Quantum Electronics of Nanostructures

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Lecture 8

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- Two-qubit operations in quantum information processing
- Two-qubit interaction
- Two-qubit Hamiltonian transformations
- Implementation schemes for two-qubit gates
- Fidelity of operations
- Challenges and perspectives

Single-qubit rotation operator

Arbitrary: $A_\phi = \exp\left(-i\phi\frac{\hat{\sigma}_a}{2}\right), a = \{x, y, z\}$ or any axis

Hadamard rotation: $H = Y_{\frac{\pi}{2}} Z_\pi = \exp\left(-i\frac{\hat{\sigma}_y}{2}\frac{\pi}{2}\right)\exp\left(-i\frac{\hat{\sigma}_z}{2}\pi\right) = \frac{1}{\sqrt{2}}\begin{bmatrix} -1 & -1 \\ -1 & 1 \end{bmatrix}$

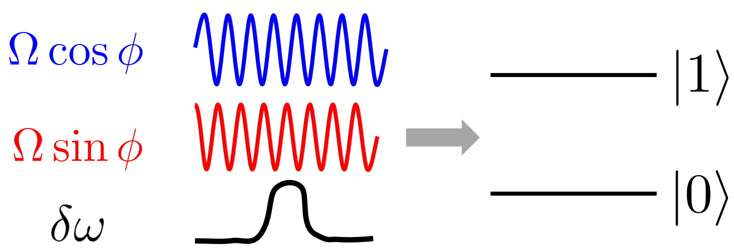
Hadamard	$-\boxed{H}-$	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$	Pauli-Z	$-\boxed{Z}-$	$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Pauli-X	$-\boxed{X}-$	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$	Phase	$-\boxed{S}-$	$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
Pauli-Y	$-\boxed{Y}-$	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$	$\pi/8$	$-\boxed{T}-$	$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$

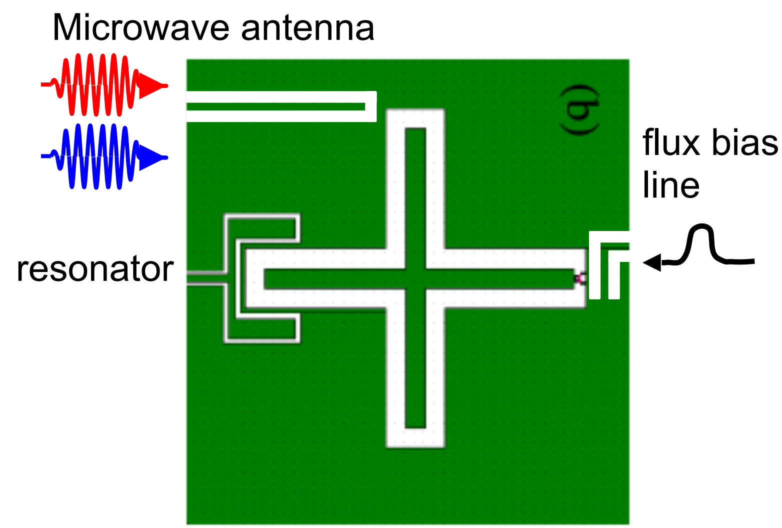
Michael A. Nielsen & Isaac L. Chuang *Quantum Computation and Quantum Information*

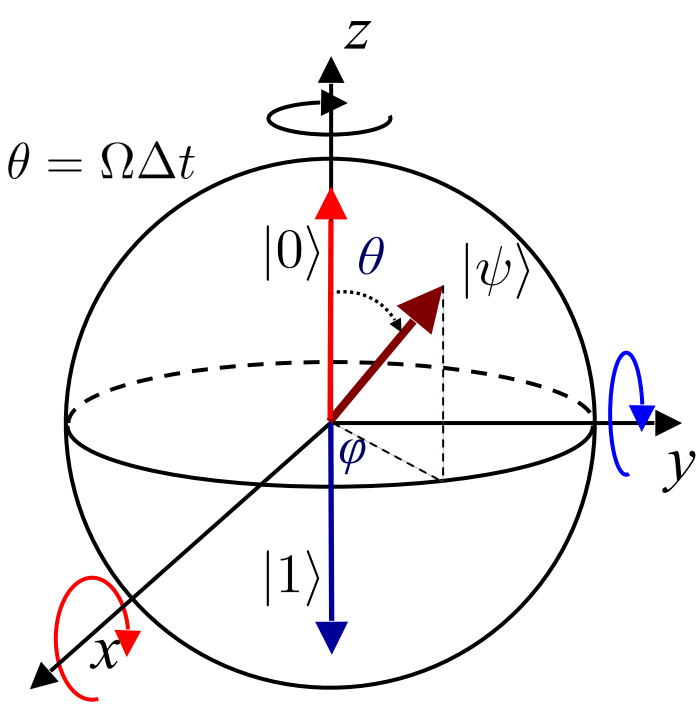
Physical implementation of single-qubit rotations

$$H_{RWA} = \frac{1}{2}\begin{bmatrix} -\omega_d + \omega_q & -i\Omega\sin\phi + \Omega\cos\phi \\ i\Omega\sin\phi + \Omega\cos\phi & \omega_d - \omega_q \end{bmatrix} = \delta\omega\hat{\sigma}_z + \Omega\cos\phi\cdot\hat{\sigma}_x + \Omega\sin\phi\cdot\hat{\sigma}_y$$

State manipulation





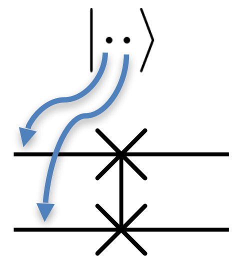


$$|\psi\rangle = \cos\frac{\theta}{2}\,|0\rangle + e^{i\phi}\sin\frac{\theta}{2}\,|1\rangle$$

Arbitrary state could be prepared

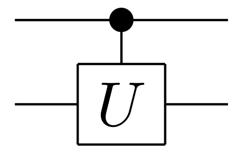
Two-qubit operations

$$
\mathrm{SWAP} = \begin{array}{c c}
\begin{array}{cccc} |00\rangle & |01\rangle & |10\rangle & |11\rangle \end{array} & \\
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} & \begin{array}{c} |00\rangle \\ |01\rangle \\ |10\rangle \\ |11\rangle \end{array}
\end{array}
$$



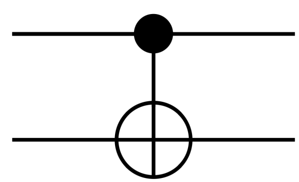
$$
\sqrt{\mathrm{SWAP}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \frac{1}{2}(1+i) & \frac{1}{2}(1-i) & 0 \\ 0 & \frac{1}{2}(1-i) & \frac{1}{2}(1+i) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
U = \begin{bmatrix} u_{00} & u_{01} \\ u_{10} & u_{11} \end{bmatrix} \Rightarrow \mathrm{C}(U) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & u_{00} & u_{01} \\ 0 & 0 & u_{10} & u_{11} \end{bmatrix}
$$



Controlled unitary

$$
\mathrm{CNOT} = CX = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}
$$



$$
\mathrm{CZ} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}
$$

$$
XZ = Z_\pi \otimes X_\pi = \begin{bmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}
$$

3-qubit gates, 4-qubit gates…?

Universal quantum computation

It is shown that the Hadamard, phase, controlled-NOT and $\pi/8$ gates are universal for quantum computation in the sense that given a circuit containing CNOTs and arbitrary single qubit unitaries it is possible to simulate this circuit to good accuracy

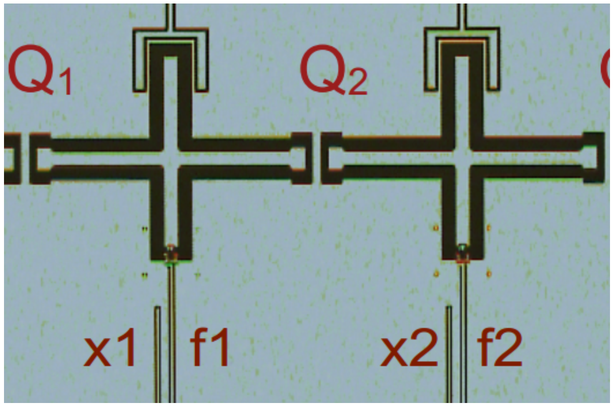
There are other universal sets with iSWAP, etc. The Solovay–Kitaev theorem therefore implies that to approximate a circuit containing m CNOTs and single qubit unitaries to an accuracy ϵ requires $O(m \log^c(m/\epsilon))$ gates from the discrete set, a polylogarithmic increase over the size of the original circuit, which is likely to be acceptable for virtually all applications.

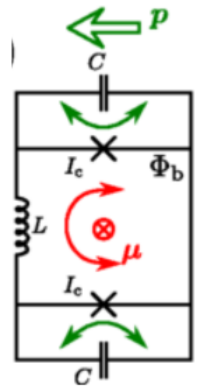
In order to create quantum computer you only need to implement single- and two-qubit gates

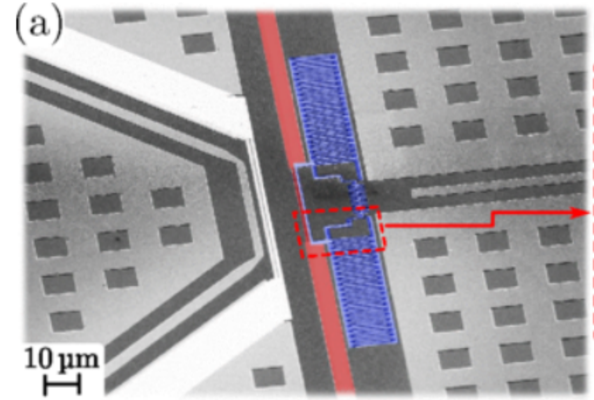
Nevertheless, it is still a challenge

Two-qubit interaction

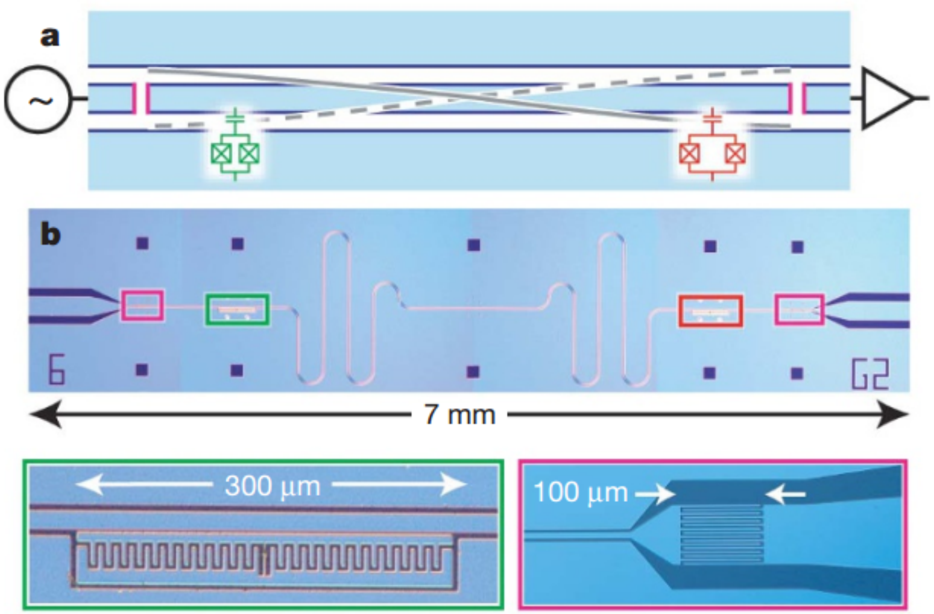
1. Direct coupling (C/L)



