JÜLICH Forschungszentrum

PGI-2

QSOLID

Parametric fSim Gate

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Abstract

We present a systematic theory of a two-transmon-one-resonator system with multiple parametric drives. By employing iSWAP-type and CZ-type transitions at the same time, we realise a continuous set of two-qubit gates called fermionic simulation gates. Our theory opens up new possibilities of designing more flexible and parasitic-free two-qubit gates.

What is fSim and why?

$$U_{fSim}(\theta,\varphi)=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & cos(\theta) & -isin(\theta) & 0\\ 0 & -isin(\theta) & cos(\theta) & 0\\ 0 & 0 & 0 & e^{i\varphi}\end{pmatrix}$$

fSim: Natural two-qubit gate set for excitation-conserving Hamiltonian

$\varphi=0: iSWAP, \theta=0: CPHASE$

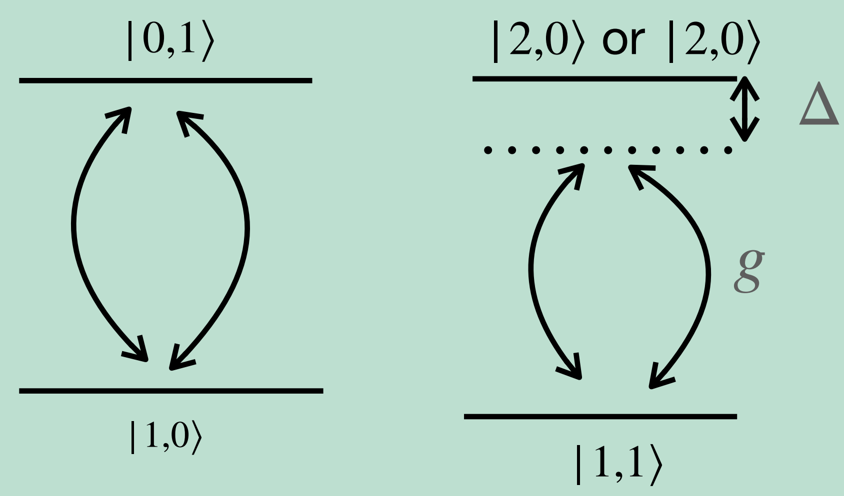
Advantages:

- Can be used to eliminate residual ZZ phase in iSWAP gate
- Reduce circuit depth for NISQ devices, e.g. simulating excitation-conserving Hamiltonian:

$$H=\Sigma_p U_p n_p+\Sigma_{p\neq q}T_{p,q}c_p^\dagger c_q+V_{p,q}n_p n_q$$

Gate strategy: simultaneous iSWAP and CZ

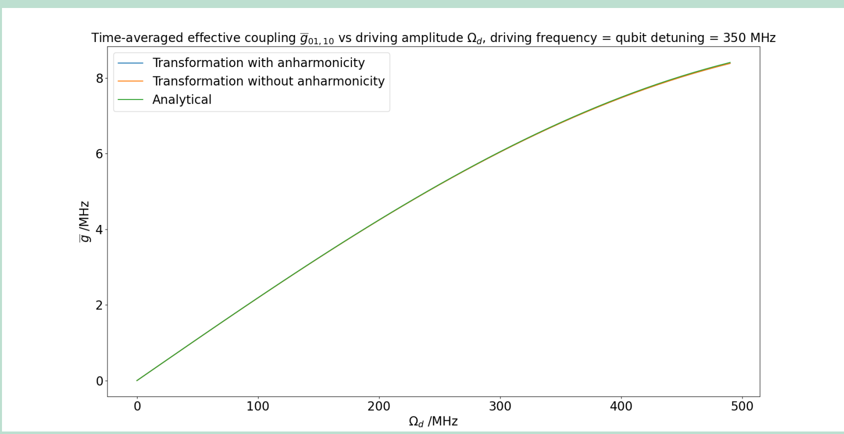
$|1{,}0\rangle \leftrightarrow |0{,}1\rangle$ transition: control θ



$|1{,}1\rangle \leftrightarrow |2{,}0\rangle$ or $|0{,}2\rangle$ transition: control φ

Analytical treatment: Bogoliubov Transformation+proper rotating frame

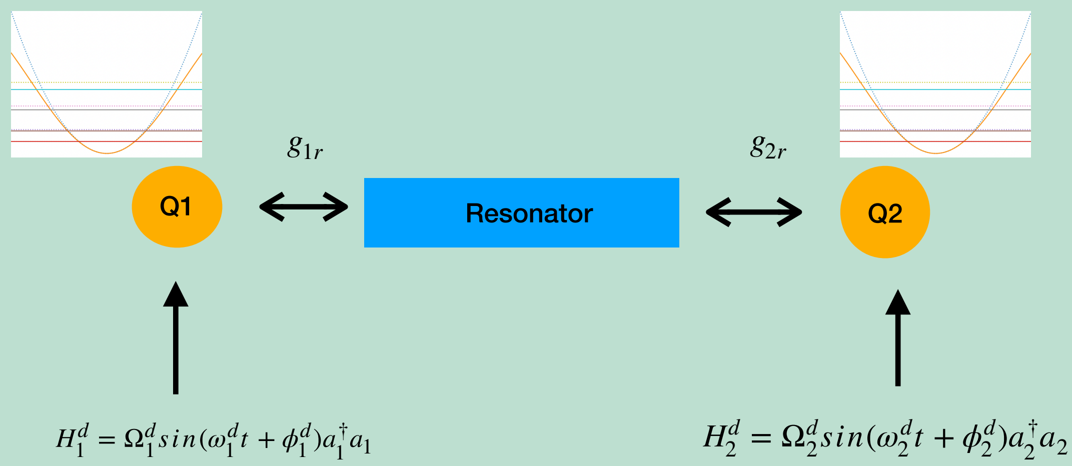
Effective coupling:



