30 December 2024 ·
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Peer Review

Review of: "A Review of Design Concerns in Superconducting Quantum Circuits"

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This review provides a thorough discussion on the process of designing superconducting circuits. I am especially impressed with the discussion on the use of electromagnetic simulations and methodologies to extract quantum circuit parameters from finite-element modeling (FEM) tools. They focus on tools like ANSYS, COMSOL, and methodologies like EPR. However, there are areas where additional clarification and contextualization could enhance the manuscript. Below are specific suggestions for improvement:

1. Grid Refinement in FEM Tools:

The manuscript discusses the role of mesh refinement in FEM simulations, contrasting the requirements in COMSOL and ANSYS. It would be beneficial to clarify that ANSYS's automatic adaptive meshing not only simplifies user interaction but can also dynamically refine regions with high field gradients during iterations. While manually defining an initial mesh can enhance simulation speed in some cases, ANSYS's auto-meshing capability is often more efficient for general applications. Including a brief comparison table highlighting differences between COMSOL and ANSYS in mesh generation and refinement could help readers better appreciate the trade-offs between these tools.

2. Electromagnetic Simulation Tools:

While ANSYS HFSS/Q3D and COMSOL Multiphysics are well-covered, the manuscript could mention additional FEM tools such as Sonnet, which performs well in mutual inductance, coupling, and cavity Q-factor simulations. Including specific scenarios or examples where Sonnet outperforms HFSS or COMSOL would strengthen this review.

3. EPR, BBQ, LOM Methodologies:

The discussion of EPR, BBQ, and LOM methods is good, but additional technical details on the implementation of EPR could be provided. For instance:

 doi.org/10.32388/E2WA6D

Highlight that EPR can extract critical quantum circuit parameters such as Kerr matrix components. The diagonal elements correspond to the anharmonicity of individual modes (e.g., transmon systems), while off-diagonal elements represent cross-Kerr couplings, such as dispersive coupling (\chi) or ZZ coupling.

Clarify the role of quantum crosstalk analysis during the design stage and how EPR, BBQ, and LOM can help compute the crosstalk.

Additionally, introducing the IEPR (Inductive-Energy Participation Ratio, PRApplied 21(3),03427,2024) methodology as an alternative multi-body Hamiltonian approach would broaden the scope. Including references and a brief summary of IEPR's unique applications could complement the current discussion.

4. Superconducting Qubit Design:

The manuscript rightly notes that varying energy ratios leads to different qubit types. However, it is worth emphasizing that superconducting circuits' topology and node structure provide additional avenues for discovering novel qubit types. For example:

Highlight the enumeration of unique circuit topologies based on the number of nodes, as shown in recent works (PRX Quantum, 2(3):030101, arXiv:2410.18497). Discuss specific examples like the 0-π qubit and Difluxmon qubit, which emerge from fully connected four-node topologies. Figures illustrating these qubits could make this discussion more accessible.

Including references to tools like scqubits, SQCircuit, and CircuitQ for analyzing these topologies and quantizing circuits would provide practical guidance for researchers exploring this area.

5. Integration of Design and Simulation Tools:

The manuscript mentions tools like Qiskit Metal for integrated layout and simulation design. While such tools standardize the design process, they may lack the flexibility needed for highly customized workflows. Mentioning alternative tools like Gdspy, commonly used for layout design, would give readers a broader perspective on design tool options.

In summary, this review addresses relevant and timely topics in the design and analysis of superconducting quantum circuits. Incorporating the above suggestions will help improve clarity and make the manuscript more comprehensive, especially for researchers seeking practical insights into FEM-based quantum circuit design workflows. Finally, I hope these suggestions are helpful.

Declarations

Potential competing interests: No potential competing interests to declare.