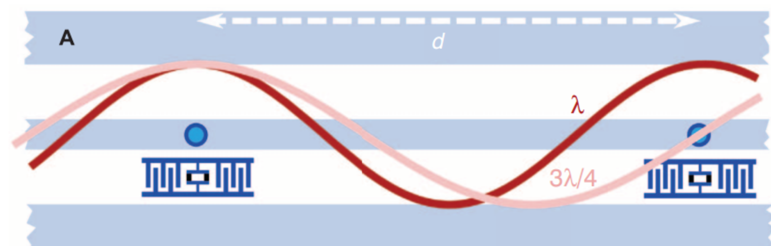




2. Coupling by cavity

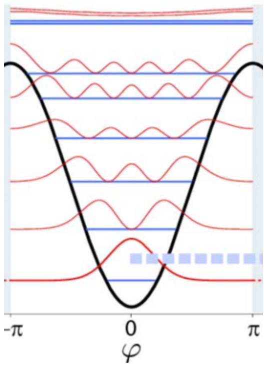


3. Coupling by waveguide



Two-qubit interaction

Effective transmon:



$$\hat{H}_{tr} = \hbar\left[\omega\cdot\hat{b}^\dagger\hat{b} + \frac{1}{2}\delta\cdot\hat{b}^\dagger\hat{b}(\hat{b}^\dagger\hat{b}-1)\right]$$

$$\omega_{n+1,n} = \frac{E_{n+1}-E_n}{\hbar} = \omega + n\delta$$

$$E_1 = \langle 1|\hat{H}_{tr}|1\rangle = \hbar\omega$$

$$E_2 = \langle 2|\hat{H}_{tr}|2\rangle = 2\hbar\omega + \delta$$

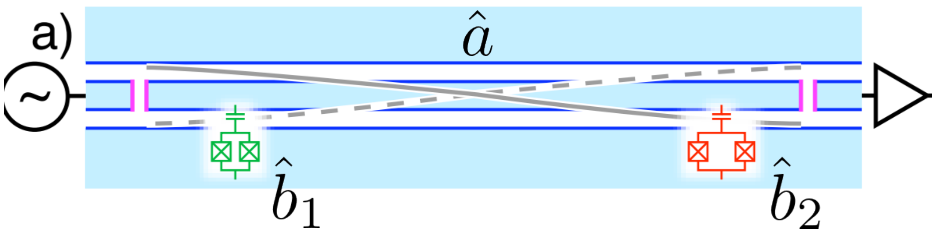
Coupling between transmons: $\hat{H} = \hat{H}_{tr1} + \hat{H}_{tr2} + \hat{H}_{int}$. How to find H_{int}?

1. Write full Hamiltonian of circuit (with charges, phases)
2. Find matrix elements of physical operators on qubit eigenvectors
3. Rewrite Hamiltonian in qubit basis

Capacitive coupling: $\hat{H}_{int} = \hbar J\left(\hat{b}_1\hat{b}_2^\dagger + \hat{b}_1^\dagger\hat{b}_2\right)$ - XX-interaction

Inductive coupling: $\mathcal{H} = \hbar\omega_{\mathrm{qb}}\sigma_z^{(\mathrm{qb})}/2 + \hbar\omega_{\mathrm{a}}\sigma_z^{(\mathrm{a})}/2 - \hbar g_{zz}\sigma_z^{(\mathrm{qb})}\sigma_z^{(\mathrm{a})}/2,$ ZZ-interaction

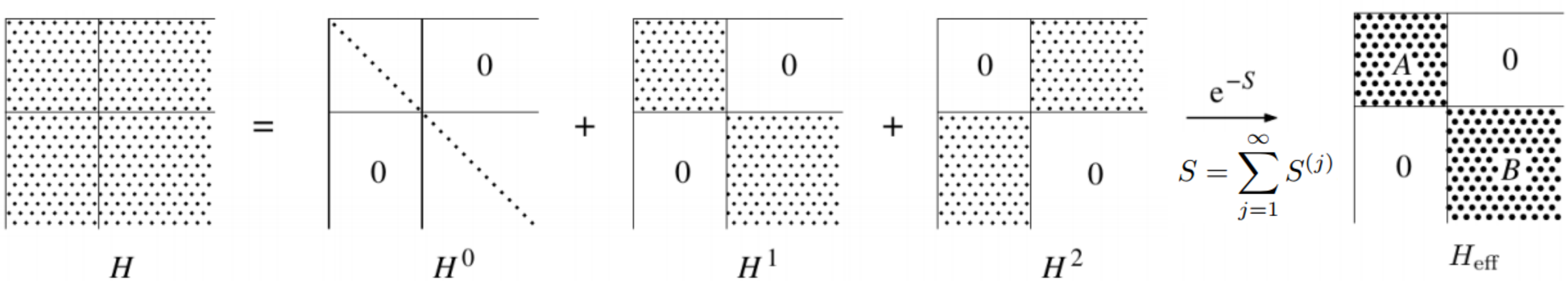
Two-qubit interaction via cavity bus



$$
\hat{H} = \hat{H}_r + \hat{H}_{tr1} + \hat{H}_{tr2} + \\
+\hbar g_1 \left(a b_1^\dagger + a^\dagger b_1 \right) + \hbar g_2 \left(a b_2^\dagger + a^\dagger b_2 \right)
$$

- Schrieffer-Wolff transformation

$$H = H^0 + H' \qquad H' = H^1 + H^2$$



$$[H^0, S^{(1)}] = -H^2$$

$$[H^0, S^{(2)}] = -[H^1, S^{(1)}]$$

$$[H^0, S^{(3)}] = -[H^1, S^{(2)}] - \frac{1}{3}[[H^2, S^{(1)}], S^{(1)}]$$

$$H_{\text{eff}} = e^{-S} H e^{S} = \sum_{j=0}^{\infty} \frac{1}{j!}[H, S]^{(j)}$$

Up to 2nd order: $H_{\text{eff}} = H^0 + H^1 + \frac{1}{2}[H^2, S^{(1)}]$

Two-level case: $$H_{\text{eff}} = \frac{\hbar\omega_1}{2}\sigma_1^z + \frac{\hbar\omega_2}{2}\sigma_2^z + \hbar\left(\omega_r + \chi_1\sigma_1^z + \chi_2\sigma_2^z\right)a^\dagger a \\ +\hbar J\left(\sigma_1^-\sigma_2^+ + \sigma_2^-\sigma_1^+\right)$$

Susanne Richer, MSc Thesis 2013

Schrieffer-Wolff example: Jaynes-Cummings model

$$H = \underbrace{\omega_r a^\dagger a - \frac{\omega_q}{2}\sigma^z}_{H^0} + \underbrace{g(a^\dagger \sigma^- + a\sigma^+)}_{H'}. \qquad \omega_r - \omega_q \equiv \Delta.$$

$$H' = H^1 + H^2 = \begin{pmatrix} & \blacksquare \\ \blacksquare & \end{pmatrix} = H^2,$$ To find $S^{(1)}$ use ansatz: $$S^{(1)} = \alpha a^\dagger \sigma^- - \alpha^* a \sigma^+,$$

$$[H^0, S^{(1)}] = -H^2 \Rightarrow S^{(1)} = -\frac{g}{\Delta}(a^\dagger\sigma^- - a\sigma^+).$$

The first correction to H^0 is

$$\frac{1}{2}[H^2, S^{(1)}] = -\frac{g^2}{2\Delta}[a^\dagger\sigma^- + a\sigma^+, a^\dagger\sigma^- - a\sigma^+]$$

$$= \frac{g^2}{2\Delta}(a^\dagger a\sigma^-\sigma^+ - aa^\dagger\sigma^+\sigma^- - aa^\dagger\sigma^+\sigma^- + a^\dagger a\sigma^-\sigma^+) = \frac{g^2}{2\Delta}(2a^\dagger a[\sigma^-, \sigma^+] - 2\sigma^+\sigma^-)$$

$$= \frac{g^2}{2\Delta}(2a^\dagger a \underbrace{(|0\rangle\langle 0| - |1\rangle\langle 1|)}_{=\sigma^z} - 2\underbrace{|1\rangle\langle 1|}_{=\frac{I-\sigma^z}{2}}) = \frac{g^2}{2\Delta}(2a^\dagger a + 1)\sigma^z - \underbrace{\frac{g^2}{\Delta}I}_{=const.},$$

Dispersive shift

Lamb shift

Schrieffer-Wolff for two qubits in resonator

- Two-level qubits $$H = \omega_r a^\dagger a + \sum_{i=1}^{2} -\frac{\omega_{q_i}}{2}\sigma_i^z + g_i(a^\dagger \sigma_i^- + a\sigma_i^+)$$

- Schrieffer-Wolf with $$S^{(1)} = -\sum_i \frac{g_i}{\Delta_i}(a^\dagger \sigma_i^- - a\sigma_i^+),$$

Up to 2nd order: $$H_{\text{eff}} = \underbrace{\sum_{i=1}^{2}\left(\omega_r + \frac{g_i^2}{\Delta_i}\sigma_i^z\right)a^\dagger a - \frac{1}{2}\left(\omega_{q_i} - \frac{g_i^2}{\Delta_i}\right)\sigma_i^z}_{\text{dispersive regime of individual qubits}} - \sum_{i\neq j}\underbrace{g_i g_j \frac{\Delta_i + \Delta_j}{2\Delta_i\Delta_j}\sigma_j^+\sigma_i^-}_{\text{two-qubit interaction}}$$

