NMR-like control of a quantum bit superconducting circuit

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The Quantronium [1] is a superconducting quantum bit circuit (Fig. 1) based on small Josephson junctions in which decoupling from the external circuit ensures a long coherence time. The state of the qubit is manipulated using resonant microwave pulses, or adiabatic pulses on the control parameters of the circuit Hamiltonian. We demonstrate here that NMR methods can be efficiently used for manipulating the qubit and probing decoherence mechanisms [2].

First, we have shown that arbitrary transformations can be implemented by combining microwave pulses. Two pulse sequences with different phases, that implement rotations around orthogonal axes, have been performed. The overall agreement with theory shows that rotations combine as expected (Fig; 2). We have addressed the issue of transformation robustness using the composite pulses developed in NMR. We have shown in particular that the CORPSE sequence efficiently compensates for of resonance effects.

In order to investigate decoherence mechanisms acting in the quantronium, we have developed new methods to probe quantum coherence. In particular, we have used two pulse experiments with a temporary change of the working point during the time delay between the two pulses, and implemented echo experiments (see Fig 3).

We have also measured decoherence during driven evolution in presence of microwaves. We have measured the decay of Rabi oscillations, and of the spin-locking polarisation following the usual spin-locking protocol in NMR (see Fig 3). We find that the decay time of Rabi oscillations and of the spin-locking polarisation can be longer than during free evolution coherence time.

These driven regime and spin echo experiments rise the question of increasing the effective coherence time; which is a central issue for qubits.

[1] D. Vion et al., Science 296 (2002).
[2] E. Collin et al., cond-mat/0404503
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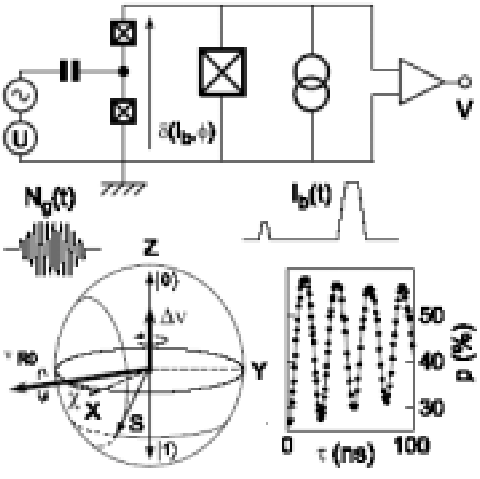

Fig 1: top: circuit diagram of the quantronium. The Hamiltonian is controlled by two parameters: the charge coupled to the box island between the two small junctions, and the phase across their series combination. The qubit state is manipulated by applying resonant microwave pulses, or adiabatic pulses on the control parameters. The oscillations of the switching probability of the readout junction reveal the Rabi oscillations of the qubit state.

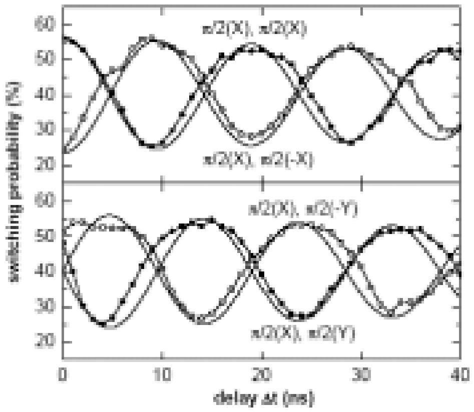

Fig.2: Switching probability after two $\pi/2$ pulses with different phases, corresponding to different rotation axes. The Ramsey patterns are shifted as predicted for each phase combination. This experiment proves that rotations can be combined in order to implement any qubit transformation.

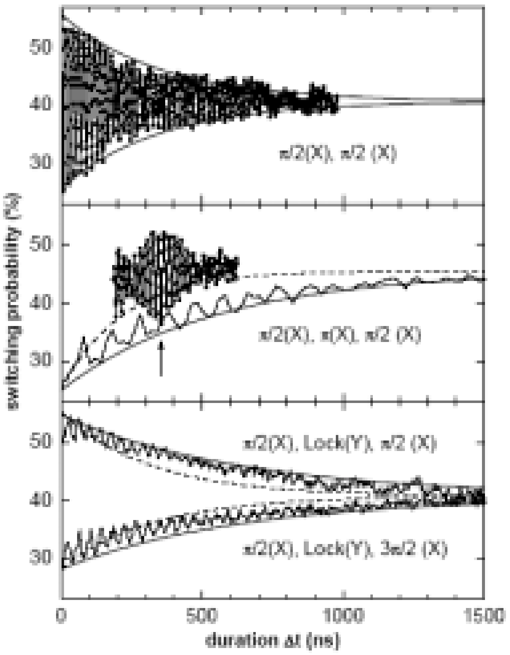

Fig. 3: Top : switching probability (dots) after a Ramsey $\{\pi/2(X), \pi/2(X)\}$ sequence as a function of the time delay between pulses. Fits of the envelope (time constant 350 ns). Middle: example of echo measured in a $\{\pi/2(X),\ \pi(X),\ \pi/2(X)\}$ sequence. Thin line: echo signal at the nominal minimum position. bold line: exponential fit of the envelope (550 ns time constant). dashed line: fit of the lower envelope of the Ramsey pattern measured in the same conditions (220 ns time constant). Bottom: switching probability after two spin-locking sequences, as a function of the sequence duration. Thick lines: exponential fits of the envelopes, with time constant 650 ns. The dashed lines show a fit of the envelope of the Ramsey pattern measured in the same conditions (time constant : 320 ns).