Resonance condition:

$$\tilde{\omega}_{(n_1,n_2,n_3)\rightarrow(n_i+1,n_j-1)}-\tilde{\omega}_{(n_1,n_2,n_3)}-n\omega_0^d-p\omega_1^d-q\omega_2^d=0$$

Setup:two tunable transoms coupled to one harmonic resonator



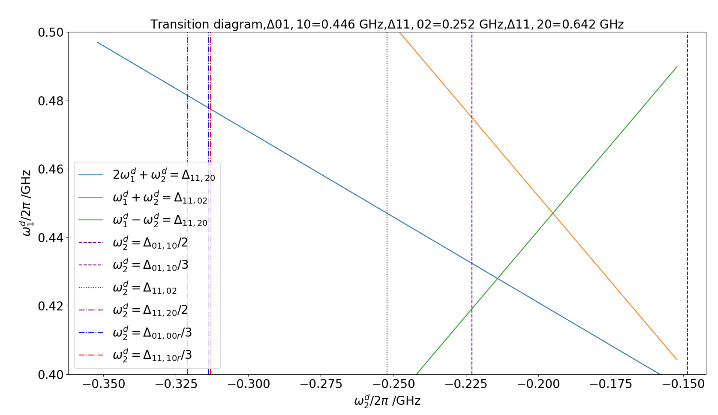
$$H_0=\Sigma_i\omega_i a_i^\dagger a_i+\frac{\delta_i}{2}a_i^\dagger a_i(a_i^\dagger a_i-1)+\Sigma_{ij}g_{ij}(a_i^\dagger a_j+a_i a_j^\dagger)$$

$$H_i^d=\Sigma_i\Omega_i^d sin(\omega_i^d t+\phi_i^d)a_i^\dagger a_i$$

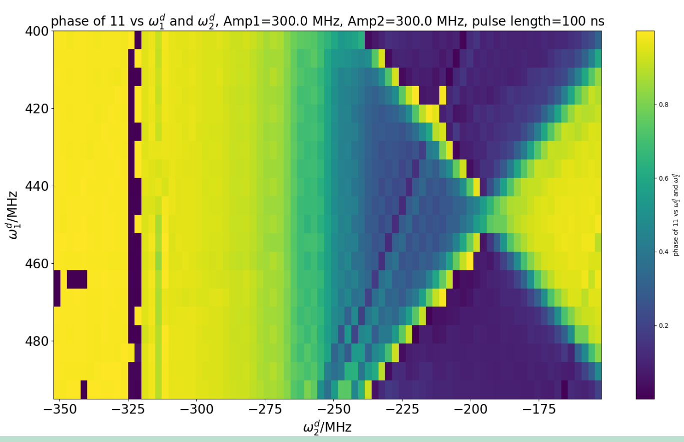
$i,j=1{,}2$ and r

$$H_{sys}=H_0+H_d$$

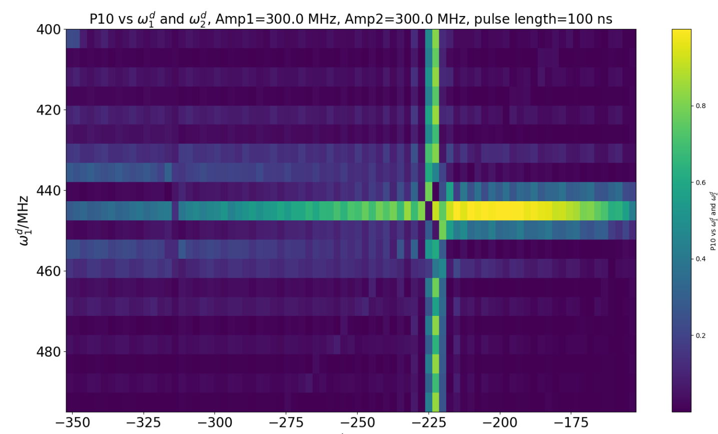
Numerical simulation:



Tuning φ



Tuning θ



[1]Foxen, Brooks, et al. "Demonstrating a continuous set of two-qubit gates for near-term quantum algorithms." *Physical Review Letters* 125.12 (2020): 120504.
[2]Reagor, Matthew, et al. "Demonstration of universal parametric entangling gates on a multi-qubit lattice." *Science advances* 4.2 (2018): eaao3603.
[3]Z. Jiang and M. Ansari, “Parametric fermionic simulation gates.”, paper in preparation

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