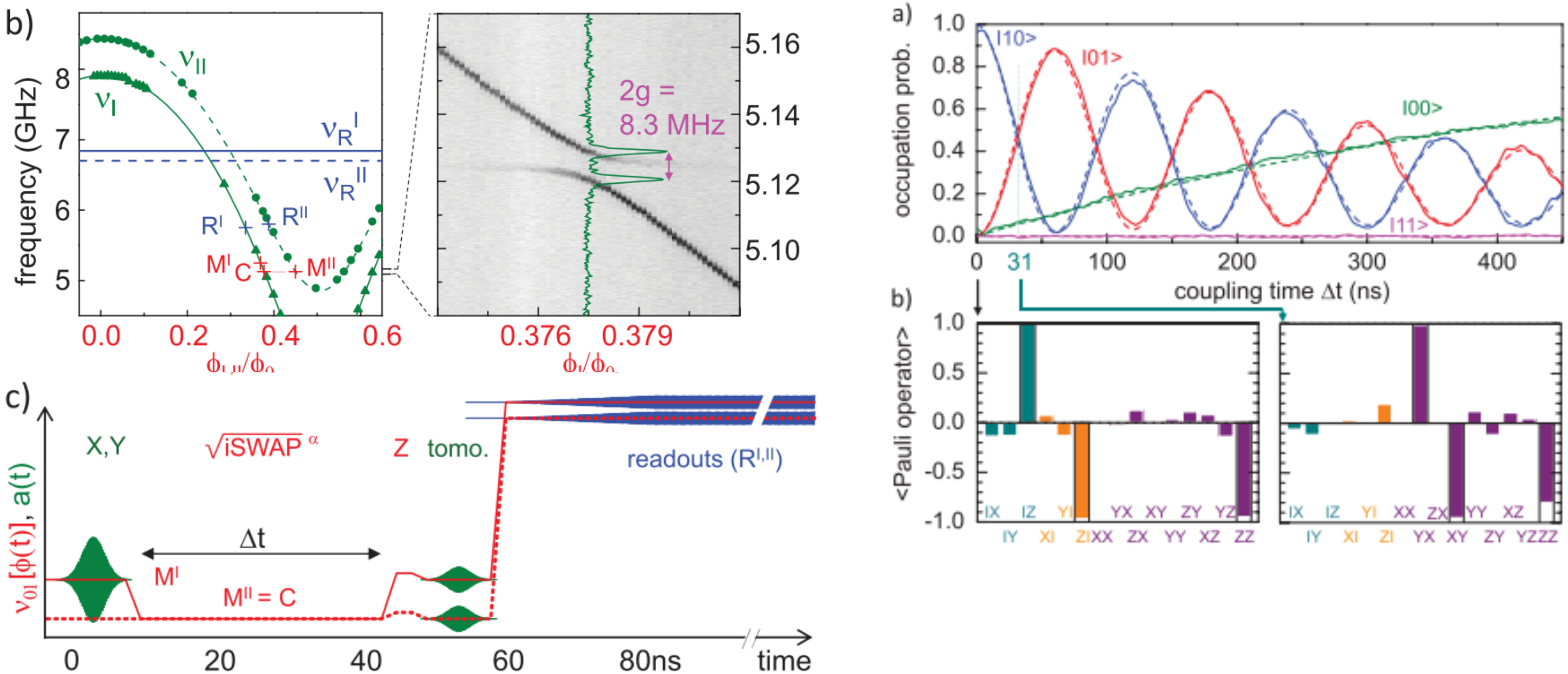
- In rotating frame for identical resonant qubits: $$H_{\text{eff}} = \frac{g^2}{\Delta}\left(a^\dagger a + \frac{1}{2}\right)(\sigma_1^z + \sigma_2^z) - \frac{g^2}{\Delta}\left(\sigma_1^+\sigma_2^- + \sigma_2^+\sigma_1^-\right)$$

$$U_{\text{eff}}(t) = e^{-i\frac{g^2}{\Delta}\left(a^\dagger a + \frac{1}{2}\right)(\sigma_1^z + \sigma_2^z)t} \cdot \begin{pmatrix} 1 & & & \\ & \cos\frac{g^2}{\Delta}t & i\sin\frac{g^2}{\Delta}t & \\ & i\sin\frac{g^2}{\Delta}t & \cos\frac{g^2}{\Delta}t & \\ & & & 1 \end{pmatrix} \Rightarrow \text{iSWAP}$$

- The recipe: take 2 frequency tunable qubits and move them to resonance RAPIDLY

iSWAP gate

PRL **108**, 057002 (2012)



Many groups completely avoid frequency-tunable qubits → what gate could be implemented?

Cross-resonance gate

$$H = -\frac{\omega_1}{2}\sigma_1^z - \frac{\omega_2}{2}\sigma_2^z + J\left(\sigma_1^+\sigma_2^- + \sigma_2^+\sigma_1^-\right)$$ - without cavity terms

$$\omega_i = \omega_{q_i} - \frac{g_i^2}{\Delta_i} \qquad J = -\frac{g_1 g_2(\Delta_1 + \Delta_2)}{2\Delta_1\Delta_2}$$

Let us apply another Schrieffer-Wolff $\qquad S^{(1)} = -\frac{J}{\Delta_{12}}\left(\sigma_1^+\sigma_2^- - \sigma_2^+\sigma_1^-\right)$

$$H_{\text{eff}} = -\frac{\tilde{\omega}_1}{2}\sigma_1^z - \frac{\tilde{\omega}_2}{2}\sigma_2^z$$

with shifted frequencies $\tilde{\omega}_1 = \omega_1 + J^2/\Delta_{12}$ and $\tilde{\omega}_2 = \omega_2 - J^2/\Delta_{12}$ and $\Delta_{12} = \omega_1 - \omega_2$

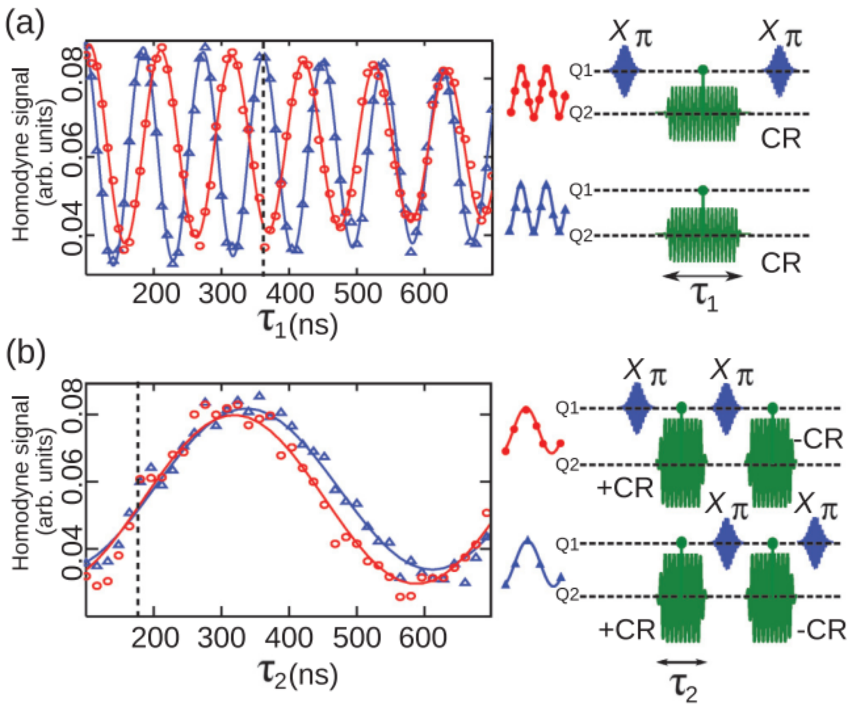
Apply drive to qubit 1 on frequency $\tilde{\omega}_2$: $\qquad H^d(t) = \frac{\Omega(t)}{2}(\sigma_1^+ e^{-i\tilde{\omega}_2 t} + \sigma_1^- e^{i\tilde{\omega}_2 t})$

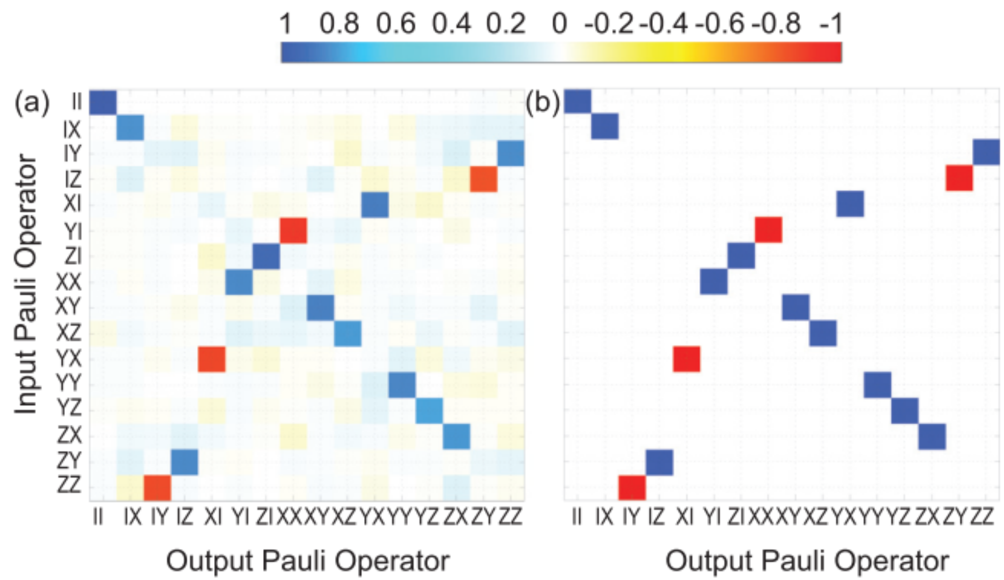
Transferring the drive to the diagonalized frame (Schrieffer-Wolff frame) and to a rotating frame at frequency $\tilde{\omega}_2$ yields

$$H_{\text{eff}}^d(t) = U\left(H^d(t) + [H^d(t), S^{(1)}]\right)U^\dagger = \frac{\Omega(t)}{2}\left(\sigma_1^x - \frac{J}{\Delta_{12}}\sigma_1^z\sigma_2^x\right)$$

$$H_{\text{total}}(t) = -\left(\frac{\tilde{\omega}_1 - \tilde{\omega}_2}{2}\right)\sigma_1^z + \frac{\Omega(t)}{2}\left(\sigma_1^x - \boxed{\frac{J}{\Delta_{12}}\sigma_1^z\sigma_2^x}\right).$$ ZX-operation

