced by the winding geometry and number of winding layers. This work investigates the design and characterization of multilayer helical resonators, with emphasis on understanding the dependence of these parameters on the number of winding layers.A theoretical model was validated against experimental measurements and used to optimize the resonator design.

Non-destructive detection of trapped ions using resonant image-current detection is an important technique for characterizing the ions in Penning traps. In this work, an axial resonator has been designed for the detection of Ar^+ ions in the Delhi Penning Trap (DPT). For the trap parameters $B_0 = 1.0$ T, $C_2 = 0.62$, and $d = 3.67$ mm, an operating trap voltage of approximately 17.8 V corresponds to an axial frequency of about 223 kHz for Ar^+ ions [1].

Initially a multilayer helical resonator was fabricated and characterized using frequency-response measurements with different external capacitances. The measured inductance was 27.3 mH, close to the calculated value, whereas the measured self-capacitance was 57.3 pF, which was higher than the initial estimate of 25 pF. This resulted in a measured self-resonance frequency of approximately 128 kHz.

To understand the observed discrepancy, a separate multilayer test resonator was fabricated and characterized for different numbers of winding layers. The measured inductance, parasitic capacitance, and self-resonance frequency were compared with theoretical models for multilayer windings [2]. The hexagonal-winding model showed good agreement with the experimental results, with average deviations of approximately 7% in inductance, 8% in capacitance, and 3% in resonance frequency. The validated model was subsequently applied to redesign the axial resonator.

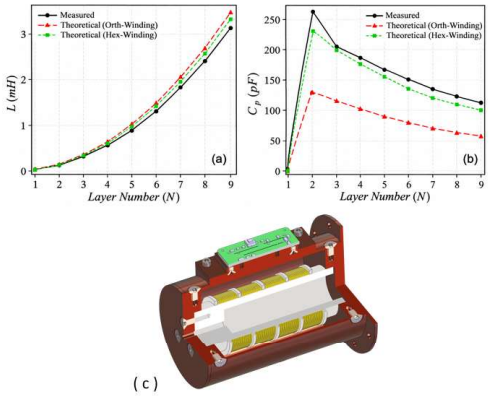

Figure 1. Comparison of theoretical and experimental (a) self-inductance and (b) parasitic capacitance as a function of winding layers, and (c) SolidWorks model of the resonator assembly.

Hence a three-layer resonator was designed with a calculated self-inductance of approximately 2.95 mH and self-capacitance of 116.95 pF, the predicted resonance frequency is approximately 218 kHz, close to the required 223 kHz axial frequency of Ar^+ ions.

References

[1] Kumar S *et al.* 2025 *J. Instrum.* **20** C05016
[2] Wan L *et al.* 2023 *IEEE Access* **11** 134460–134472

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