Simulating and Optimizing Quantum State Transport

FERMILAB-POSTER-23-164-STUDENT

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Summary

The goal of this project was to produce an accurate simulator of the "pitch and catch" process of sending quantum states between SRF cavities, and to find a method for optimizing the control pumps.

Introduction

To develop a modular quantum computer, there needs to be a way of transporting quantum states with high fidelity. We are working to establish an efficient means of converting quantum states stored in an SRF cavity into microwave pulses, which can be sent over a transmission line and converted back into the same quantum state in another cavity. To simulate the dynamics of the sending and receiving cavities, we use equations of motion derived by Axline (2018). These differential equations can be difficult to solve numerically, since the drive pumps can produce high frequency Stark shifts that reduce transport efficiency and require high numerical precision to simulate.

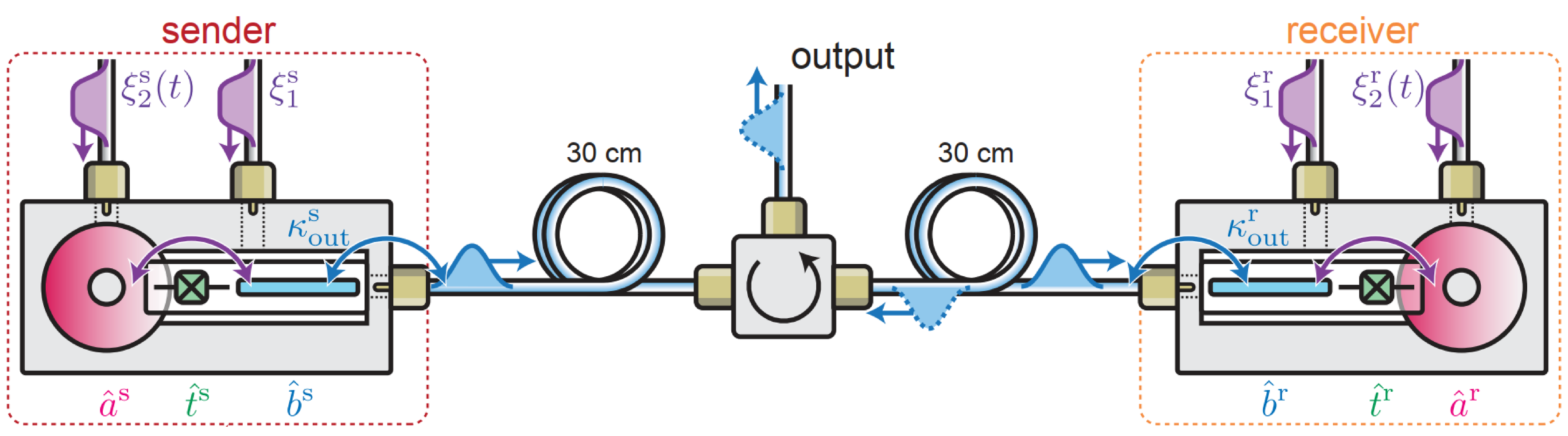
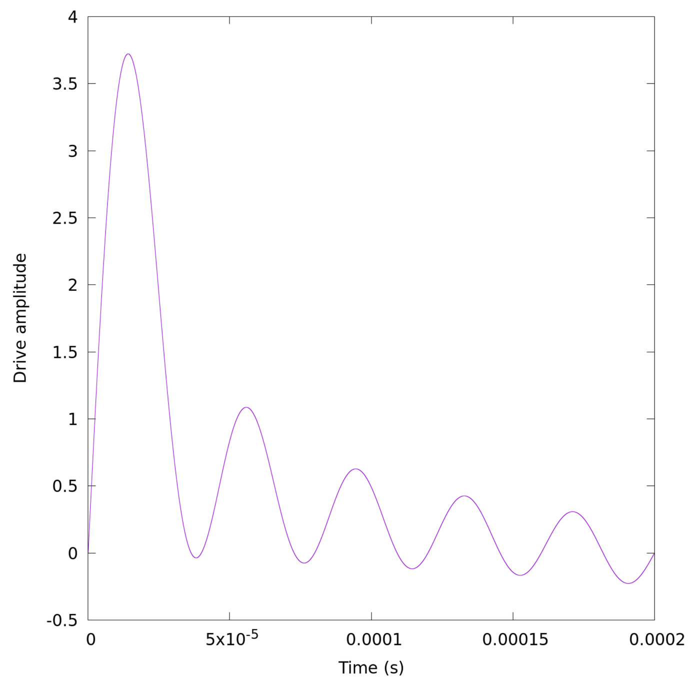
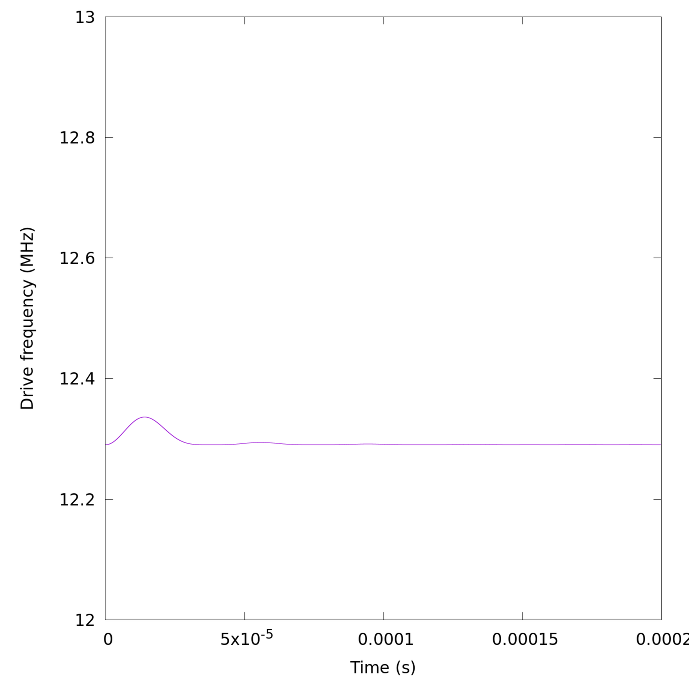
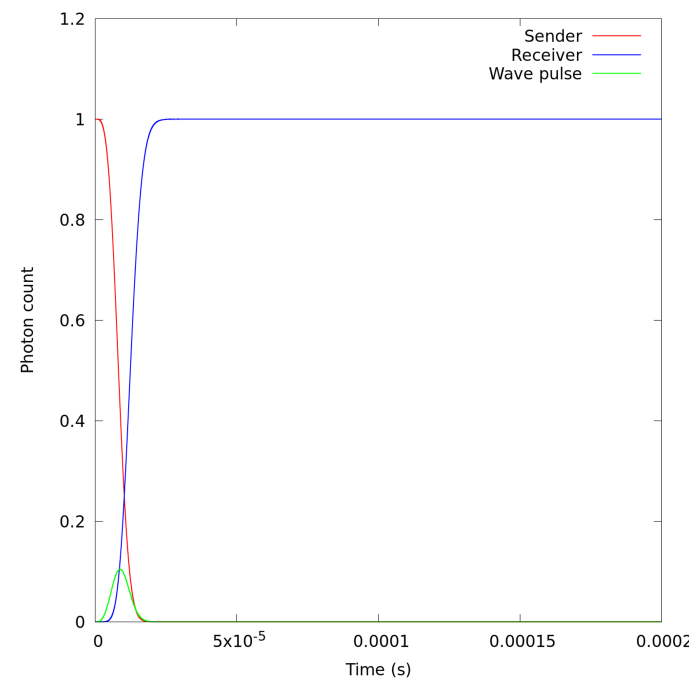


