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Streamlining and Automating the Design of Superconducting Transmon Qubits

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Introduction

With the rapid progress in quantum computing, quantum optimisation algorithms have been gaining traction in simulation of atoms and molecules to explore their energy landscapes. Unarguably, quantum hardware forms the bedrock for experimental realisations on the quantum computer. Therefore, this study explored two open-source novel frameworks – Qiskit Metal and CircuitQ – for design and analysis with the aim of simulating dihydrogen on the superconducting quantum computer.

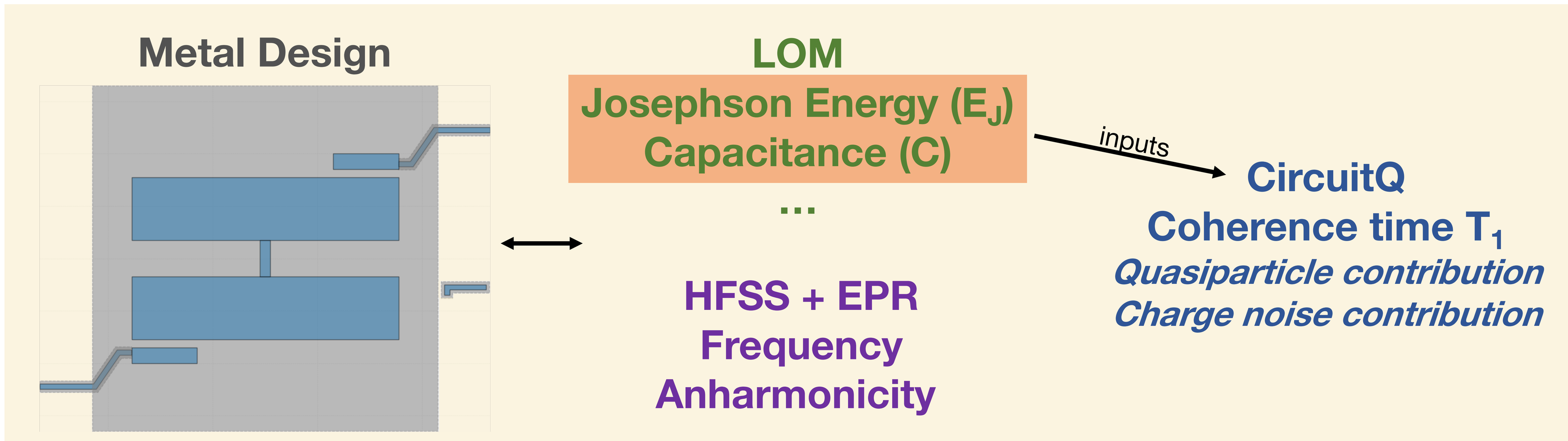


Fig. 4. Interconnection between design in Metal, analysis in Ansys and CircuitQ

Methodology

Qiskit Metal allows for flexible design of qubits from pre-existing components. Subsequently, analysis via the external renderer Ansys is done using the lumped-oscillator model (LOM) and HFSS-energy-participation-ratio models.

