# High-Fidelity Quantum Logic Operations and Entangled Ancilla States

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Abstract: We describe a high-fidelity approach to linear optics quantum computing in which the quantum logic operations always produce an output. A method for generating the required entangled states is also described.
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Knill, Laflamme, and Milburn [1] have shown that quantum logic operations can be performed using linear optical elements, additional ancilla photons, and post-selection based on the results of measurements on the ancilla. Their approach is probabilistic in the sense that the correct logical output is known to have been produced when the measurements on the ancilla yield specific results, which occurs with a probability that scales as $1/N$, where $N$ is the number of ancilla. We have recently proposed an alternative approach [2] in which the logic gates always produce an output with an error that scales as $1/N^2$. We expect that this new approach will be useful in reducing the errors below the threshold for quantum error correction whenever the most general form of errors must be corrected by the code.

Our high-fidelity approach is based on a more efficient form of quantum teleportation in which the probability of an error in the teleportation process also scales as $1/N^2$. The basic procedure is outlined in Figure 1, which shows two input qubits q and q' as well as additional ancilla registers labeled x, y, x', and y'. A quantum Fourier transform is applied to registers q and x as well as to registers q' and x', after which the number of photons in each mode of those registers is measured. After appropriate phase corrections, the teleported qubits appear in specific modes of registers y and y'. As suggested by Gottesman and Chuang, [3] quantum logic operations can be performed by applying the desired logic operation to the entangled ancilla before the teleportation process.

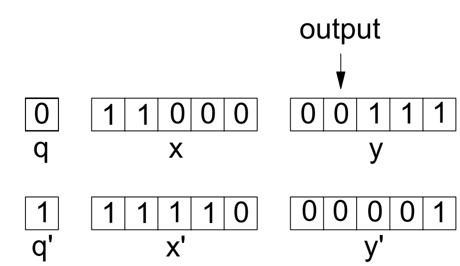


Figure 1. Ancilla registers x, y, x', and y' used to teleport two input qubits q and q' in order to perform a quantum logic operation.

A nonlinear sign flip operation can be performed in this way if the ancilla photons are initially in an entangled state give by

$$\left|\psi_{AA'}\right\rangle = \sum_{j=0}^{n} f(j)\,\left|1\right\rangle^{j}\,\left|0\right\rangle^{n-j}\left|0\right\rangle^{j}\,\left|1\right\rangle^{n-j}\sum_{j'=0}^{n}(-1)^{jj'}f(j')\left|1\right\rangle^{j'}\,\left|0\right\rangle^{n-j'}\,\left|0\right\rangle^{j'}\,\left|1\right\rangle^{n-j'}$$

Here the $f(j)$ are coefficients that are chosen to maximize the fidelity of the output states. A method for generating an entangled state of this form using logic operations similar to those of Ref. [2] will be described.

[1]. E. Knill, R. Laflamme, and G. J. Milburn, Nature **409**, 46 (2001).
[2]. J.D. Franson, M.M. Donegan, M.J. Fitch, B.C. Jacobs, and T.B. Pittman, Phys. Rev. Lett. 89, 137901 (2002).
[3]. D. Gottesman and I. Chuang, Nature (London) **402**, 390 (1999). See also M. A. Nielsen and I. L. Chuang, Phys. Rev. Lett. **79**, 321 (1997).