Cross-resonance gate





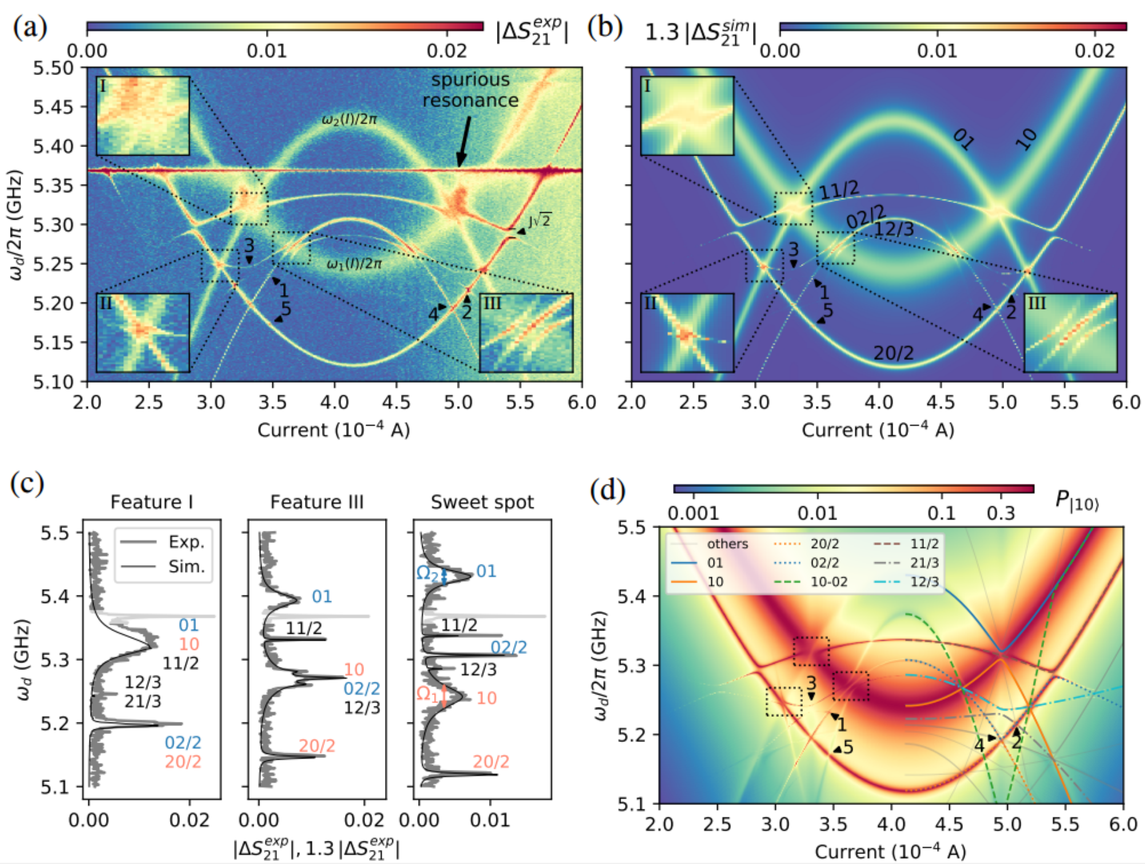
the frequency of qubit 2 (target). Depending on whether a π rotation is applied to qubit 1 prior to the CR pulse (circles) or not (triangles), different Rabi rates are observed on qubit 2. In

Two-qubit gates with real multilevel transmons

- The multilevel Hamiltonian:

$$H = \left(\omega_1 - \frac{\delta_1}{2}\right) c_1^\dagger c_1 + \frac{\delta_1}{2}(c_1^\dagger c_1)^2 + \left(\omega_2 - \frac{\delta_2}{2}\right) c_2^\dagger c_2 + \frac{\delta_2}{2}(c_2^\dagger c_2)^2 + J(c_1^\dagger c_2 + c_1 c_2^\dagger),$$

- The system has a complex spectrum with different multiphoton transitions:

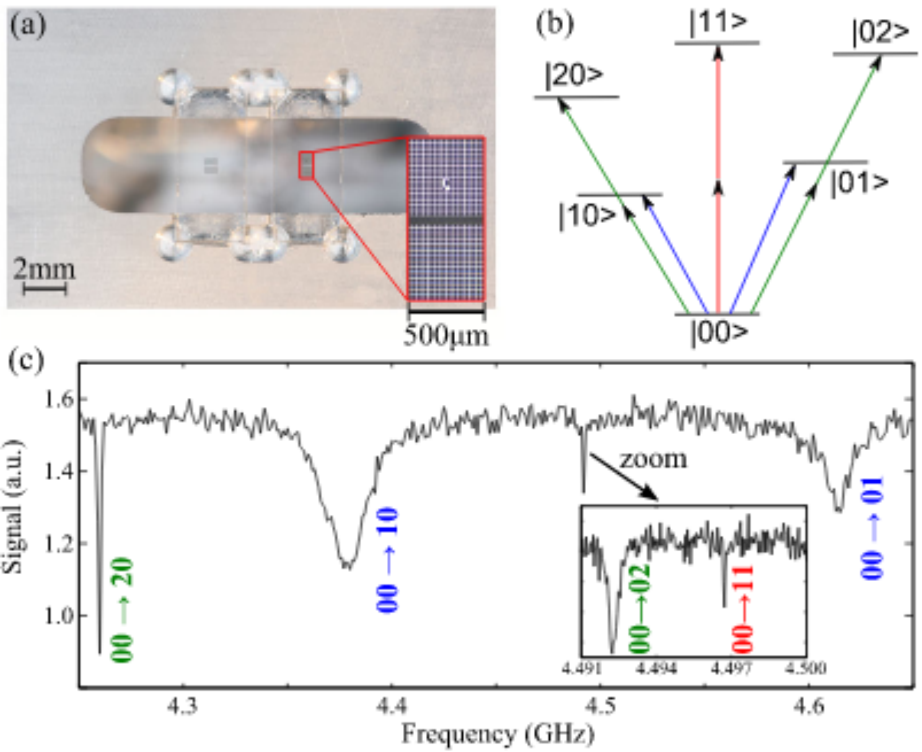


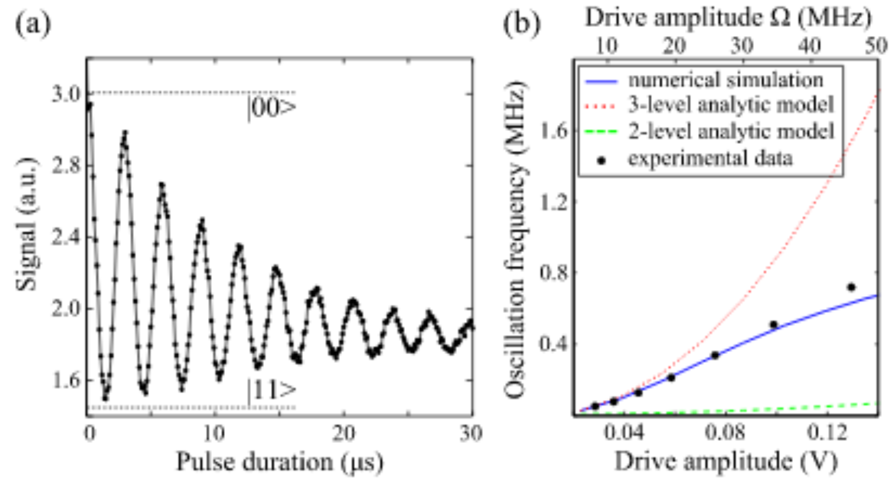
- Can we use this complexity for our purposes?

- Yes.

bSWAP gate

Poletto, S., et al. Physical review letters 109.24 (2012): 240505





$$
U_B(t) = \begin{pmatrix} \cos\left(\frac{\Omega_B t}{2}\right) & 0 & 0 & -ie^{-2i\phi}\sin\left(\frac{\Omega_B t}{2}\right) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -ie^{2i\phi}\sin\left(\frac{\Omega_B t}{2}\right) & 0 & 0 & \cos\left(\frac{\Omega_B t}{2}\right) \end{pmatrix} \tag{2}
$$

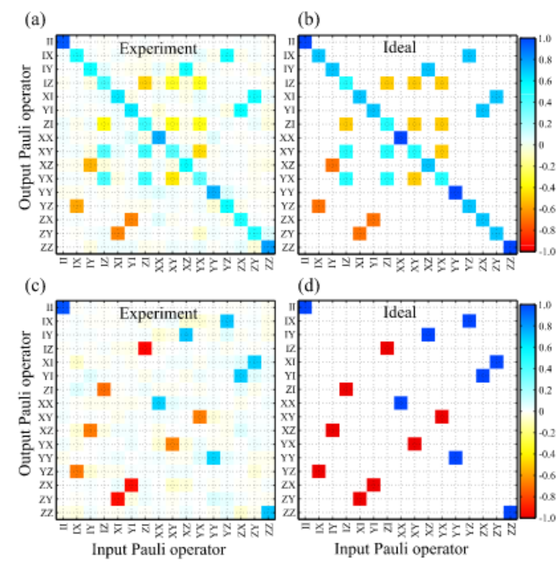
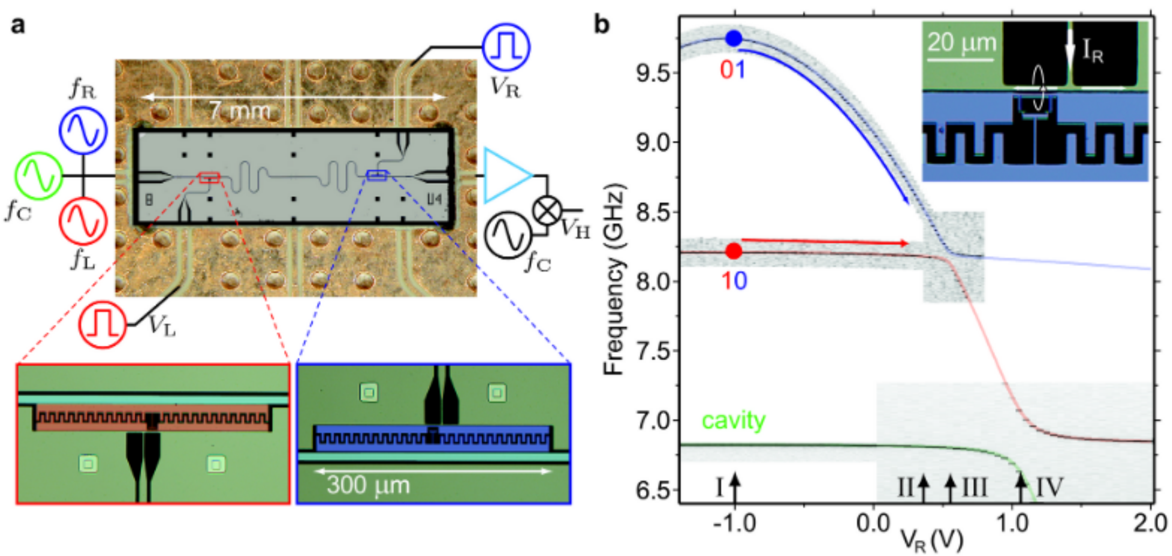
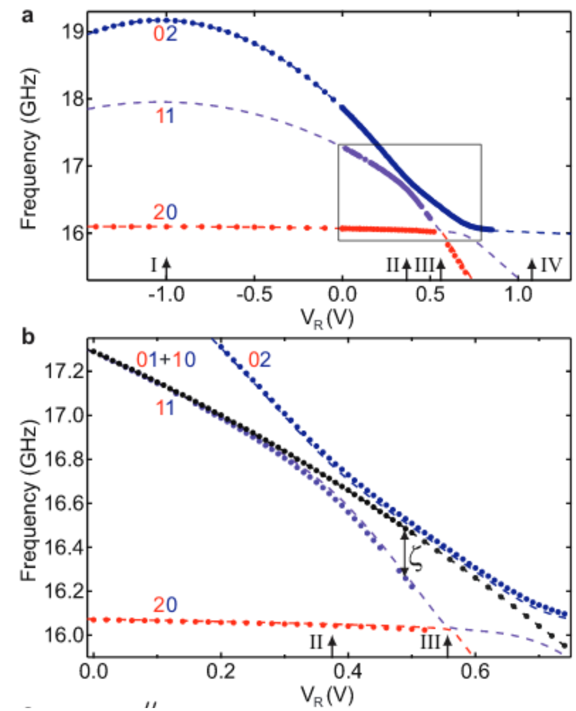