Diagram of sender and receiver modules connected by transmission line. (Credit: Axline, et al., 2018)



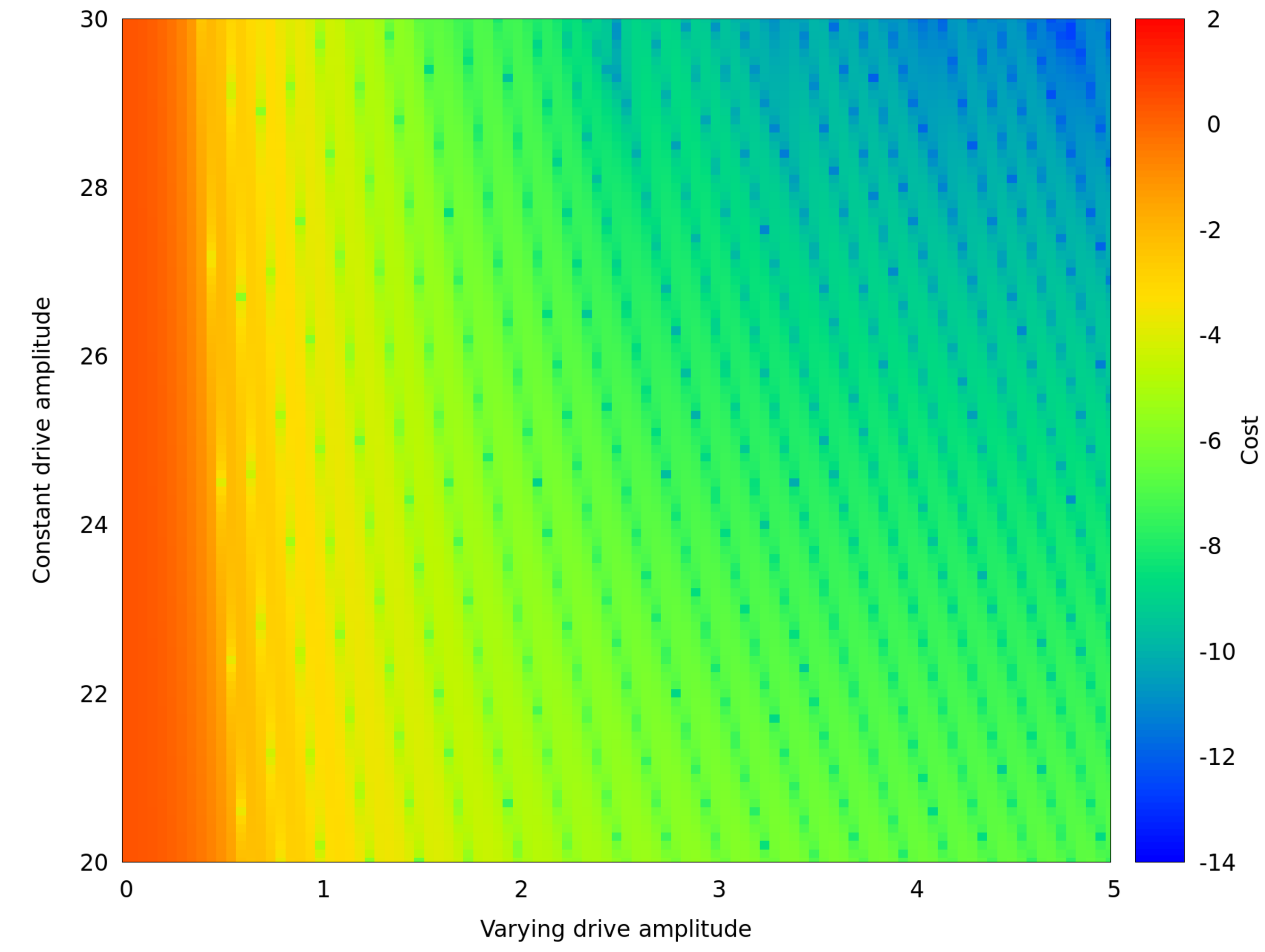




The two graphs above show an example of an optimal control drive, and the graph on the right shows the simulation results.

Methods

Rather than attempting to exactly solve the equations for a drive function that produces a desired wave pulse as was previously attempted, we use optimal control methods to find an approximate solution. An initial drive is used to integrate the equations for both the sender and receiver, with the outcome defining a cost function. We can then use optimization techniques to determine the drive that minimizes the cost. This requires a fast and precise ODE solver with fine tuning, and so we developed code in C++ to implement numerical techniques such as high order explicit Runge-Kutta. In defining the drive parameter, we also added a time-dependent frequency term that attempts to account for the Stark shifts, which significantly improved the performance.



Cost evaluated as a function of varying $\xi_1(t)$ and constant ξ_2 drive amplitudes.

Results and Conclusion

Our program can simulate quantum state transport for a given set of hardware parameters to an arbitrary level of accuracy, with reasonable speed and efficiency. This has made it possible to analyze the cost function and find optimal control parameters far more quickly than previous methods. Using this C++ program as a base, we plan on interfacing with Python to allow others to make use of this code more easily, and to add more user functionality and constraints that can make this program accessible to other researchers.

Acknowledgements

a. This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

b. This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).