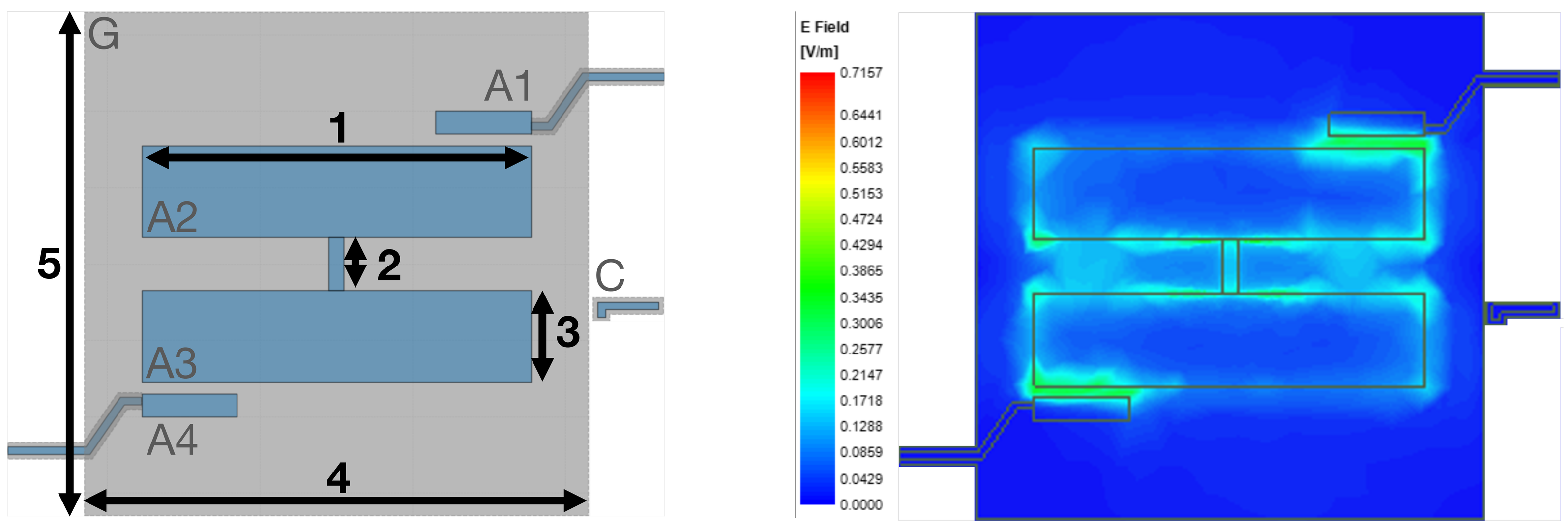


Fig. 1. (left) A generic transmon layout in Metal with important transmon properties for adjustment: **1** *pad width*, **2** *pad gap*, **3** *pad height*, **4** *pocket width*, **5** *pocket height*, Josephson junction between the 2 large pads has an inductance (L_J) . **(right)** E-field plot of the qubit from HFSS microwave simulations in its first mode.

