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ZERO APPLIED FORCE MAGNETIC FLUX NOISE IN JOSEPHSON JUNCTION ARRAYS

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Abstract

We present zero applied force magnetic flux noise occurring in a Josephson junction array (10^6 junctions) as a function of temperature and applied static magnetic field. The spectral density of the flux noise power $S_\phi(\nu, T)$ is $1/\nu^\alpha$-like with $\alpha \approx 1$ in the range of our observation. As a function of temperature, $S_\phi(4Hz, T)$ shows a peak which correlates with the dissipation peak observed in ac conductance measurements.

In a two-dimensional proximity effect Josephson junction array (JJA) thermal fluctuations of the phase of the superconducting wave function play a central role in governing the transition from the normal to the superconducting state. In particular, the thermally induced vortex-unbinding transition [1] has been studied extensively in experiments using magnetic [2] or electric [3] drive forces. In an applied normal magnetic field, expressed with the parameter $f = \phi/\phi_0$ where ϕ is the applied flux per unit cell of the array, the response of a JJA exhibits rich structures reflecting the interaction between the flux line lattice (FLL) and the pinning potential (PP) provided by the array. For rational values of f, the FLL is commensurate with the PP and merely pinned by the array. For f irrational, (or $f = p/q$ with q large) the FLL is incommensurate with the PP and has therefore an increased mobility, leading to increased dissipation and decreased superfluid density.

For the study of vortex motion we propose the alternative method of measuring the spectral density of magnetic flux noise $S_\phi(\nu, T)$ (ν is the frequency, T the temperature) across the superconducting transition for various values of f without applying any drive field.

In this communication we present data for a JJA consisting of 10^6 Pb/Cu/Pb proximity effect junctions on a triangular lattice with lattice parameter $L = 8\mu m$. In order to first put the array in a known magnetic state we use our two-coil complex conductance technique [4] with an rf SQUID as a detector. An ac current in the drive coil induces screening currents in the sample. The receive coil, a superconducting first order gradiometer, is in series with the input coil of an rf SQUID system. A change in the sample's conductance induces a change in the coils' mutual inductance which is detected by the SQUID. Then, in order to measure $S_\phi(\nu, T)$ the drive coil is disconnected. The SQUID (operated in the flux-locked-loop mode) output is proportional to the total flux through the detection coil, which, in turn is proportional to the flux in the array. If one neglects the very small field applied to the sample across the feedback circuit of the SQUID, there is no externally applied driving force and the array, at least for a rational f, is in an equilibrium state.

The upper curve in Fig. 1 shows the spectral density $S_\phi(\nu, T)$ as a function of frequency measured at 3.47 K. The superconducting transition temperature at $f = 0$ is measured inductively to be at 3.77 K . The lower curve provides the reference background noise measured at 4.5 K. A clear $\nu^{-\alpha}$, $\alpha \approx 1$ dependence can be observed between 0.1 and 100 Hz. Above 100 Hz background noise dominates.

On the left-hand scale of Fig. 2 we show the result of an ac complex conductance measurement performed at 160 Hz for $f = 1/2$ as a function of temperature. The roll-off measures mainly the superfluid density whereas the peak is related to the dissipation in the sample. On the right-hand scale $S_\phi(\nu = 4Hz, T)$ is presented. The background noise was substracted. The frequency dependence is similar to the one shown in Fig. 1, the exponent $\alpha \approx 1$ not being significantly temperature dependent.

To conclude this preliminary report, zero drive force magnetic flux noise correlates (in temperature) with the dissipation observed when the sample is driven. The fact that we see magnetic flux noise in the critical region is not a surprise. However, these results are different from those obtained in flux flow noise experiments where at least 100 times more vortices are subject to a substantial drive current. We believe that in the $f = 0$ case the noise arises from the motion of thermally activated vortices and maybe from lattice or additonal defects in the $f = 1/2$ case. Noise figures in these two cases are almost equivalent, however. Similar magnetic flux noise has been observed by Ferrari et al [5] in high temperature superconducting films which are highly disordered systems compared to a periodic JJA.

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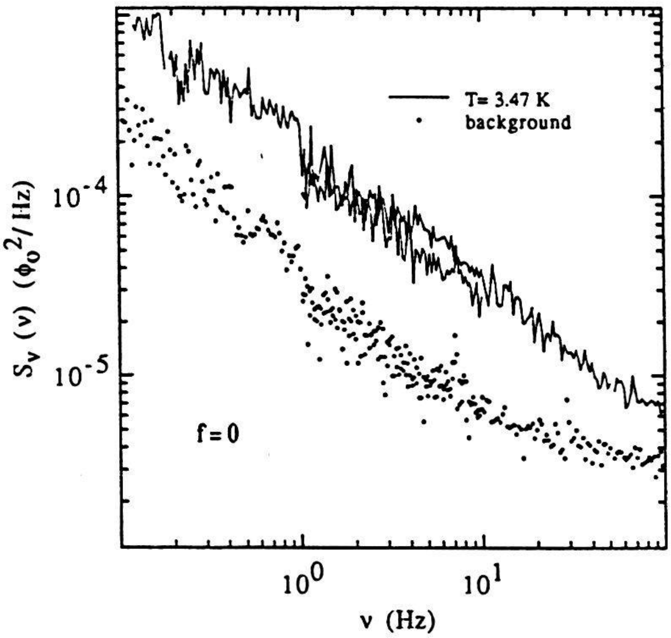

Figure 1: a) Spectral density of $S_\phi(\nu, T = 3.47)$ of a JJA (noise floor not substracted). b) Same quantity measured above the transition.

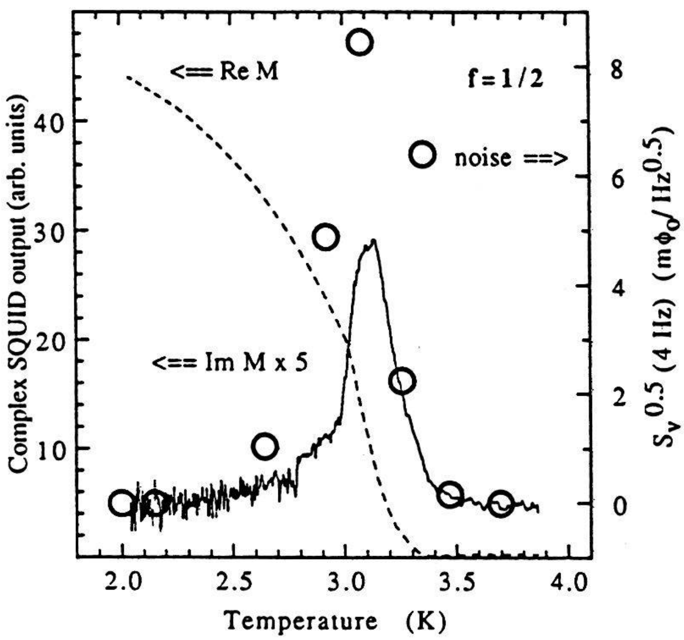

Figure 2: Response (left hand scale) of an ac shielding measurement as a function of temperature. On the right hand scale magnetic flux noise $S_v(\nu = 4Hz, T)$.

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