SUPERCONDUCTING FLUX QUBITS

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Superconducting Qubits

A useful quantum computer should contain thousands of quantum bits with the associated driving and read-out circuitry. Solid state quantum bits are of particular interest because they are most naturally connected to the nanofabrication techniques developed for electronic integrated circuits. In general it is difficult in solid state devices to isolate two quantum states from the multitude of electronic and bosonic degrees of freedom. Superconductivity provides the advantage that all electrons are condensed into a single quantum state, separated by a considerable gap. In the last years considerable progress has been made in the development of superconducting qubits. One distinguishes charge qubits [1,2], phase qubits [3,4] and flux qubits [5,6,7,8]. In all types, extreme care in designing the driving and measuring circuitry has to be taken to prevent relaxation between the states and dephasing. The theoretical understanding of decoherence is well enough advanced to optimize this aspect, leading to an attractive window for operation. However, in practice uncontrolled fluctuations with an approximate 1/f spectrum lead to stronger dephasing and the relative merit of qubit types is strongly influenced by phenomena due to defects. Recently, first experiments on coupled superconducting qubits have been published [9].

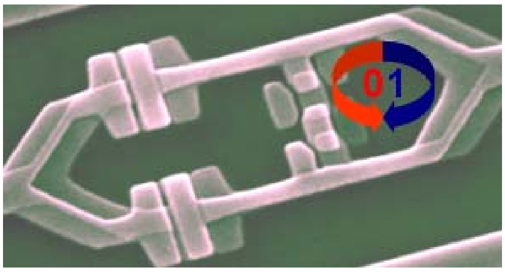
Flux qubits

In flux qubits, a superconducting ring with Josephson junctions is biased at a flux near half a superconducting flux quantum and the states are fluxoid states connected with circulating persistent currents of opposite direction. They are well decoupled from the charge noise that is abundantly present in practical circuits. In Delft, we study a type that contains three junctions. It does not require the loop's geometric inductance to define the two states and can be made small. Transitions between the two states are induced by resonant microwave signals. With continuous radiation, the level splitting can be determined spectroscopically [7]. From such measurements the ocurrence of superpositions of the macroscopic states could be determined, invoking references to Schrodinger's cat.

Coherent quantum dynamics

More recently, we studied coherent quantum dynamics of a three-junction flux qubit. The sample is shown in figure one. The qubit and the SQUID are integrated and share a large fraction of their loops. The circulating current in the qubit reduces or enhances the critical current of the SQUID. Reversely, the fast measurement on the SQUID shifts the qubit bias so that quantum operation and readout can each be performed at their optimum bias point.

Fig. 1. Flux qubit (small loop with three junctions on the right, integrated with measuring SQUID (large loop with two larger junctions).



With this sample, it was possible to observe Rabi oscillations (Fig.2). With strong drive, more than 300 oscillations could be seen. The Rabi frequency depends linearly on microwave amplitude, as indicated by theory. We applied multiple pulse sequences to determine the decoherence time and found 20 ns for the dephasing (T2) time, while the relaxation (T1) time was 900 ns. We expect that these times can be improved very considerably. We performed measurements with 10 SQUID readings per point, which clearly showed the Rabi oscillations. Even with single shot read-out the oscillations could be recognized.

Two coupled qubits

We performed first measurements on a system of two coupled qubits. Read-out was performed with a single SQUID surrounding both qubits and determining the sum of their magnetizations. Spectroscopic measuremnts were performed with a microwave drive that influenced both qubits. The effect of the coupling could be seen in the results.

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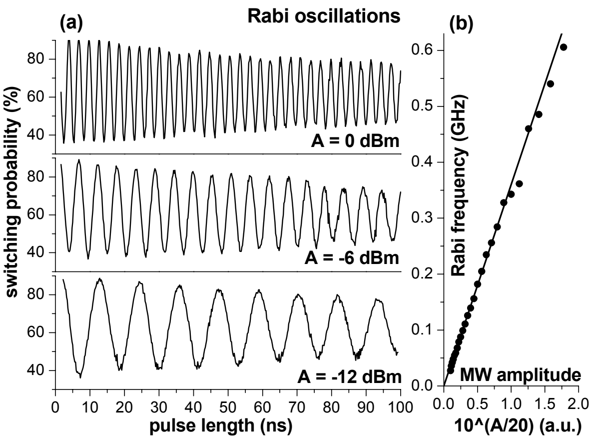

Fig. 2. Rabi oscillations: SQUID signal versus pulse length for three different micro-wave amplitudes. Right hand: Rabi fre-quency versus microwave amplitude.

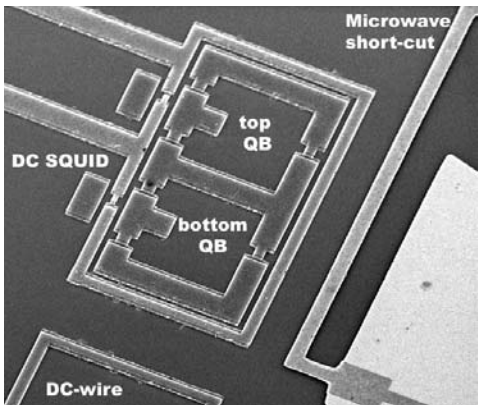

Fig. 3. Two coupled flux qubits. The qubits are surrounded by the SQUID loop.