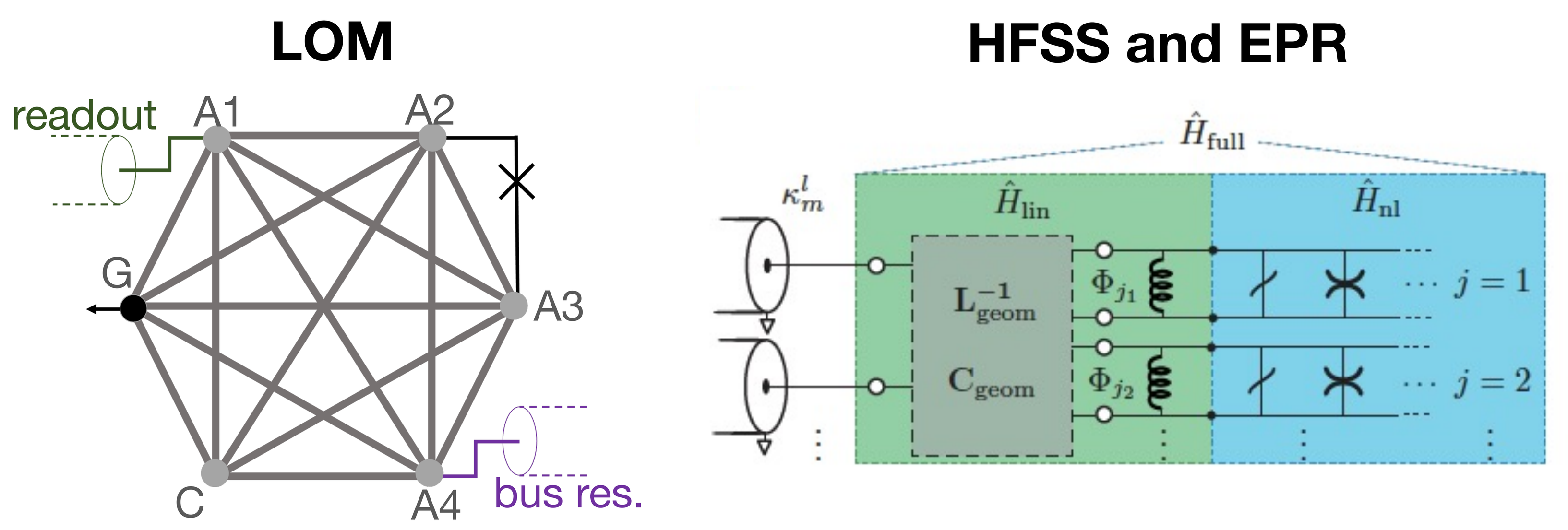


Fig. 2. (left) LOM Network of sub-systems: **A1** *readout pad*, **A2** *top pad*, **A3** *bottom pad*, **A4** *bus resonator pad*, **C** *charge line*, **G** *ground plane*. LOM examines the capacitive coupling of different subsystems of the qubit. **(right)** EPR diagram of the circuit considering purely dissipative, linear or non-linear elements. EPR with HFSS eigenmode simulation determines how much energy is stored in a mode of the qubit. Quantities such as qubit frequency and anharmonicity are analysis outputs.

CircuitQ analyses the resulting symbolic Hamiltonian from a generic circuit input using a nodes-based approach. It takes in the Josephson energy E_J and capacitance C from Qiskit Metal analysis and then outputs the transmon coherence time, T_1, also known as the longitudinal relaxation time.

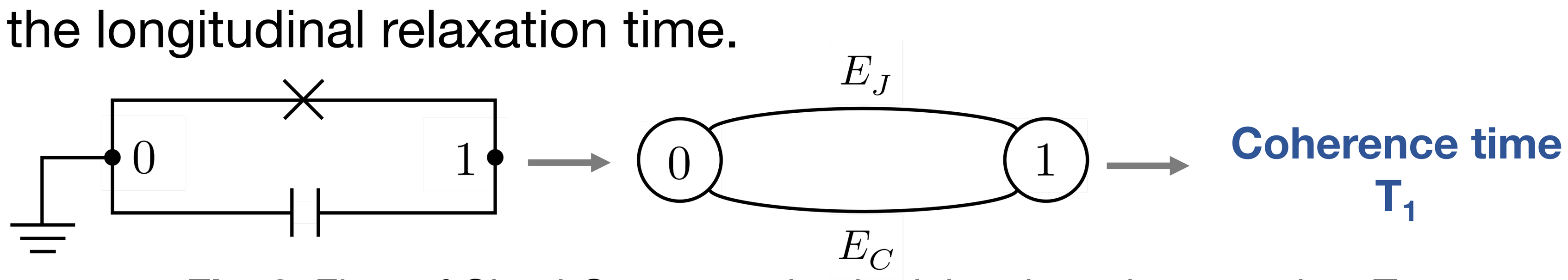


Fig. 3. Flow of CircuitQ program in obtaining the coherence time T_1.

Results

Based on the ideal qubit frequency range of 5-7 GHz and anharmonicity being larger than 200 MHz, the parameters of the qubits are tuned.