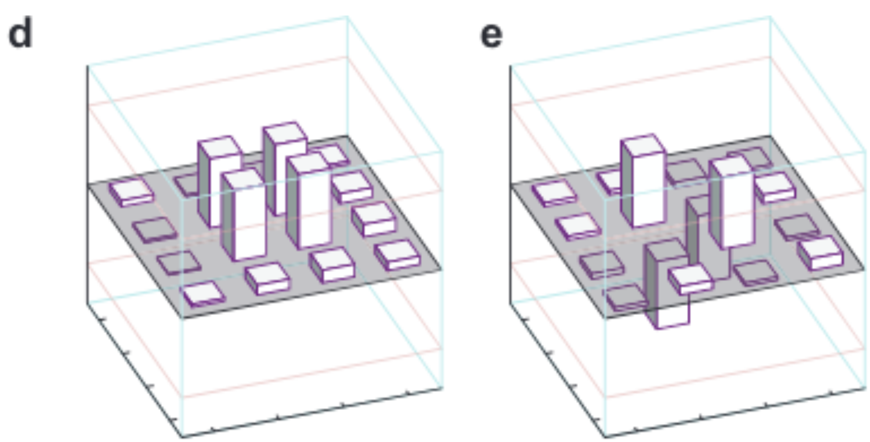
FIG. 4 (color online). Experimental [(a) and (c)] and ideal [(b) and (d)] Pauli transfer matrices for the $\sqrt{\text{bSWAP}}$ [(a) and (b)] and the bSWAP [(c) and (d)] gates.

cPhase gate

DiCarlo, Leonardo, et al. " Nature 460.7252 (2009): 240-244.







$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left(|0,1\rangle + |1,0\rangle\right)$ $|\Phi^-\rangle = \frac{1}{\sqrt{2}}\left(|0,1\rangle - |1,0\rangle\right)$

$$U = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{i\phi_{01}} & 0 & 0 \\ 0 & 0 & e^{i\phi_{10}} & 0 \\ 0 & 0 & 0 & e^{i\phi_{11}} \end{pmatrix}$$

cPhase gate

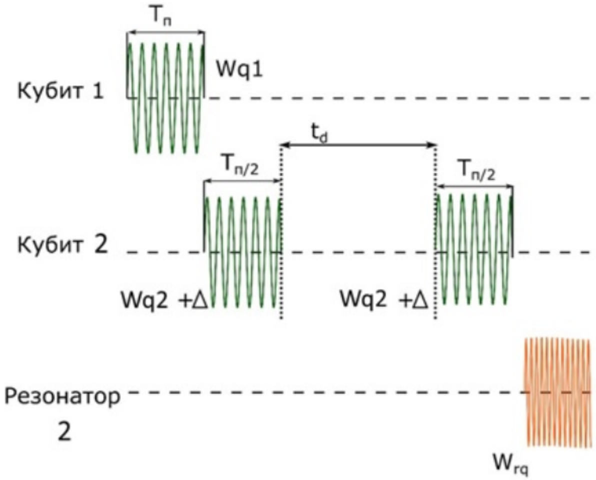
$$\hat{H}^{D}_{\rm sys} = \hbar\left[\tilde{\omega}_1 \hat{b}^\dagger \hat{b} + \frac{1}{2}\delta_1 \hat{b}^\dagger \hat{b}(\hat{b}^\dagger \hat{b} - 1)\right] + \hbar\left[\tilde{\omega}_2 \hat{c}^\dagger \hat{c} + \frac{1}{2}\delta_2 \hat{c}^\dagger \hat{c}(\hat{c}^\dagger \hat{c} - 1)\right] + \hbar J(\hat{b}\hat{c}^\dagger + \hat{b}^\dagger \hat{c})$$

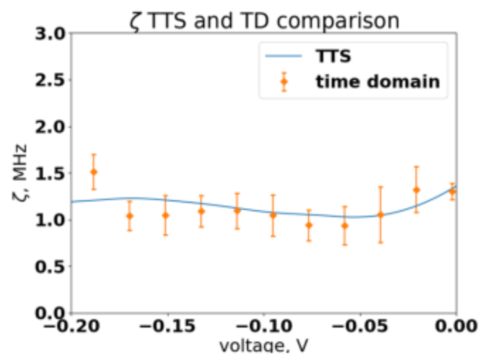
$$\hat{H}^{D_2}_{\rm sys} = -\frac{\omega_1 + J^2/\Delta_{12} + \zeta/2}{2}\hat{Z}\hat{I} - \frac{\omega_2 - J^2/\Delta_{12} + \zeta/2}{2}\hat{I}\hat{Z} + \frac{\zeta}{4}\hat{Z}\hat{Z}$$

$$\zeta = (E_{11} - E_{10} - E_{01})/\hbar = -\frac{2J^2(\delta_1 + \delta_2)}{(\Delta_{12} + \delta_1)(\delta_2 - \Delta_{12})}.$$

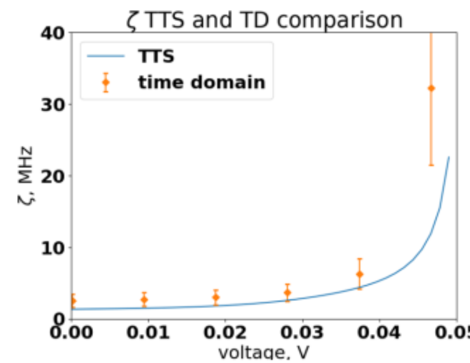
$$\hat{U}_{\rm cPhase}(\theta) = \exp[-i\theta(\hat{Z}\hat{Z} - \hat{I}\hat{Z} - \hat{Z}\hat{I})/4] = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{-i\theta} \end{pmatrix}$$

cPhase gate (MIPT)

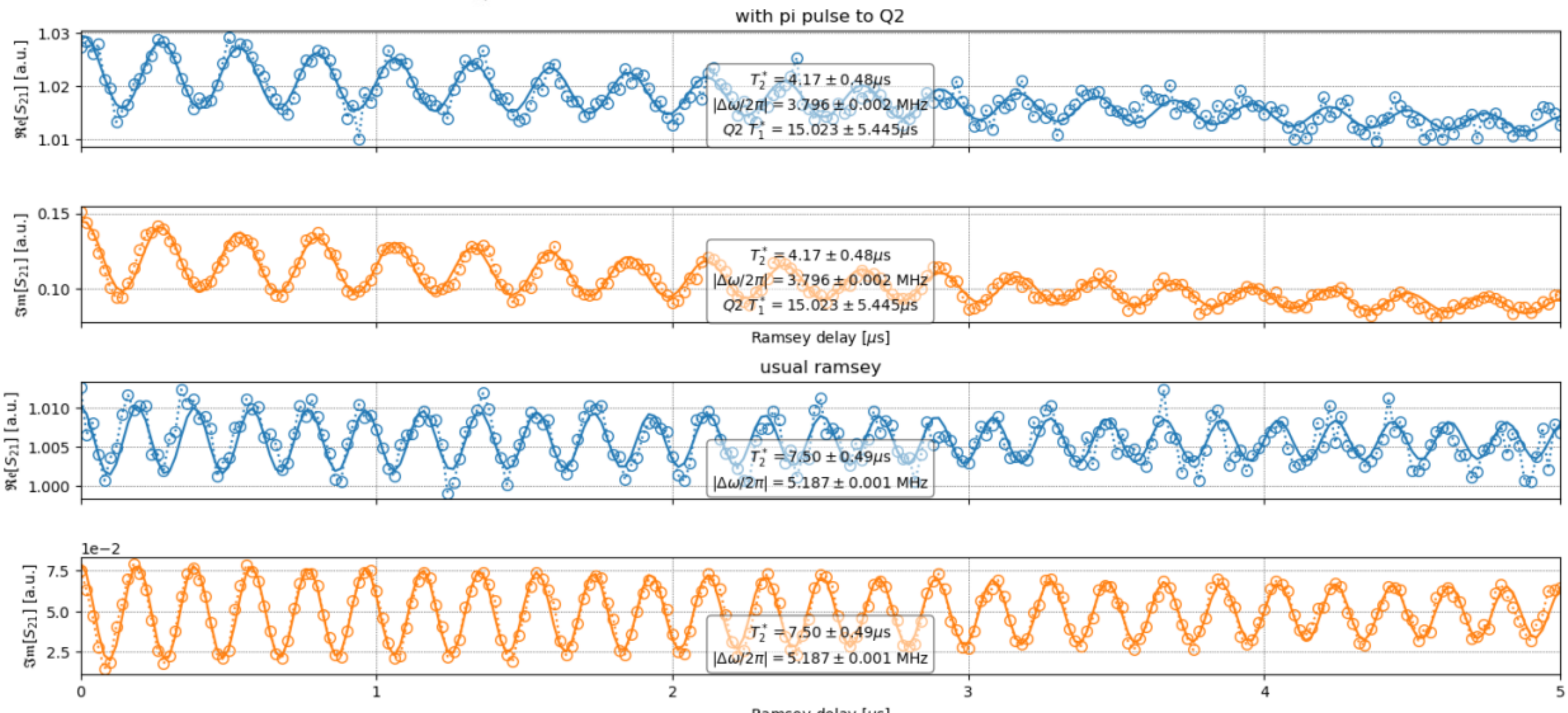


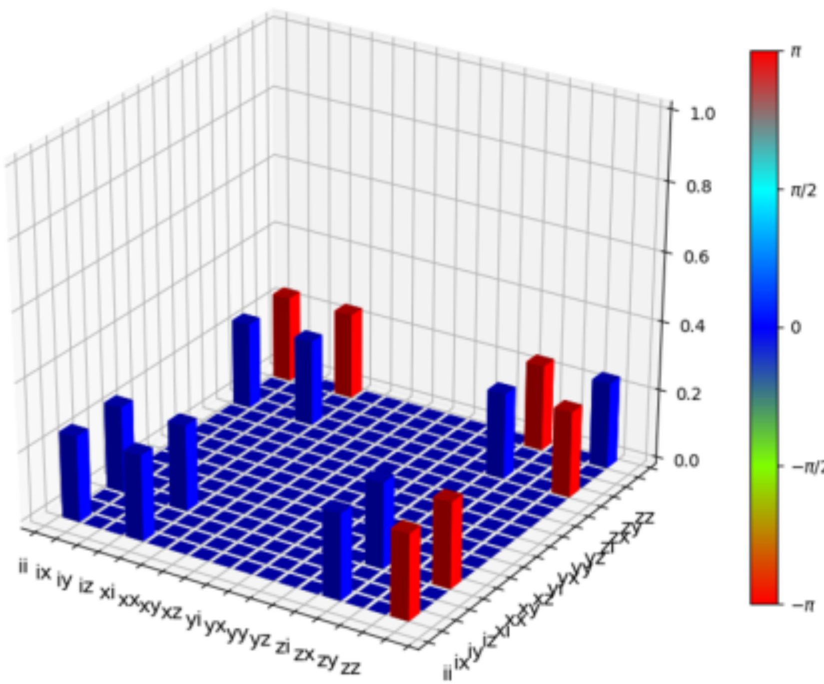


(a)

