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TOWARDS METROLOGICAL STANDARD OF ELECTRICAL CURRENT AND OBSERVATION OF THE BERRY PHASE

We study a Cooper-pair pump, a structure assembled of tunable Josephson junctions, as a potential candidate for metrological standard of electrical current. The two important quantities in electrical measurements, voltage and resistance, are determined by standards based on quantum phenomena in microstructures. The existence of a standard of electrical current would, in particular, enable one to combine these three into the so-called quantum triangle and thus to check their self-consistency.

In this kind of devices the charge pumped through the Josephson junction array is closely related to the geometrical phase accumulated in the ground state of the Hamiltonian. Indeed, adiabatic temporal evolution induces a complex geometrical phase of the quantum state in the non-degenerate subspace, which is referred to as Berry phase. To date, the Berry phase has been observed for example in systems of electrons circulating about a wire carrying electric current known as Aharonov-Bohm effect, and in systems of neutrons or molecules circulating about a line of electric charge known as Aharonov-Casher effect. In superconducting circuits the yet unrealized observation of the Berry phase reduces into detection of low currents.

Our aim is to theoretically analyze the measurement scheme for the charge-pumping. The ultimate goal is to develop an accurate source of electric current for metrological purposes and to perform a quantitative measurement of the Berry phase according to theoretical predictions.

The work on standard of electrical current is performed in collaboration with MIKES and VTT Microsensing.

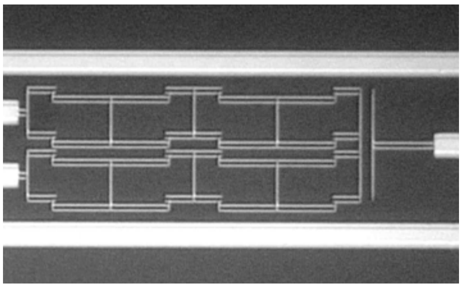

Figure a) A Cooper- pair pump. Controlling the magnetic field through the loops in the middle and manipulating the charge by voltage on the gate on the right, we generate electric current through the device.

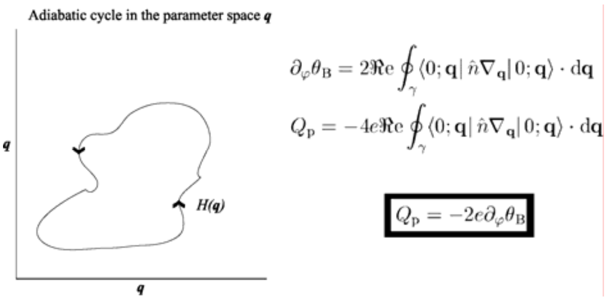

Figure b) Generation of Berry phase. While a closed path is traversed in the parameter space, the Berry phase accumulates in the ground state of the Hamiltonian. The pumped charge is manifested as a detivative of this geometric phase.

Shot noise measurements in Josephson junction circuits

Generally the accuracy in measuring a physical quantity is limited by its fluctuations. These fluctuations originate from thermal and quantum motion of matter and its discreteness. The spontaneous random current and voltage fluctuations in electronic devices are usually called noise. Noise yields fingerprints of a mesoscopic conductor beyond those obtained from conductance measurements. On the other hand, some noise sources depend on the technology used in manufacturing the devices, and, in principle, can be eliminated by technological improvement. The physics of fluctuations is, therefore, especially important in understanding the transport mechanisms and in developing highly sensitive devices.

Josephson junctions can be used as very sensitive threshold detectors of electrical current. We perform measurements of the influence of shot noise in Josephson tunnel junctions (Fig.1). A smaller junction in its normal state is used as the shot noise source, while the larger junction or a SQUID acts as a threshold detector. The escape threshold current from superconducting into the resistive state decreases monotonically with increasing average current through the noise source. Escape is predominantly determined by excitation due to the wide-band shot noise. This process is equivalent to thermal activation (TA) over the barrier at temperatures up to about four times above the critical temperature of the superconductor. The presented TA model is in excellent agreement with the experimental results [J. Pekola et.al. Physical Review Letters **95**, 197004 (2005)].

Presently, the focus in experiments is in measuring higher moments of current fluctuations and noise due to the phase diffusion of Josephson junctions.

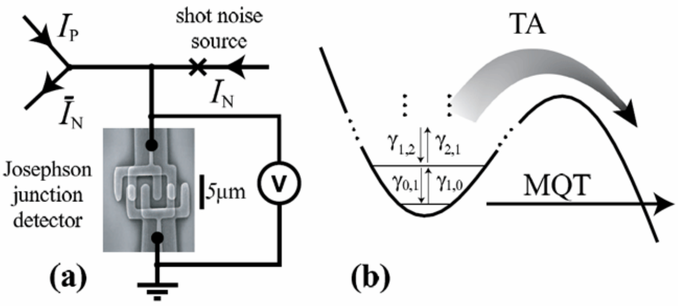

Fig.1 (a) Measurement scheme. Current I_N runs through the noise source. The DC-component of I_N is compensated such that there is no DC current due to I_N passing through the detector. Thus, only the fluctuations of I_N are admitted through the detector. These fluctuations are probed by applying repeatedly trapezoidal pulses of height I_P through the detector. (b) Schematic presentation of thermal activation and macroscopic quantum tunneling regimes of detector escape to normal state out from the Josephson washboard potential well.

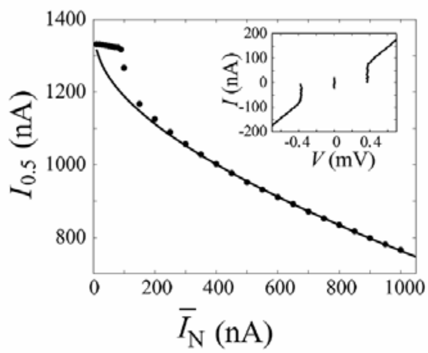

Fig.2 Experimental results (dots) and theoretical fit (solid line) on the switching threshold current against the average current I_N through the shot noise source. *Inset* IV- haracteristic of the noise source junction.

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