Flux-assisted adiabatic single-island Cooper pair pump (sluice)

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Fast and accurate pumping of charge in Josephson junction circuits poses a twofold problem. On one hand the speed is typically limited by the magnitude of Josephson coupling E_J due to Landau-Zener crossing, whereas errors due to supercurrent leakage and quantum interference effects increase with increasing E_J. Moreover, simultaneous suppression of the latter two is difficult due to their mutually orthogonal dependence on Josephson phase difference. To circumvent these apparent problems we propose and test an alternative device concept, the Cooper pair sluice, shown schematically in Fig. 1.

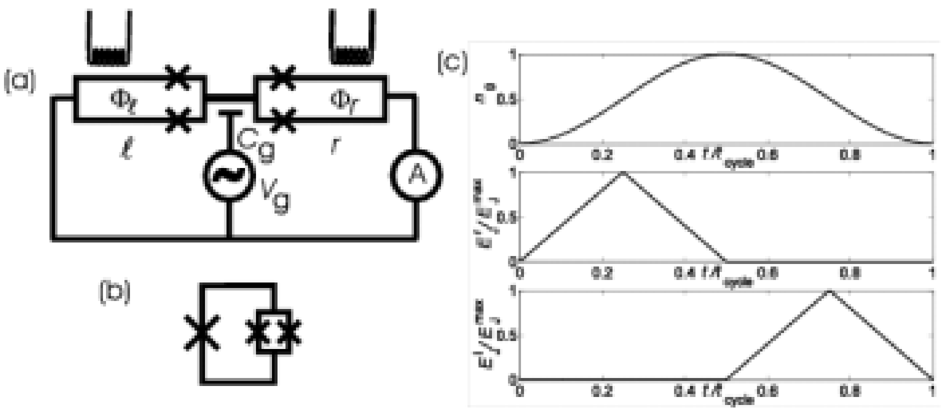

Figure 1. (a) Basic configuration of a Cooper pair sluice. (b) Three junction SQUIDs for better suppression of Josephson coupling. (c) Gate and flux cycles to pump one Cooper pair from right to left through the island.

The central idea of the sluice is to vary the Josephson couplings in time in order to allow fast charge transport when necessary but to suppress leakage contributions at other times. Therefore the sluice consists of two tunable mesoscopic junctions (DC-SQUIDs), with just one island in between [Fig. 1 (a)]. An example of an operating cycle is shown in Fig. 1 (c). Initially the system is in the neutral charge state with n_g (gate charge) and Josephson couplings E_{Jr} and E_{Jl} set to zero. Thereafter one of the Josephson couplings E_{Jr} is tuned adiabatically to maximum, and simultaneously n_g is ramped up also. In the middle of the cycle E_{Jr} has been turned off again. At this moment when $E_{Jr} = 0$ again, exactly one pair (or in general an integer number of pairs depending on the amplitude of n_g) has been brought from the right source to the central island. In the second half of the cycle the pair(s) is (are) taken out through the left SQUID in a similar fashion.

We demonstrate theoretically that it is possible to obtain a current as high as 0.1 nA at better than ppm accuracy using a sluice (and standard aluminium technology). We discuss the influence of imperfect suppression of the Josephson coupling and the finite operating frequency.

Figure 2 shows scanning electron micrograph of the SQUIDs and input coils of the sluice in (a) and a blow-up of the island region in (b). The tickmark in (b) is 1 μm long. The two-dimensional flux-modulation of the supercurrent through the sluice in (c) indicates better than 90 % suppression of Josephson couplings and only very weak cross-coupling between the SQUIDs and their input coils.

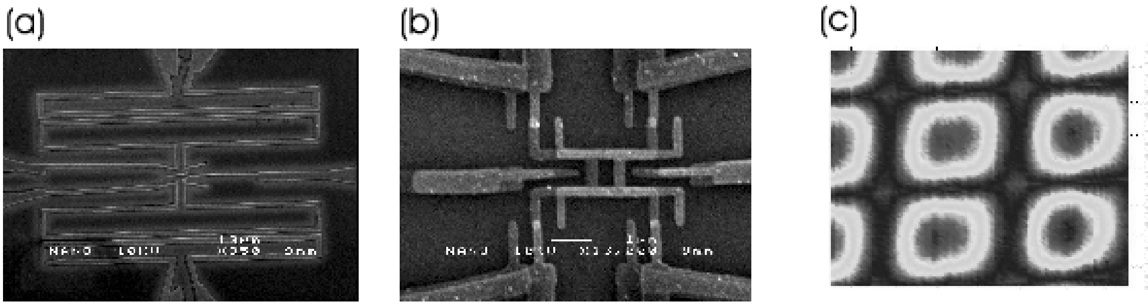

Figure 2. (a) and (b) show a fabricated sluice structure. Supercurrent through the sluice plotted against the two applied fluxes (i.e., currents in the input coils).

The first pumping measurements have demonstrated the operation of the device but still with non-optimal circuit parameters.