

Numerical Modeling of Josephson Traveling-Wave Parametric Amplifier-Enhanced Multiplexed Superconducting Qubit Readout

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Superconducting qubits are among the most promising technologies for developing paradigm-shifting quantum computers. However, these devices are currently limited by the need for external wiring to control and measure each individual qubit, inhibiting the development of larger systems capable of solving critical problems. One approach to consolidate measurement hardware is multiplexed readout, where many frequency-multiplexed qubits are measured using a single readout circuit. Critically, this process requires an ultralow-noise amplifier with a wide bandwidth to enable detection of the ultralow-power signals used for measurement. One of the amplifiers most suited to meet this need is the Josephson traveling-wave parametric amplifier (JTWPA), which uses a parametric mixing scheme to provide wideband gain without significant noise or dissipation. However, in the presence of multiple readout tones used in multiplexed readout, this mixing process produces additional undesired tones. While this effect is well studied in isolation, it is challenging to determine how it impacts the readout process. To provide insight into that issue, we combine two numerical approaches for simulating superconducting qubits (T. E. Roth and S. T. Elkin, “Maxwell-Schrödinger modeling of a superconducting qubit coupled to a transmission line network,” *IEEE Journal on Multiscale and Multiphysics Computational Techniques*, vol. 9, pp. 61-74, Jan 2024) and JTWPAs (S. T. Elkin, M. Haider, and T. E. Roth, “Multiphysics numerical method for modeling Josephson traveling-wave parametric amplifiers,” *IEEE Journal on Multiscale and Multiphysics Computational Techniques*, vol. 9, pp. 247-257, Jul 2024) in order to model the dynamics of multiplexed readout directly. Further, we use an analytical approach to process the outputs of the combined simulation and calculate the readout fidelity, which characterizes the effectiveness of the system. As a result, this procedure can be used to inform system designers on how to optimize their readout circuitry. In Fig. 1, we demonstrate such a use case by determining the tradeoff between readout fidelity and integration length for various spacings between qubit frequencies and coherence times for a three-qubit readout circuit.

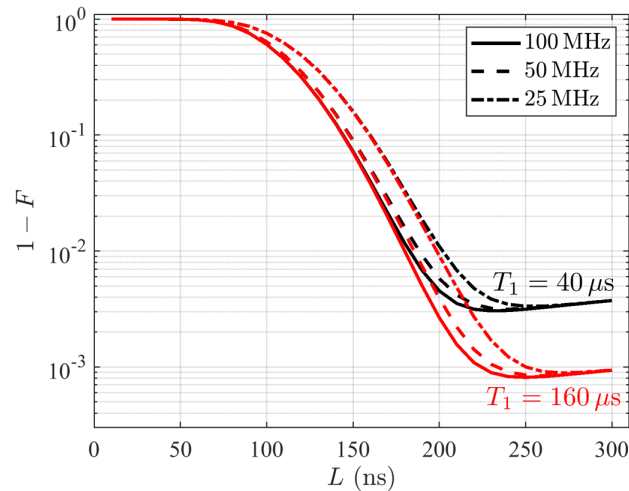


Figure 1: Readout error ($1 - F$) vs integration window length L for a three-qubit readout circuit. The frequency values refer to the spacing between each qubit frequency, and T_1 is the qubit coherence time.