Properties of the Cooper pair shuttle

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Very recently, Gorelik *et al.* [1] proposed a very appealing setup, the Cooper pair shuttle, able to create and maintain phase coherence between two distant superconductors. It consists in a superconducting SET transistor where the metallic grain is driven in a periodic motion between the two electrods. The shuttling effect manifests in the fact that there is charge transport even though the grain, during is motion, is always in contact with only one of the elecrodes. Because of the superconducting electrodes, the shuttle does not only carry charge, as in the normal metal case, but it also establishes phase coherence between the superconductors. This is witnessed by the presence of a steady stste Josephson current.

We analyze how the presence of the environment affects the coherent transport, both in the average current and its moments, in the Cooper pair shuttle [2]. For the environment we consider the case when this is determined gate voltage fluctuations. The expression of the Josephson current depends on the phases of the superconducting electrodes, on the dynamical phases acquired during the motion of the central island and on the dephasing rates. Depending on the value of the dynamical and superconducting phases the critical current can be negative, i.e. the system can behave as a π-junction. An analysis of the critical current as a function of the dephasing rates reveals another interesting aspect: the Josephson current is a non-monotonous function of the damping the Josephson current can *increase* on increasing the coupling to the environment. The typical behaviour of the Josephson current as a function of the phases is shown in Fig.1

Cooper pair shuttling is a result of a non equilibrium steady state process. Therefore, to better characterize the transport, we analyzed supercurrent noise fluctuations. This should be contrasted with the standard Josephson effect, where the supercurrent is an equilibrium property of the system. Finally, we briefly discuss the finite frequency spectrum in the case of strong dephasing. Superimposed to the peak at the Josephson energy, there are oscillations of frequency of the order of period. The presence of these oscillations is related to the periodicity of the island motion. The modification of these fringes as a function of the phases is a signature of the coherence in the Cooper pair shuttle.

The full-counting statistics was analyzed by one of us in [3].

A possible experimental test of our results which does not require any mechanically moving part. The time dependence of the Josephson couplings can be regulated by a time dependent magnetic field and gate voltage, respectively. The setup consists of a superconducting nanocircuit in a uniform magnetic field. By substituting the Josephson junction by SQUID loops, it is possible to control the E_J by tuning the applied magnetic field piercing the loop. A configuration with three type of loops with different area, allows to achieve the require time dependence by means of a *uniform* magnetic field. This implementation has several advantages. It allows to control the coupling with the environment by simply varying the time dependence of the applied magnetic field. The time scale for the variation of the magnetic field should be controlled at the same level as it is done in the implementation of Josephson nanocircuits for quantum computation.

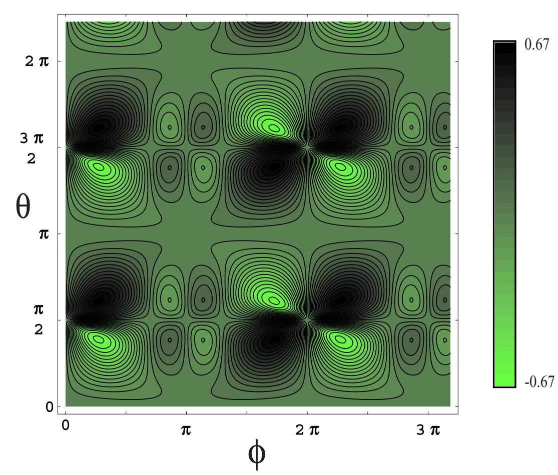

FIG. 1: Supercurrent (in units of e/T) as a function of the superconductor phase difference ϕ and of the phase accumulated during the contact to one of the electrodes θ.

In the limit in which the Josephson energy is much larger than the charging energy, the Cooper pair shuttle implements [4] a paradigm model for quantum chaos, the quantum kicked rotator. In this limit one can study dynamical localization and by further coupling the shuttle to a Cooper pair box it is possible to measure the dynamical fidelity as suggested in [5].

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