READOUT OF FLUX QUBITS

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In this talk, we report the observation of the readout of a superconducting flux qubit comprising three Josephson junction in a superconducting loop.

We first talk about the observation of multiphoton transition between superposition states of macroscopically distinct states [1]. The observed distinct resonant peaks and dips are attributed to situations, in which the effective energy separation between the ground and the first excited states matches an integer multiple of the RF photon energy. Based on this technique we have achieved multi-photon Rabi ocsillations up to four photons. The Rabi frequency as a function of microwave strength clearly showed Bessel-function dependnences J_n (n=1,2,3,4). We also have succeeded in parametric operations [2]. By using two-frequency microwave pulses, we have observed Rabi oscillations stemming from parametric transitions between the ground state and first excited states when the sum or the difference of the two microwave frequencies matches the Larmor frequency of the qubit (Fig. 1).

Resonant microwave pulse methods induce coherent quantum oscillations between these macroscopic quantum states, e.g., Rabi oscillations or Ramsey fringes**.** We have observed Larmor precession (11.4 GHz) of a flux qubit with the phase shifted double pulse method. This new method provides an arbitrary unitary transformation of a single qubit with a rapid control (~10 GHz) of the flux qubit [3]. Compared with the previous method (detuning one), the new method can save time for each quantum-gate operation and results in a 10-100 times faster gate operation than the previous one.

The operation of a single qubit is almost accomplished for many types of solid state qubit. The next target is of course to achieve entangled state using coupled two qubits. It is very promising to analogically apply the so-called cavity QED to a superconducting device coupled with a microwave cavity. It is because we can use many sophisticated methods established in atom physics. We have achieved the coupling between the flux qubit and a LC-resonator (microwave cavity see Fig. 2) and observed red and blue sideband resonance. We demonstrated Rabi oscillations at the red and blue sidebands. Moreover we have confirmed vacuum Rabi oscillations in time domain [4] (Fig. 3). These clearly indicate that entangle states are generated between two macroscopic quantum systems.

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[4] J. Johannson, S. Saito, T. Meno, H. Nakano, M. Ueda, K. Semba and H. Takayanagi, Phys. Rev. Lett. **96**, 127006 (2006).

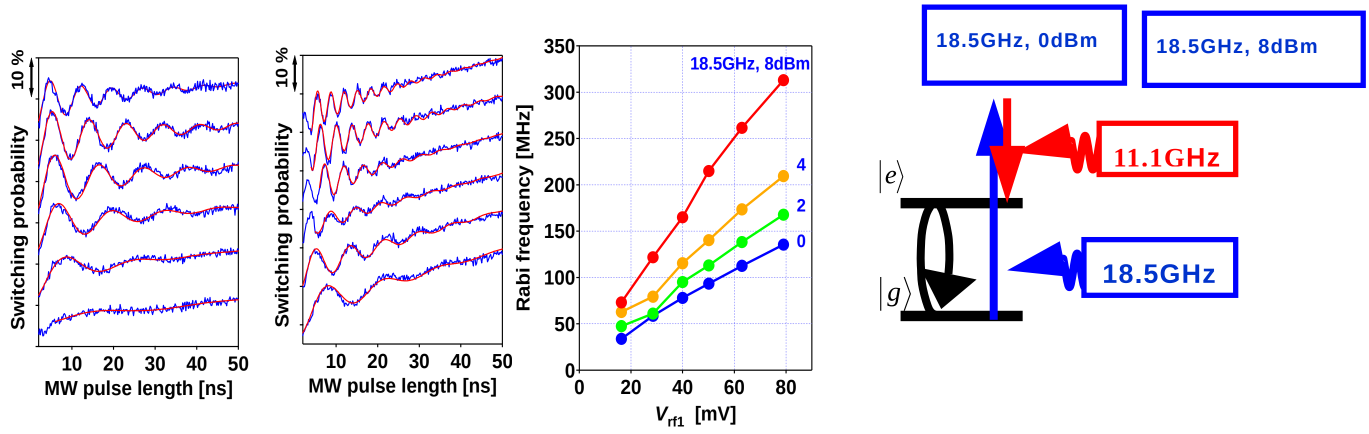

Fig. 1. Observed Rabi oscillations with two colors, two photons and difference frequency.

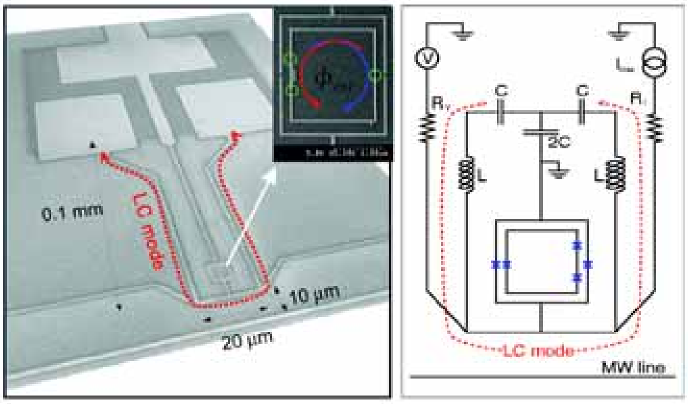

Fig. 2. Flux qubit and a LC-resonator.

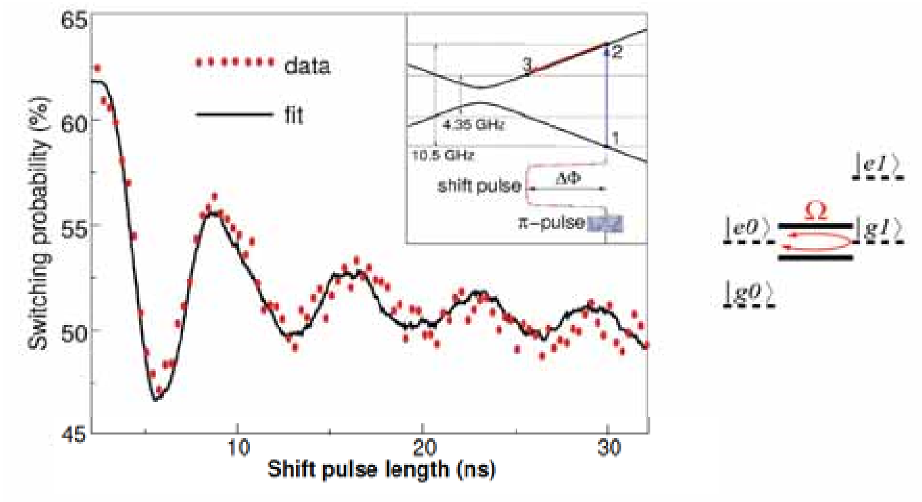

Fig. 3. Observed vacuum Rabi oscillation.