Two-Qubit Clifford Gates

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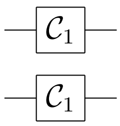
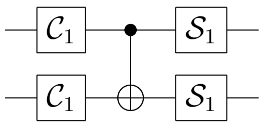
The decomposition of two-qubit Clifford gates is detailed in Ref. [1]. They can be divided into the following four classes.

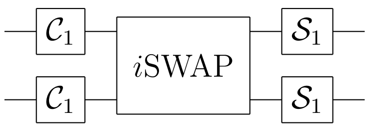
1. $24^2 = 576$ single qubit Clifford gates on each individual qubit.



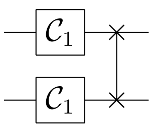
2. $24^2 \times 3^2 = 5184$ "CNOT-like" gates.



3. $24^2 \times 3^2 = 5184$ "iSWAP-like" gates.



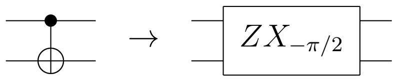
4. $24^2 = 576$ "SWAP-like" gates.

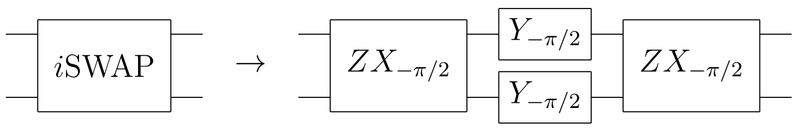


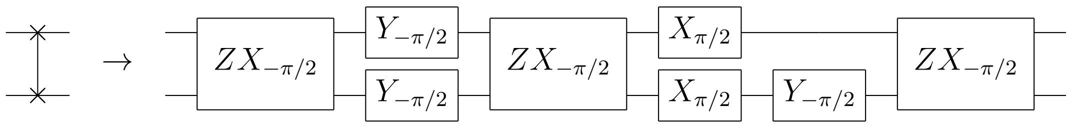
Here $\mathcal{C}_1 = \{C_i, i = 1, \cdots, 24\}$ is the single qubit Clifford group and $\mathcal{S}_1$ is the group $\{I, S, S^2\}$, where $S = \exp[-i\pi(X + Y + Z)/3\sqrt{3}]$. **In our convention for single qubit Clifford gates**, $\mathcal{S}_1 = \{C_1, C_{17}, C_{18}\}$. In total there are $576 + 5184 + 5184 + 576 = 11520$ two-qubit Clifford gates.

For a typical cQED implementation, the CNOT, iSWAP and SWAP gates are decomposed into either cross-resonance ($ZX_{-\pi/2}$) gate [1] or parametric exchange (iSWAP) gate [2], together with some single qubit gates. The single qubit gates at the beginning and end of a decomposition can be incorporated into the pre-$\mathcal{C}_1$ and post-$\mathcal{S}_1$ gates, so it is more convenient to use the following replacement.

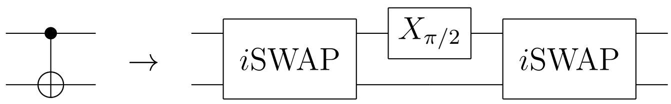
1. $ZX_{-\pi/2}$ based decomposition (See Ref. [1]).

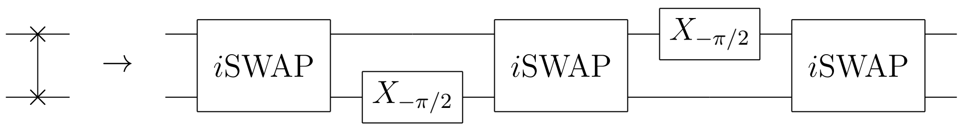






2. iSWAP based decomposition (See Ref. [3]).





References

[1] A. D. Córcoles, J. M. Gambetta, J. M. Chow, J. A. Smolin, M. Ware, J. Strand, B. L. T. Plourde, and M. Steffen. Process verification of two-qubit quantum gates by randomized benchmarking. *Phys. Rev. A* **87**, 030301 (2013).

[2] D. C. McKay, S. Filipp, A. Mezzacapo, E. Magesan, J. M. Chow, and J. M. Gambetta. Universal gate for fixed-frequency qubits via a tunable bus. *Phys. Rev. Appl.* **6**, 064007 (2016).

[3] N. Schuch and J. Siewert. Natural two-qubit gate for quantum computation using the XY interaction. *Phys. Rev. A* **67**, 032301 (2003).