Dual-rail encoding with phononic network in trapped ion system

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(Dated: October 14, 2024)

We propose a dual-rail encoding scheme within a trapped-ion system's phononic network. For this scheme, we exhibit single and two-qubit gates on dual-rail qubits using the interaction between internal qubits and vibrational modes. This interaction provides beamsplitter between two modes and the nonlinearity, which is crucial for two-qubit operation. We utilize this nonlinearity to construct a total phonon number parity-dependent gate that allows the implementation of two-qubit gates between dual-rail qubits. By leveraging the all-to-all connectivity of the trapped-ion system, we extend this scheme to a hybrid quantum computing scheme that integrates internal and dual-rail qubits, forming a complete connectivity. Also, we propose an n-Toffoli gate implementation method in this hybrid quantum computation scheme using the vibrational modes. Although this requires ancillary vibrational modes, this reduces the number of operations to implement the n-Toffoli gate.

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