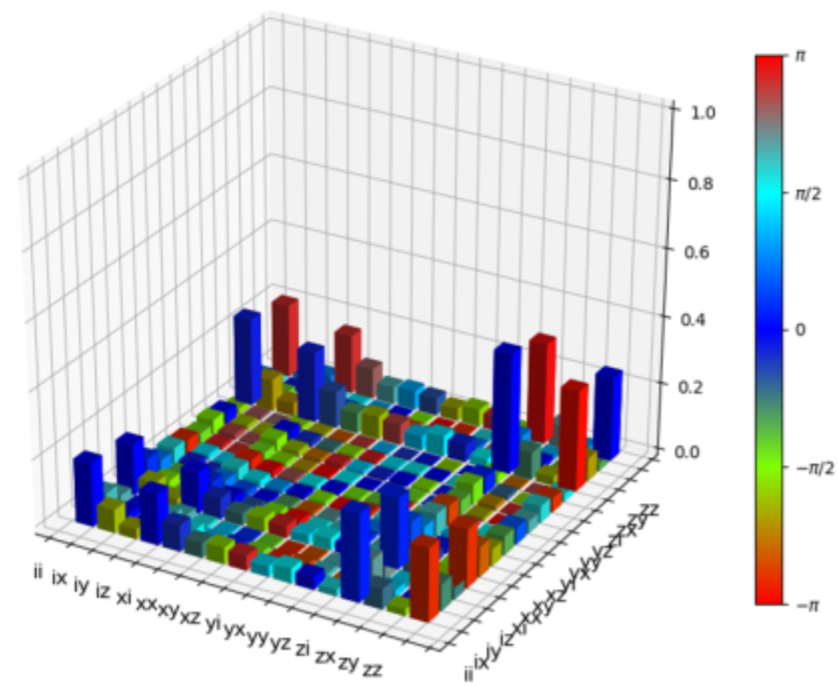


(b)



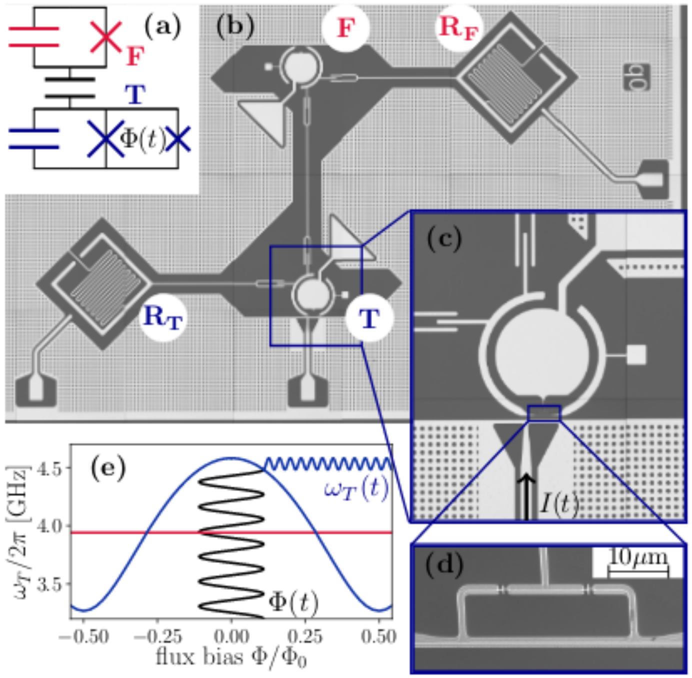


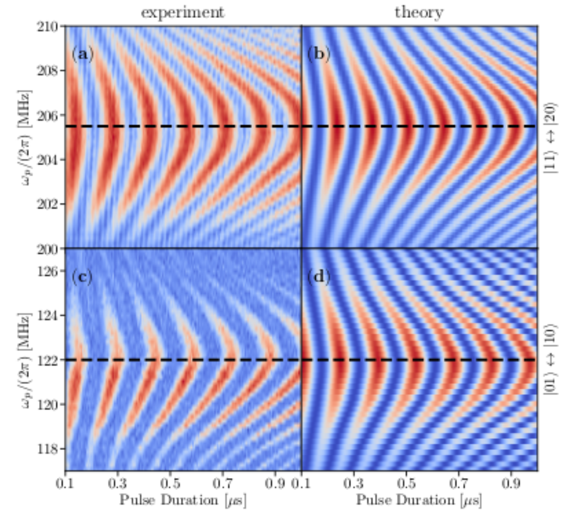
(a) Матрица переноса Паули для гейта CZ, расчитанная по формуле (2.74).

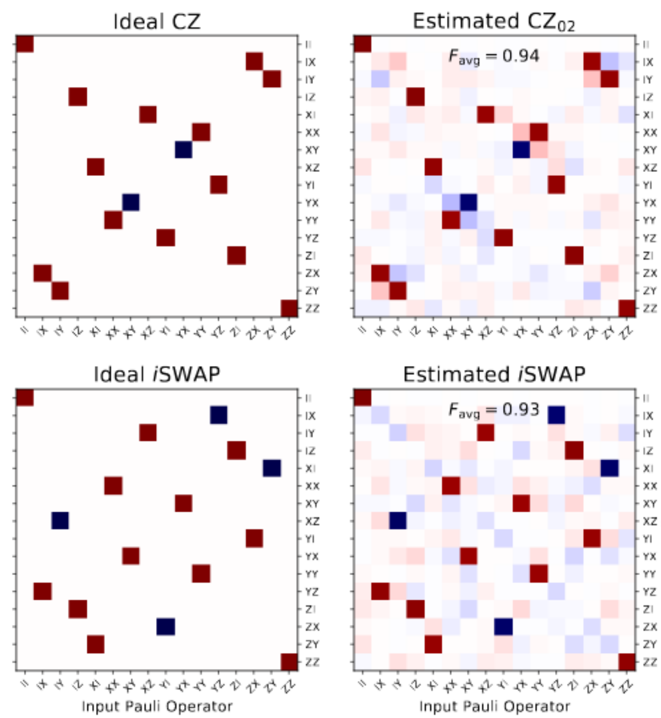


(b) Матрица переноса Паули для гейта CZ, измеренная в ходе томографии процесса. Методика измерений описана в п.2.6.2.

Parametrically activated iSWAP and cPhase gates







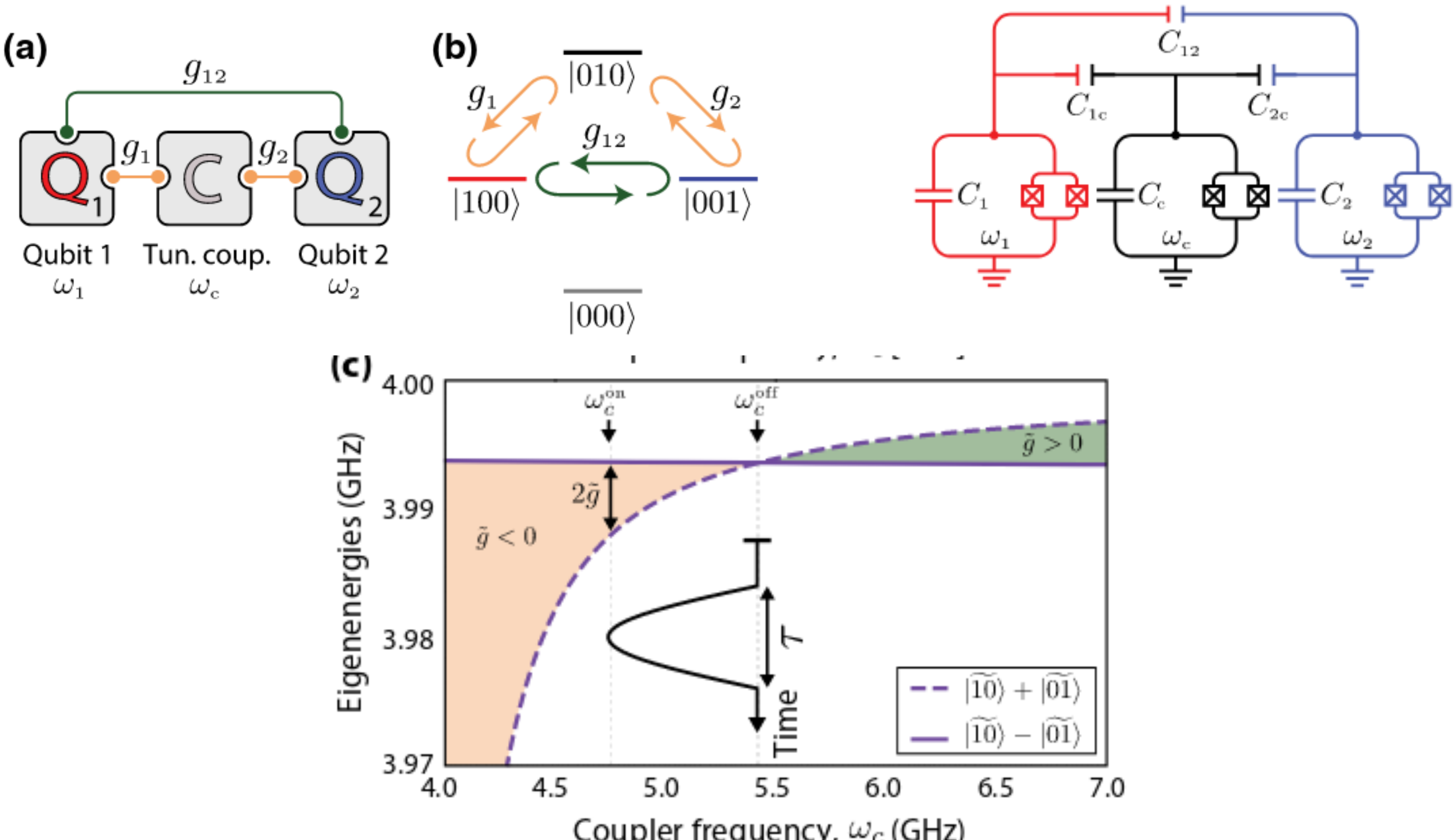
$$\hat{H}_{\mathrm{int}} = g \sum_{n=-\infty}^{\infty} \mathrm{J}_n\left(\frac{\widetilde{\omega}_T}{2\omega_p}\right) e^{i(2n\omega_p t+\beta_n)}$$

$$\times \left\{ e^{-i\Delta t}\,|10\rangle\langle 01| + \sqrt{2}e^{-i(\Delta+\eta_F)t}\,|20\rangle\langle 11| + \sqrt{2}e^{-i(\Delta-\eta_T)t}\,|11\rangle\langle 02| + \mathrm{h.c.}\right\},$$

“Fermionic simulation” gate (iSWAP+cPhase)

Yan, Fei, et al. Physical Review Applied 10.5 (2018): 054062.

