Theory of superconducting nanostructures

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The kicked rotator is a paradigm model in classical and quantum chaos. The chaotic regime of the classical rotator is characterized by the exponential separation of nearby trajectories, with rate given by the maximum Lyapunov exponent, and chaotic diffusion in the momentum variable.

The classical-like diffusive behavior is destroyed by quantum interference effects, leading to a dynamically localized state after the localization time.

Despite the long-standing interest in the quantum kicked rotator, only few proposals have been put forward and the only experimental implementation so far has been realized with cold atoms exposed to time-dependent standing waves of light.

We explored the possibility to realize the quantum kicked rotator by means of a superconducting nanocircuit. We analyzed the chaotic dynamics of a periodically driven Superconducting Single Electron Transistor and show that under appropriate conditions it reduces to a "generalized" kicked rotator as the external phases of the superconducting electrodes can be used to tune the quantum dynamics of the superconducting device.

The system we consider, illustrated in the figure 1, is very closely related to the Cooper pair shuttle but it operates in the regime where the Josephson coupling is much larger than the charging energy. The capacitive coupling to a Cooper pair box is needed for the measurement of the fidelity. The Cooper pair shuttle is a superconduct device composed by a small superconducting island coupled to two macroscopic leads. The couplings to left (L) and right (R) electrodes are time dependent with period 2T, and the island is never connected to both leads simultaneously. The two leads are macroscopic and have definite phases $q_{R/L}$ while the superconducting island is described by the number n of excess Cooper pairs present on it.

For later times quantum interference effects (upper panel in the figure 2) suppress this chaotic diffusion: the wave function is exponentially localized in the charge basis. The fluctuations of the charge in the central island saturate. The localization length can be further tuned by

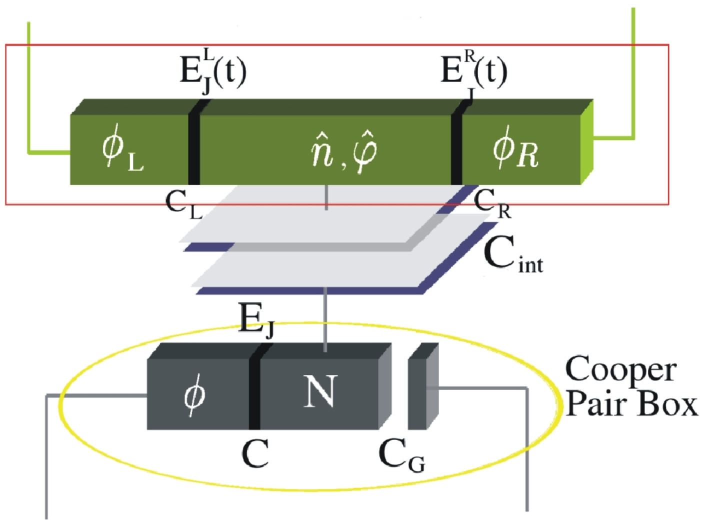

Fig. 1
Schematic drawing of a Cooper pair shuttle (square red box) capacitively coupled to a Cooper pair box.

changing the phase difference as shown in the lower panel of the figure.

We would like to comment on the experimental feasibility of our proposal. Due to physical constraints, in the proposed setup we cannot explore the whole parameter space. By choosing the duration of the kicks of the order of 10^{-10} sec and the charging energy $E_C \sim 10^{-8}$ eV, we can access parameter values corresponding to interesting physical regimes. For instance we can observe dynamical localization for times between the kicks of the order of 10^{-8} sec and Josephson couplings of the order of 10^{-4} eV.

The setup proposed in this work allows to measure also the fidelity defined as the overlap between the initial and final state of the system when it evolves with a given Hamiltonian for a time t and then evolves backward with a slightly shifted Hamiltonian. A study of the fidelity allows the experimental investigation of exponential instability of quantum motion inside the Ehrenfest time scale, chaotic diffusion and quantum dynamical localization.

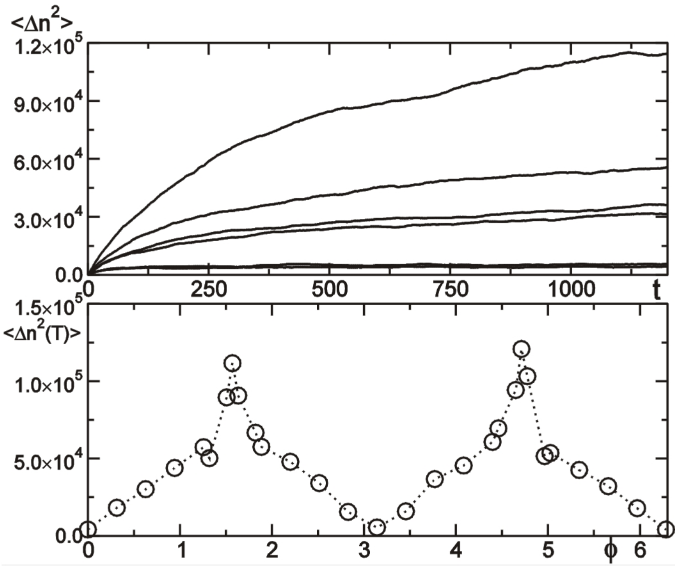

Fig. 2
Upper figure: fluctuation of the charge on the island as a function of time for different values of the phase difference $f = f_L - f_R$.
Lower figure: Saturation value of $(Dn)^2$ as a function of f .

References
[1] "Chaotic dynamics in superconducting nanocircuits", S. Montangero, A. Romito, G. Benenti and R. Fazio, Cond-mat/0407274
[2] "Full counting statistics of Cooper pair shuttling", A. Romito and Yu.V. Nazarov, Phys. Rev. B 70, 212509 (2004)