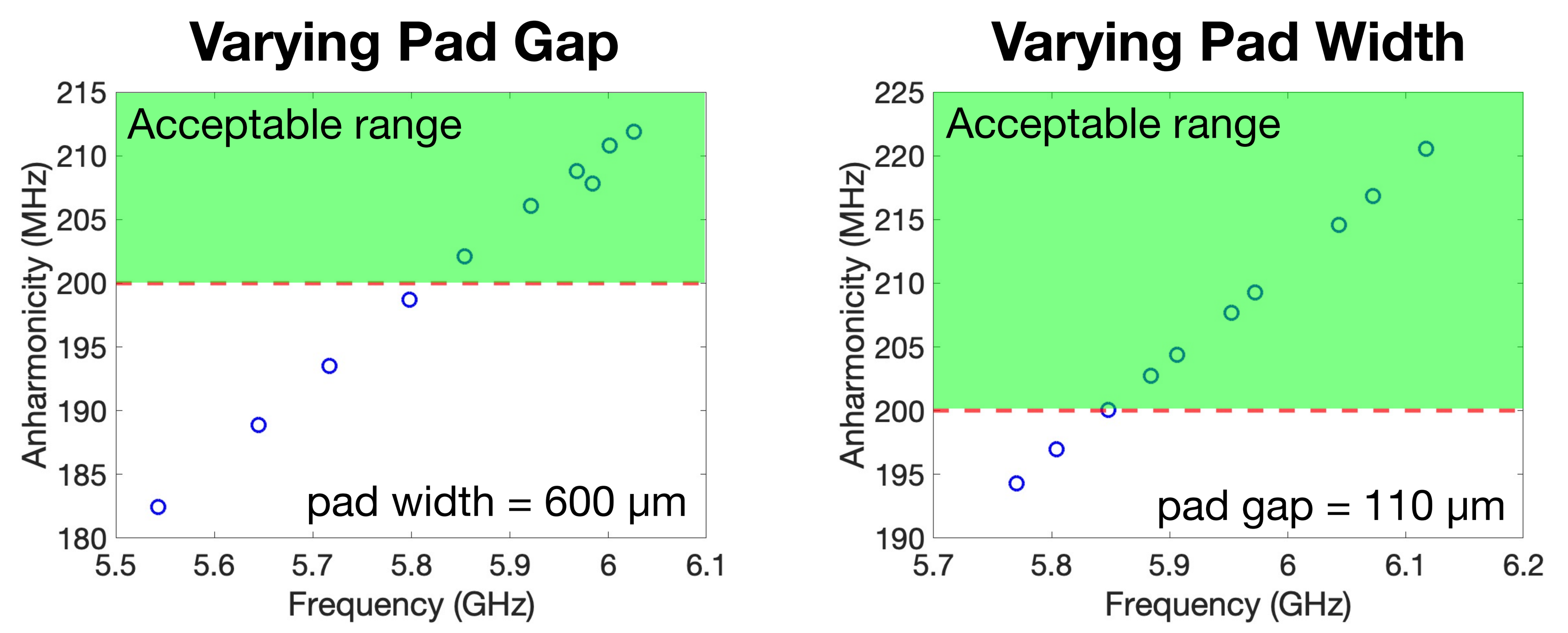
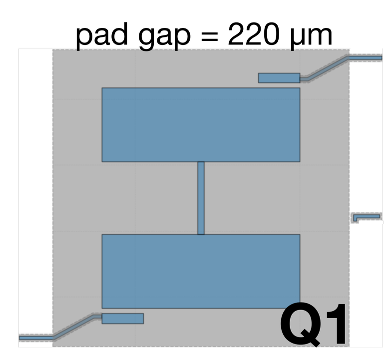


Fig. 5. Plot of qubit frequency against anharmonicity from HFSS and EPR with **(left)** varying pad gap **(right)** varying pad width. Other dimensions kept the same: pad height (225 μm), pocket width and height (900 μm) and junction inductance L_J (7 nH).