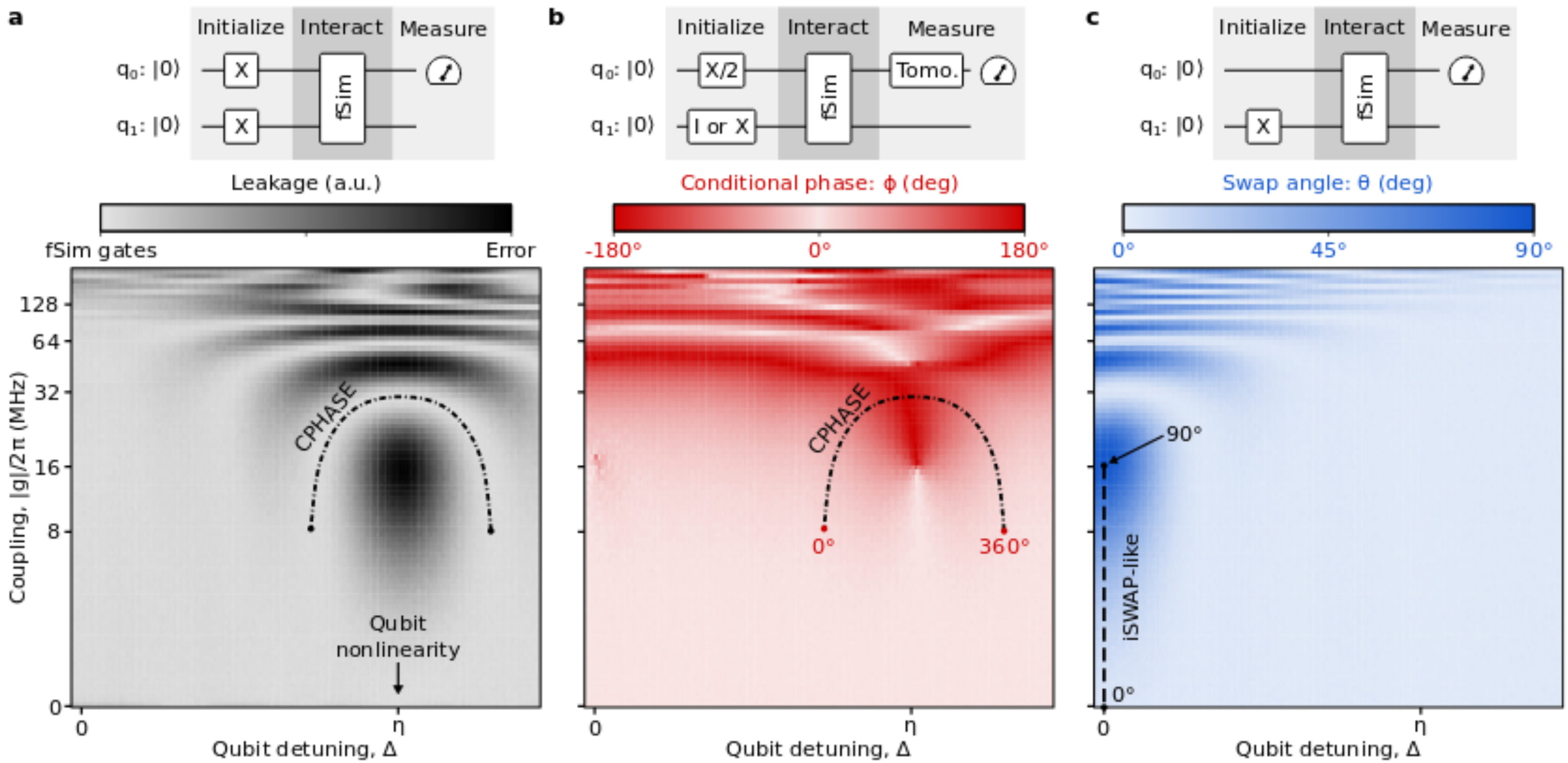
- Tunable coupling is used for this kind of a gate:



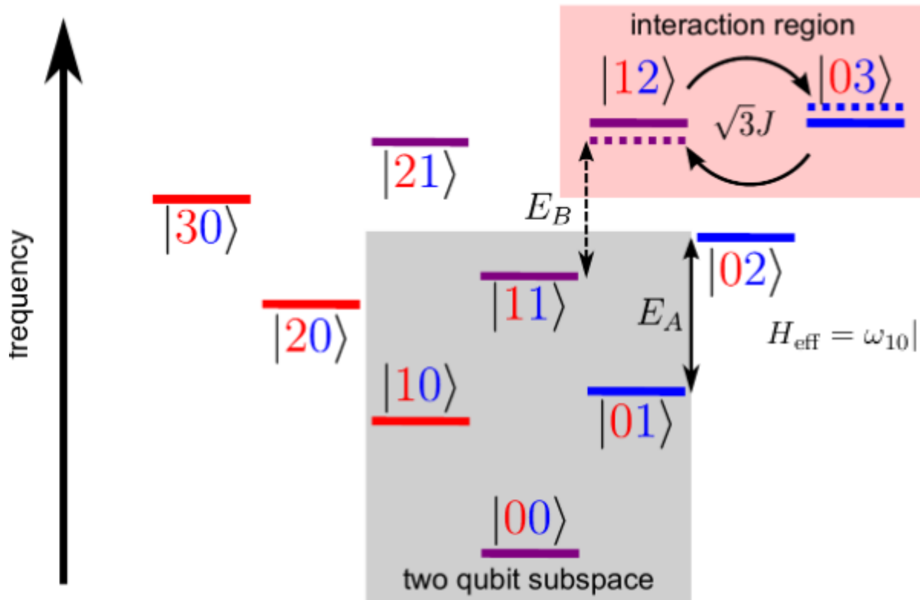
“Fermionic simulation” gate (iSWAP+cPhase)

https://arxiv.org/pdf/2001.08343.pdf

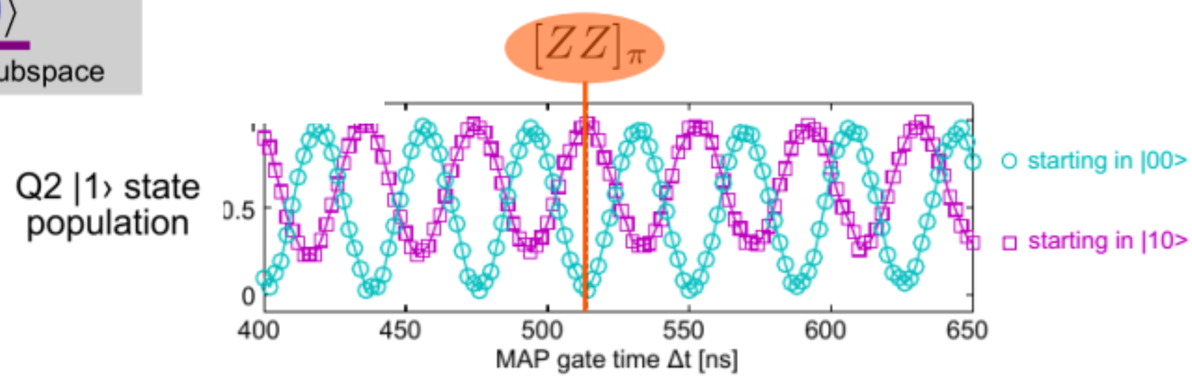
$$\mathrm{fSim}(\theta,\phi) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -i\sin\theta & 0 \\ 0 & -i\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & e^{-i\phi} \end{pmatrix}$$

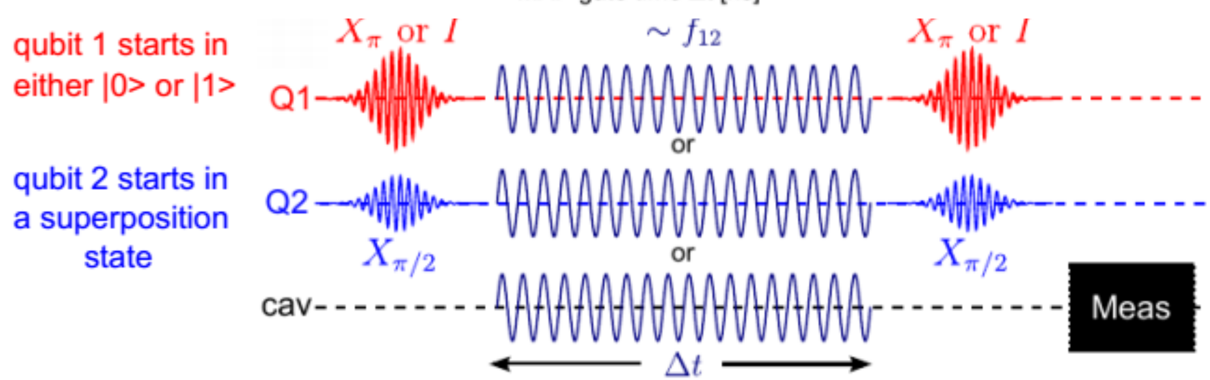


MAP (microwave-activated cPhase) gate



$$
\begin{aligned}
H_{\text{eff}} &= \omega_{10}|1,0\rangle\langle 1,0| + \omega_{01}|0,1\rangle\langle 0,1| + (\omega_{10}+\omega_{01}+\zeta)|1,1\rangle\langle 1,1| \\
&= -\frac{1}{2}\left(\omega_{10}-\frac{\zeta}{2}\right)\sigma_1^z - \frac{1}{2}\left(\omega_{01}-\frac{\zeta}{2}\right)\sigma_2^z + \frac{\zeta}{4}\sigma_1^z\sigma_2^z
\end{aligned}
$$





Fidelity of operations

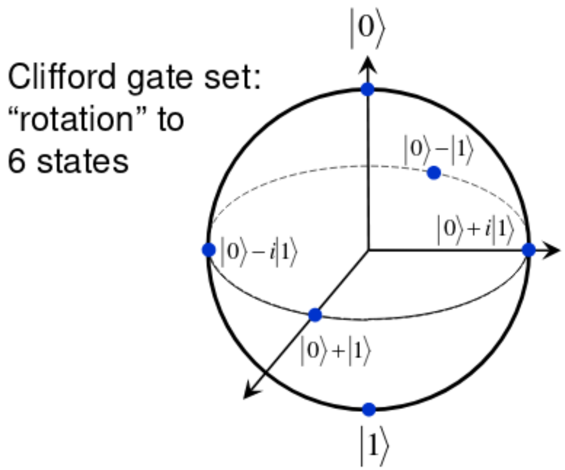
https://arxiv.org/pdf/1905.13641.pdf

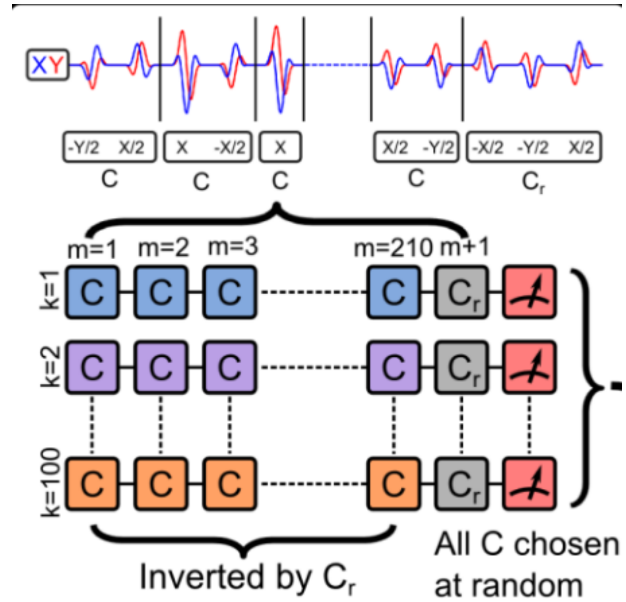
Given two density operators ρ, σ, the fidelity is generally defined as $F(\rho,\sigma) = \left[\mathrm{tr}\sqrt{\sqrt{\rho}\sigma\sqrt{\rho}}\right]^2$

