Finding the Optimal Signal for a 2-cell SRF Cavity

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Project Goals

The purpose of this project is to find an optimal signal for the transmon drive in a transmon & cavity system, so that a target state or a target gate can be generated in the cavity. Specifically, we look at the cavity displacement operator and the selective number-dependent arbitrary phase operation (SNAP) in a displacement-SNAP-displacement sequence. These operators are of particular importance as they form a set of universal gates for a cavity-based quantum computer [1].

$$H(t) = H_0 + \sum_j u_j(t) H_j$$

$$H(t) \approx H(t_k) = H_0 + \sum_{j=1}^{N} u_{jk} H_j$$

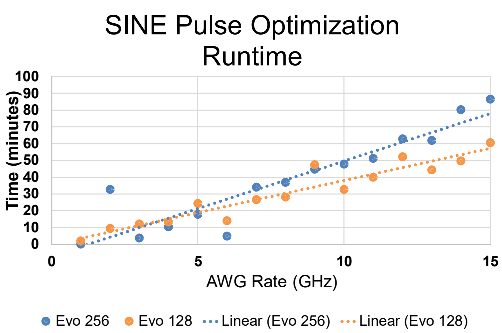
Top: **Time dependent Hamiltonian of a closed quantum system.**
Bottom: **Hamiltonian indexed by discrete time slots (t_k).**

$$\hat{D}(\alpha) = \exp(\alpha \hat{a}^\dagger - \alpha^* \hat{a})$$

$$\hat{S}_n(\theta_n) = e^{i\theta_n |n\rangle\langle n|}$$

$$U(\alpha, \hat{\theta}) = D(\alpha) S(\hat{\theta}) D(\alpha)$$

Top: **Displacement operator.**
Middle: **SNAP Operator**
Bottom: **Target transformation.**

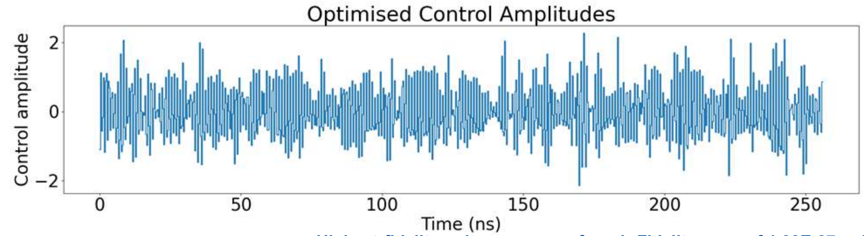


Runtime (in minutes) of pulse optimization sequences at various AWG Rates using a sinusoidal initial pulse

Method

Simulation of the quantum system and subsequent pulse optimization were achieved using QuTiP (Quantum Toolbox in Python). Arbitrary values were chosen for the alpha coefficient and theta vector in the target transformation. Effectiveness of the optimization algorithm was first verified using a randomly generated initial pulse.

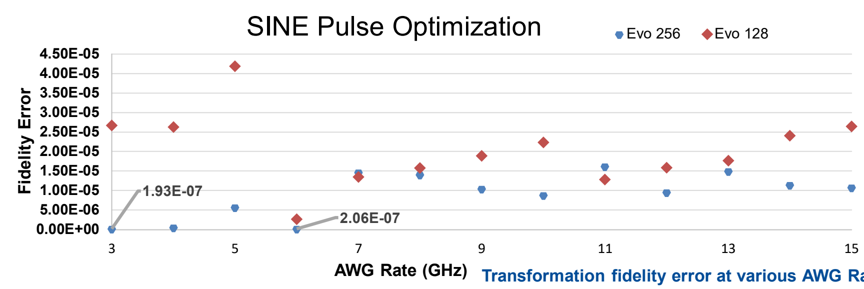
Further testing was done using a Sinusoidal initial pulse as to mimic a wave generator used in a hypothetical physical implementation. The timescale of the evolution and the rate of the arbitrary wave generator (AWG Rate) were varied for subsequent optimization routines. The number of timeslots used in each optimization is a product of AWG Rate and evolution time rounded to the nearest integer.



Highest fidelity pulse sequence found: Fidelity error of 1.93E-07 using a Sinusoidal initial pulse, AWG rate of 3GHz and evolution time of 256ns.

Pulse Optimization

The Hamiltonian of a closed quantum system can be described as the summation of its free (H_0) and control (H_j) components, where "u_j" represents a time dependent amplitude function for each control [3]. Solving for these "u_j" terms reveals the necessary pulse sequence for a given unitary operation on the state space of the system. As these solutions cannot typically be found analytically, an iterative algorithmic approach is taken. Gradient Ascent Pulse Engineering (GRAPE) was used to calculate control amplitudes. The systems evolution is broken into discrete time slots with "k" representing their index. The control amplitudes of these time slots are iteratively measured and adjusted based on a target fidelity [2]. The fidelity figure is calculated by comparing overlap between the target state and the propagated state.



Transformation fidelity error at various AWG Rates using a sinusoidal initial pulse. Frequencies under 3GHz result in large error values.

Conclusion

Identifying relationships between input parameters and the resulting fidelity of a signal sequence could lead to more efficient search methods. No clear pattern was found in the data gathered when relating transformation fidelity to AWG Rate and evolution time. Searching for high quality signals through arbitrary parametrization is a relatively slow process, with data points taking upwards of an hour to generate as the time slot quantity is expanded. Newer, faster optimization algorithms could help reduce processing times. Ideally, additional data and more advanced processing techniques could reveal patterns that help to pick parameters in a more educated and controlled manner.

Acknowledgement

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References

[1] Krastanov et al., PRA 92, 040303(R) (2015)
[2] Rowland and Jones, Phil. Trans. R. Soc. A (2012) 370, 4636–4650
[3] Wu et al., arXiv:1712.01780v4 [quant-ph] (2018)