Optimizing Optical Circuit Designs for Quantum Processing using Time-evolved Block Decimation

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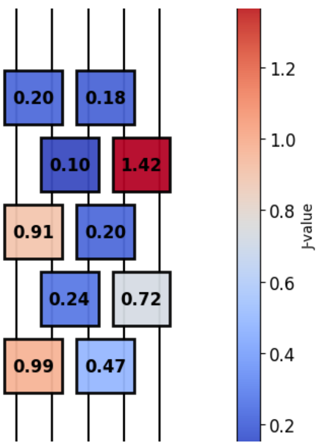
We harness time-evolved block decimation (TEBD) methods in combination with gradient-based machine learning techniques to optimize optical circuits, augmented with an optical Kerr-type nonlinearity, for the task of quantum state generation. To experimentally realize our designs, we focus on a GaAs-based platform whose nonlinearity stems from a strong coupling of the light to the exciton resonance, i.e., we exploit exciton-polaritons confined in GaAs waveguide structures.

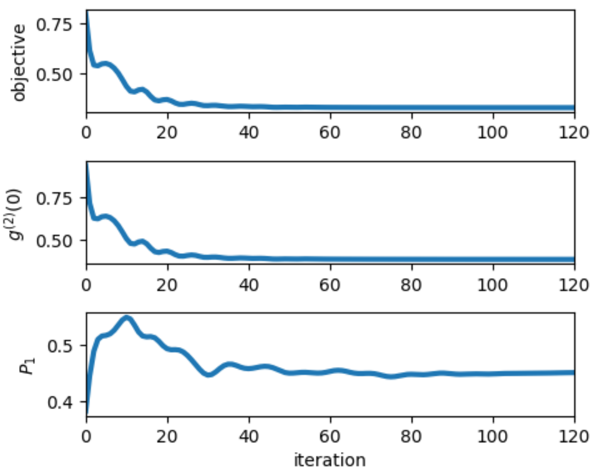
The gradient-based optimization procedure iteratively updates the strength of the gates coupling neighboring waveguides towards a setting that optimizes a well-specified quantum-state generation objective. We explicitly include photonic dissipation in the form of Markovian photon losses with Monte-Carlo quantum trajectories. The developed TEBD toolbox allows us to scale our design simulation and optimization tasks to circuits featuring 20 – 30 waveguides (bosonic modes), despite the exponential growth of the underlying Hilbert space.

As an initial benchmark, we expect that our circuits optimized for the task of single-photon generation – realizing maximal probability of occurrence and minimal density-density correlations, see Fig. 1 – will be taped out on GaAs chips in the near future. More complex circuit configurations are currently under investigation for cat-state generation and, in the longer term, we aim to design optical GaAs-based chips for generating quantum states useful in the context of quantum metrology and quantum communication.

The manuscript of this work is currently in preparation for publication. It is based on first ideas and research results from Ref. [1], without using the toolbox of TEBD.



(a) Optimal circuit (down → up)



(b) Obtained value for objective, $g^{(2)}(0)$ correlation and single-photon probability P_1

Figure 1: An example case of a small circuit optimized for simultaneous minimization of $g^{(2)}(0)$ in the third circuit output, while balancing the single-photon output probability. (a) The circuit with optimized coupler strengths (e.g., $\pi/4 \approx 0.78$ would be 50:50 splitting), (b) $g^{(2)}(0)$ and single-photon probability P_1 for different iterations in the optimization procedure, using a balanced optimization objective (loss function).

Acknowledgments

This project has received funding from the European Union's EIC Horizon Europe Pathfinder Challenges action under the grant agreement No 101115575 (Q-ONE).

References

[1] Van Regemortel, Mathias, Peelaers, Wolfger, and Van Vaerenbergh, Thomas. "Designing Polaritonic Integrated Circuits for Quantum Processing." In *NeurIPS 2024 Workshop Machine Learning with New Compute Paradigms*, 2024.

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