Parameters
Pad width = 600 μm
Pad height = 225 μm
Pocket width= 900 μm
Pocket height= 900 μm
Junction inductance L_J=7 nH

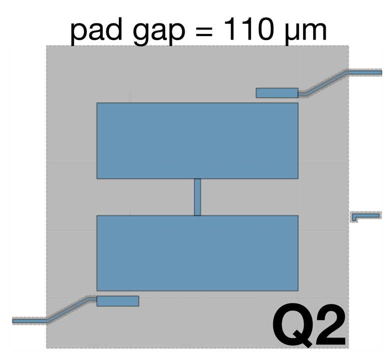


Fig. 6. (left) A schematic of qubit 1 and **(right)** qubit 2. **(center)** Common parameters.

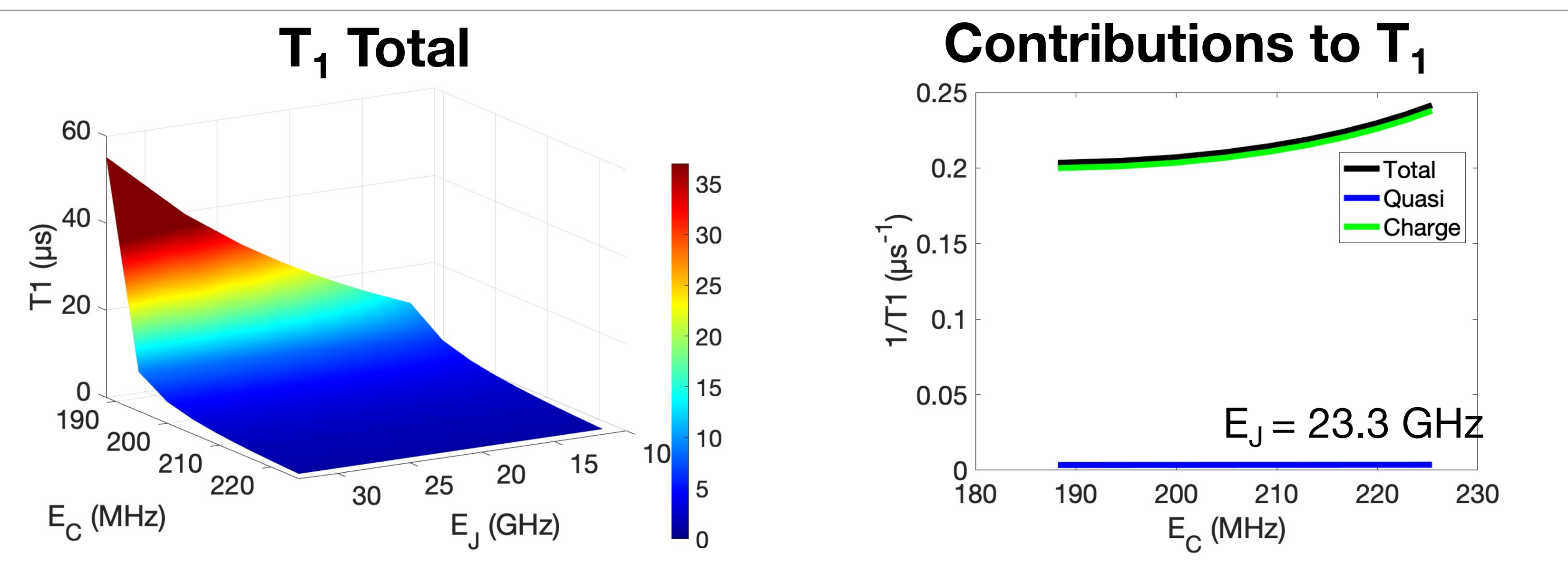


Fig. 7. (left) Contour plot of T_1 time for the qubit against E_J and E_C. **(right)** Plot of T_1 contributions from quasiparticles and charge noise against E_C.

Conclusion

Using Qiskit Metal and CircuitQ, a two-transmon chip has been designed. Future work includes fabrication and characterisation of the chip for implementation of the VQE algorithm in finding the ground state energy of dihydrogen on the superconducting quantum computer.