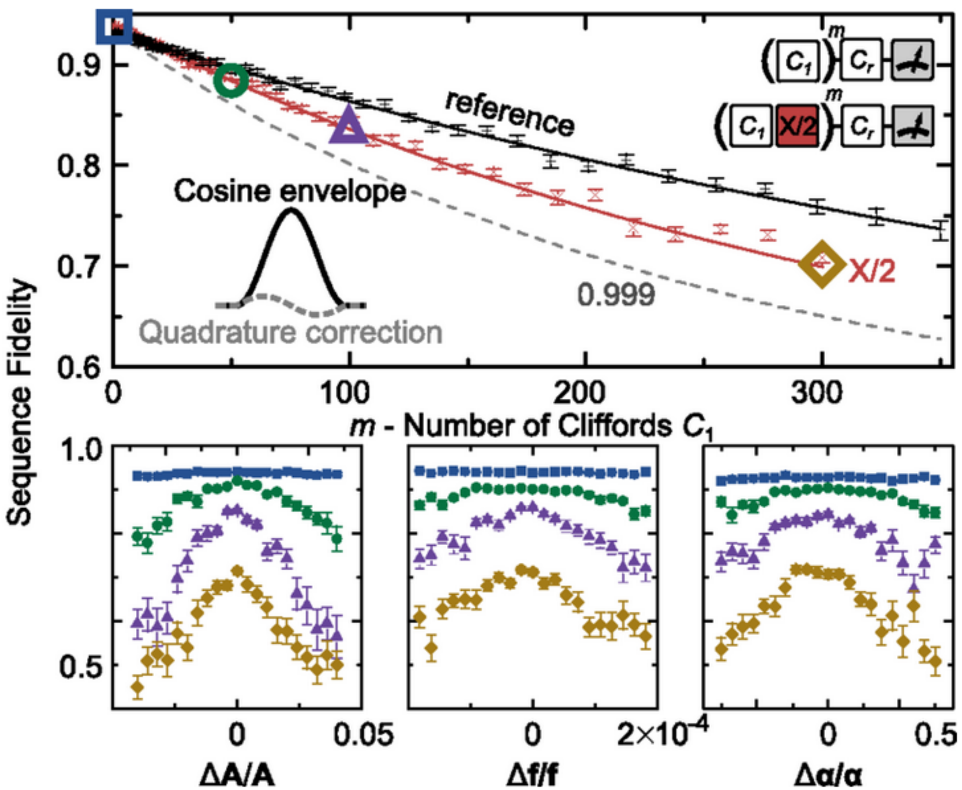
Acronym[a]	Layout[b]	First demonstration [Year]	Highest fidelity [Year]	Gate time
CZ (ad.)	T–T	DiCarlo et al. (72) [2009]	99.4%† Barends et al. (3) [2014] 99.7%† Kjaergaard et al. (73) [2020]	40 ns 60 ns
$\sqrt{\text{iSWAP}}$	T–T	Neeley et al. (81)° [2010]	90%* Dewes et al. (74) [2014]	31 ns
CR	F–F	Chow et al. (75) [2011]	99.1%† Sheldon et al. (5) [2016]	160 ns
$\sqrt{\text{bSWAP}}$	F–F	Poletto et al. (76) [2012]	86%* ibid.	800 ns
MAP	F–F	Chow et al. (77) [2013]	87.2%* ibid.	510 ns
CZ (ad.)	T–(T)–T	Chen et al. (56) [2014]	99.0%† ibid.	30 ns
RIP	3D F	Paik et al. (78) [2016]	98.5%† ibid.	413 ns
$\sqrt{\text{iSWAP}}$	F–(T)–F	McKay et al. (79) [2016]	98.2%† ibid.	183 ns
CZ (ad.)	T–F	Caldwell et al. (80) [2018]	99.2%† Hong et al. (6) [2019]	176 ns
CNOT_L	BEQ-BEQ	Rosenblum et al. (13) [2018]	~99%□ ibid.	190 ns
CNOT_{T-L}	BEQ-BEQ	Chou et al. (82) [2018]	79%* ibid.	4.6 μs

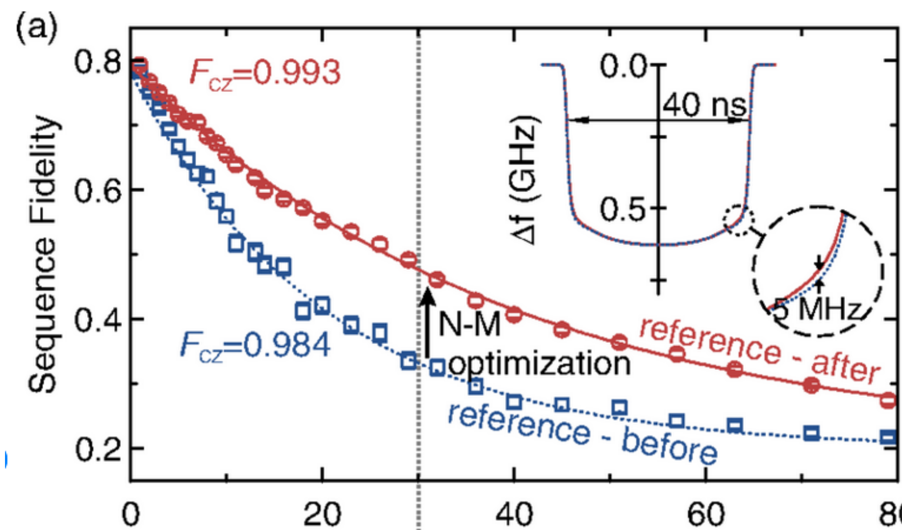
- But how to measure the fidelity when our control itself is inaccurate?
- Randomized benchmarking!

Fidelity of operations – randomized benchmarking





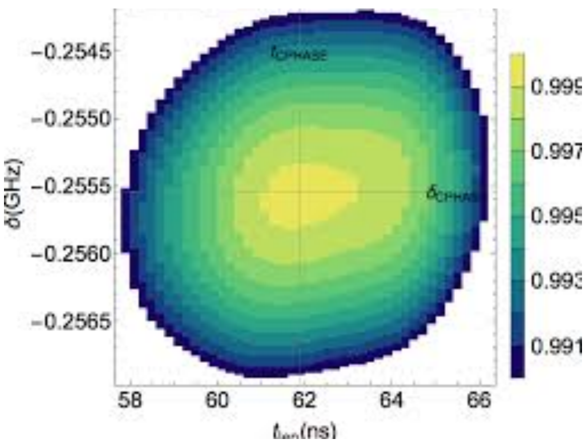


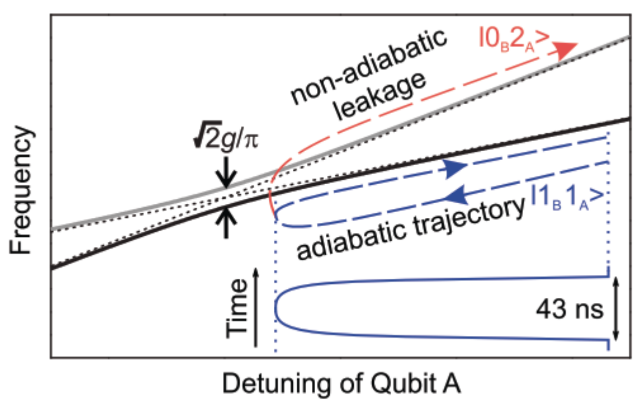


Error sources

Coherent (reversible)

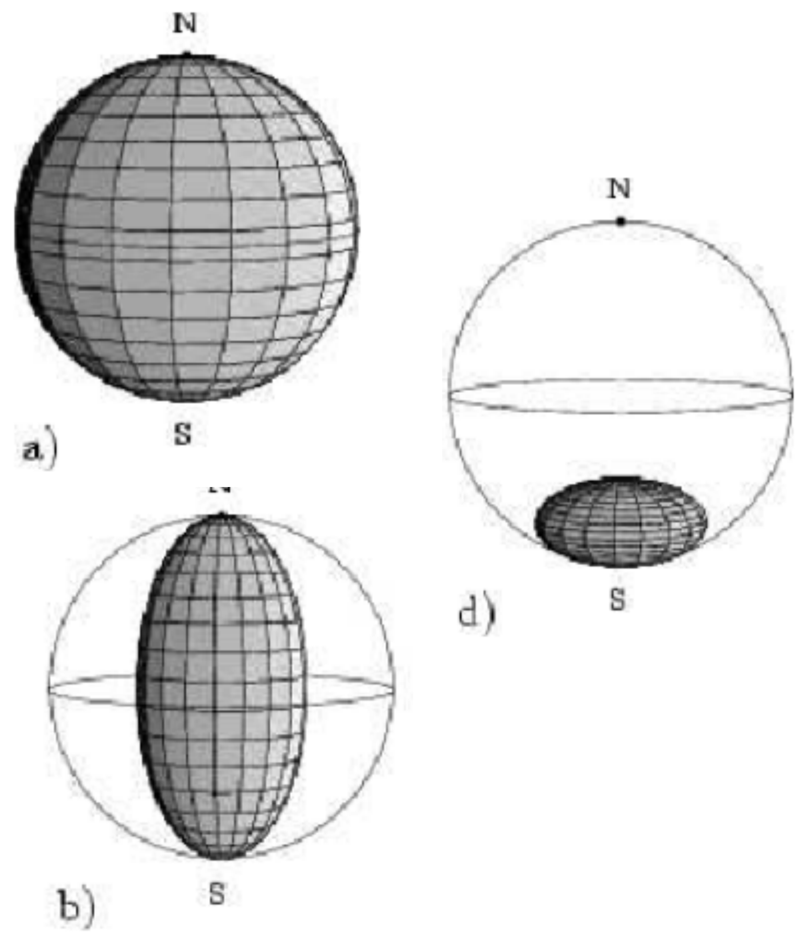
1. Rotation errors
2. Leakage out of the computational basis





Incoherent

1. Relaxation
2. Dephasing



Challenges and perspectives

- Many different two-qubit gates suggested and performed – quantum mechanics is standing tall
- Gates mostly done on transmons
- All fidelities are currently very low (approx. 90-99%)
- Errors mostly come from decoherence

Waiting for superconducting systems with longer lifetimes!

Entanglement power