Quantum computing with X- junction for 2D navigation of trapped ion qubits

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Synopsis At JGU Mainz, we are advancing scalable trapped-ion quantum computing by engineering precise ion transport across a segmented X-junction trap fabricated via Selective Laser Etching, using optimized voltage waveforms that minimize motional excitation during shuttling. The contribution covers the experimental setup, ground-state cooling, and junction-crossing benchmarks, demonstrating progress toward a scalable 2D architecture.

Trapped-ion quantum processors are currently transitioning from proof-of-concept laboratory experiments to robust, scalable, and user-ready devices. A critical requirement for large-scale computation, particularly within a Quantum Charge-Coupled Device (QCCD) architecture, is the ability to dynamically shuttle ions through multi-zone, micro-structured trap arrays. Leveraging advanced trapped ion control electronics, our team at Johannes Gutenberg University Mainz (JGU) is refining the reliable transport of ion crystals across complex trap junctions.

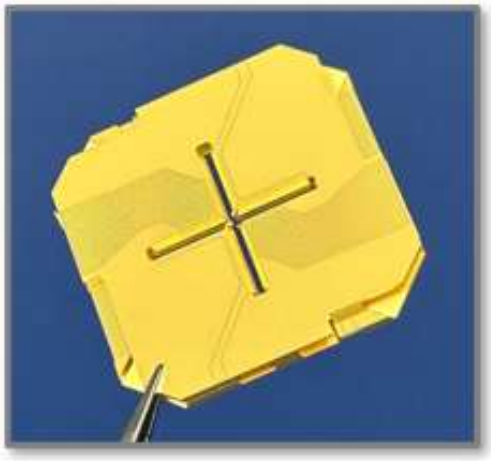

Figure 1. X-Junction ion trap with mutually perpendicular linear trapping segments. DC and RF tracks are also visible.

We utilize a segmented X-trap which is fabricated in our own clean room via Selective Laser Etching (SLE). Fully sculptured trap geometry has been meticulously engineered and scaled down to optimize radiofrequency (RF) requirements, mitigate anomalous heating, and minimize stray capacitance. The design features a central X-junction equipped with a split bridge to facilitate highly controlled transport. The voltage protocols driving this transport are generated using a recently developed numerical toolchain tailored for fast, low-excitation ion shuttling in segmented trap [1]. Based on a precise electrostatic model of our trap electrode geometry, this framework combines an electrostatic field solver with efficient unconstrained optimization and dynamical simulations of ion motion. It computes time-dependent voltage waveforms that realize prescribed transport trajectories across the junction while strictly adhering to real-world experimental constraints.

Here, I describe the experimental setup in detail. Moreover, I sketch the sequence comprising initial ground-state preparation via sideband cooling, followed by the transport of an ion crystal across the X-junction to benchmark the performance of both the SLE trap and the computed waveforms. Important characterizations include the measurement of the motional excitation per round trip. The X-trap will eventually serve to distribute qubit entanglement in a scalable 2D quantum computing architecture.

References

[1] A. Conta, S. Bogino, F. Köhncke, F. Schmidt-Kaler, and U. G. Poschinger, "Toolchain for shuttling trapped-ion qubits in segmented traps," *AVS Quantum Science*, vol. 8, no. 2, 2026.

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