Design of Coupled Qubit

Personnel

B. Singh, J. Habif, and W. Kaminsky (T. P. Orlando and S. Lloyd)

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The main requirement for the coupled qubits is that the coupled qubit system have 4 distinguishable states corresponding to 4 properly spaced energy levels.

Distinguishability here refers to the possibility of making a distinction between each of the 4 states by measurement. For a fully functioning 2-qubit quantum computer, it is necessary that the 4 qubit states that are functionally orthogonal be experimentally distinguishable. In the current design, the coupled qubits are actualized as two PC qubits weakly coupled by their mutual inductance. In the single qubit case, the DC measurement SQUID measures the state of the qubit through the flux induced in the DC SQUID by the qubit circulating current. The basic idea is unchanged for the coupled qubit system. In this case, there is one DC SQUID that measures the collective state of the coupled qubits through the total induced flux created by both qubits. For example' the |00> state could correspond to qubits 1 and 2 both having counterclockwise circulating current. In this case, the |11> state would correspond to both qubits with clockwise circulating current. If the individual qubits were measurable with the DC SQUID, then the |00> and |11> states of the coupled qubit system should also be measurable because the total qubit flux induced on the DC SQUID is simply the sum of the individual qubit fluxes. The difficulty in measurement comes in differentiating the |01> and |10> states.

A difference in the measured flux from the |01> and |10> states can come from a difference in the mutual inductance between the individual qubits and the measurement SQUID and/or a difference in the magnitude of the circulating current for the two qubits. Currently, it is not practical to achieve the separation of flux states from adjusting mutual inductance values. Therefore, the approach has been to create two qubits with differing circulating current magnitudes. The magnitude of the circulating current is determined by the size of the junctions. Our analysis shows that there are 6 acceptable qubit parameter choices given the fabrication constraints for a single qubit. Since there are 2 qubits in the coupled qubit system, there are a total of 15 possible "distinct" coupled qubit combinations. Not all of these 15 possibilities are practical, because some still require rather large qubit-SQUID coupling for distinguishability between the |01> and |10> states. The qubit-qubit and qubit-SQUID mutual inductance are parameters that can be varied through choices in geometry. As in the single qubit case, there are inherent tradeoffs in deciding on the appropriate size of the coupling.

The need for properly spaced energy levels comes from the mode of operation of the qubit. The qubits will be rotated, be it individually or collectively, through RF radiation of the appropriate frequency. In the first round of experiments, the signal will come from an off-chip oscillator. For the full functionality of the couple qubit system, it is required that there be 4 non-degenerate energy levels corresponding to the |00, |01, |10, and |11 states and that the 6 possible state transitions have sufficiently different resonant frequencies. If these conditions are met, then pulses with the appropriate linewidth would be able to do universal quantum computation on the 2-qubit system, including the "CNOT" operation. Following along the previous assumption that the coupled qubit system is accurately described as two individual qubits with weak mutual inductive coupling, it should be clear that the |00 and |11 states (corresponding to both qubits in the ground or excited states) should be well separated in energy. To meet the other requirements on the energy levels, the qubit-qubit mutual inductive energy needs to be sufficiently large and the qubits need to have different junction sizes. The latter requirement is already necessitated by the measurement limitations. The former represents another tradeoff in the design, as there are problems if the coupling is too strong. Beyond the aforementioned desiderata, it is necessary that the magnitude of these resonant frequencies be practical for experiments.

For the current fabrication run, there are 6 coupled qubit designs. An effort was made to span the acceptable parameter space for the tradeoffs mentioned above.