Simulation of the entangled states generation of two qubits by using of unipolar picoseconds pulses

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Recently the superconducting circuit quantum electrodynamics is an actively developing field, in which significant progress has been achieved in the manipulation of quantum bits (qubits). One of the interesting directions in this area is the use of new generation of energy-efficient logic family for fast read-out and control of quantum registers [1,2].

In this paper, we are going to study the simplest two qubits register whose transition frequencies are located in the micro- or millimeter ranges, and the times of longitudinal and transverse relaxation are microseconds [1]. It is well known that in this field of quantum logical manipulation usually the Rabi-technique is involved. We propose here a new approach for the implementation of quantum logic which is based on the control of the qubit system by unipolar sub-nanosecond solitary-like pulses of the rectangular shape. Such kind of magnetic field pulses may be generated by fluxons in transmission lines [2]. The analysis was carried out by numerical solution of the master equation for the density matrix operator and the populations of qubit levels were calculated. It was shown that the optimal way to control a system of two qubits can be achieved when two control pulses with proper delay may be applied. Hamiltonian for two coupled flux qubits can be represented as

$$H(t) = -\frac{1}{2}\left(\varepsilon_1(t)\sigma_z^{(1)} + \Delta_1\sigma_x^{(1)}\right)\otimes I^{(2)} - \frac{1}{2}I^{(1)}\otimes\left(\varepsilon_2(t)\sigma_z^{(2)} + \Delta_2\sigma_x^{(2)}\right) - \frac{1}{2}J\sigma_z^{(1)}\otimes\sigma_z^{(2)} \quad (1)$$

where Δ_i is tunnel splitting in the i-th qubit ($i=1,2$), $\Delta_2 = \Delta_1 + \delta\Delta$, where $\delta\Delta << \Delta_i$, J is the interaction constant. We used square pulses $\varepsilon_i(t) = A_i\left(\theta(t+t_{in,i}) - \theta(t-t_{off,i})\right)$, where A_i is an amplitude, $t_{in,i}$, $t_{off,i}$ are the turn-on and turn-off times for the pulse, which determine the duration $\tau_i = t_{off,i} - t_{in,i}$. The relaxation dynamics of the system in the Born-Markovian approximation is described by the equation for the density matrix [3].

It is interesting to study the initialization of Bell's states, which are very important for the implementation of two-qubit quantum logic. The Bell states are four specific maximally entangled quantum states for two qubits. In this case, the intermediate states of the qubit system have the same the level populations $W_2(t) = W_3(t) \sim 0.5$. The degree of entanglement (the concurrence) of the individual qubits states is maximal: $C(\rho) \to 1$ [4]. In Fig. 2 it is shown that it is possible to select parameters for the Bell states generation. At the same time, the degree of entanglement reaches its maximum value.

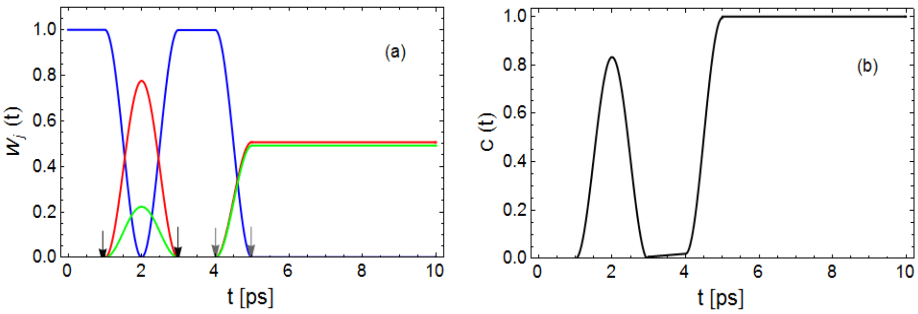

Figure 2. Evolution of the level populations Wj of two coupled qubits in the recording of Bell states (a) and the dynamic of the concurrence C(t) (b). The blue curve characterizes the behavior of $W_1(t)$, the red curve – $W_2(t)$, the green – $W_3(t)$, the black – $W_4(t)$.

In this paper, we showed that by varying the parameters of such impacts (amplitude, duration), one can realize initialization of the nonlocal entangled states. These ranges of operating parameters were obtained numerically, based on the solution of the master equation. The effects of quantum noise on these manipulations were studied and it was found that decoherence affects only when the duration of the signal is increased (i.e., at times $1/\gamma_i \sim 0.1$ μs). The degree of entanglement (the concurrence) was estimated and it was demonstrated that for Bell states it can be realized with accuracy of up to 98%, and in nonlocal states with an accuracy of 99%.

[1] M. H. Devoret and R. J. Schoelkopf, *Science* **339**, 1169-1174 (2013).
[2] D. V. Averin, K. Rabenstein, and V. K. Semenov, *Phys. Rev.* B **73**, 094504 (2006).
[3] M.O. Scully, M.S. Zubairy. *Quantum Optics* (Cambridge University Press, 1997).
[4] W. K. Wootters, *Phys. Rev. Lett.* **80**, 2245 (1998).