Zeitschrift: Helvetica Physica Acta
Band: 65 (1992)
Heft: 2-3

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DOI: https://doi.org/10.5169/seals-116442

Self-field Effects and Subharmonic Shapiro Steps in Josephson Junction Arrays

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Abstract. Subharmonic giant Shapiro steps have been observed in the current-voltage characteristics of 2D arrays of proximity coupled Josephson junctions in zero field. Simulations indicate that the magnetic field generated by currents in the array generate these subharmonic steps.

Introduction

Recent experiments[1] on proximity coupled Josephson junction arrays driven by RF and DC currents demonstrated the existence of both giant Shapiro steps (at integer-valued normalized voltages $n=2eV/\mathcal{N}h\nu$ where $\mathcal{N}$ is the number of junctions in the direction of the current and ν is the RF frequency) and fractional giant steps. The fractional steps occur in transverse magnetic fields that give rational values of the flux per plaquette of p/q times the flux quantum and they occur at voltages np/q. They result from motion of the field-induced vortex superlattice due to the external current.

In addition to the field-induced step at $p/q=1/2$, we also observe half-integer steps in zero applied field[2]. We believe that these "subharmonic" steps are the result of vortex nucleation induced by the asymmetric self-field of the array currents. Simulations that include such self-fields show similar half steps.

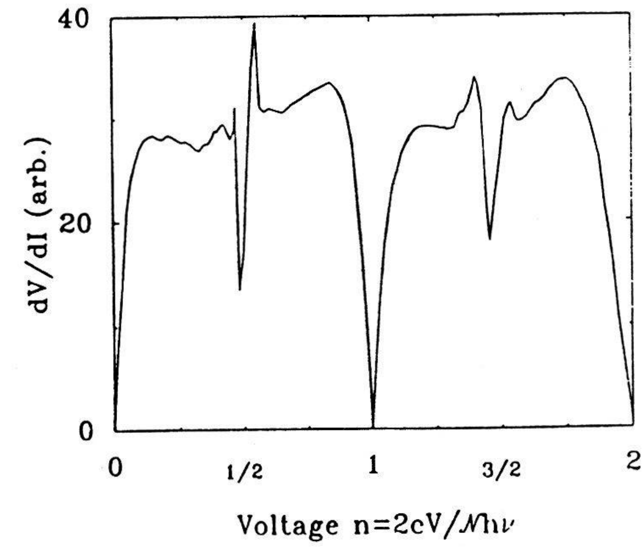

Figure 1 Experimental dynamic resistance vs. voltage for 300x300 array in zero applied field. Giant Shapiro steps occur at integer values of the voltage. Note the subharmonic steps at n=1/2 and n=3/2.

Experiments and Simulations

The experiments were performed on 300x300 square arrays of niobium crosses on a gold underlay; the lattice constant is 10 μm. Measurements of V_{DC} vs. I_{DC} clearly show the integer giant and fractional giant Shapiro steps. To see the weaker subharmonic steps, we looked at the dynamic resistance, dV/dI, vs. V_{DC}. A typical plot is shown in Fig. 1. In this representation, Shapiro steps appear as dips in dV/dI.

For an MxN array, where M is the number of islands across the array and N is the number in the direction of the current, we may approximate the self-field by calculating the field of a set of M infinite wires coincident with the parallel elements of the array. The drive current is assumed to be distributed uniformly among these wires. We treat the resultant field across each junction as an external field, using the Landau gauge (the only junctions affected by the field are parallel to the external current).

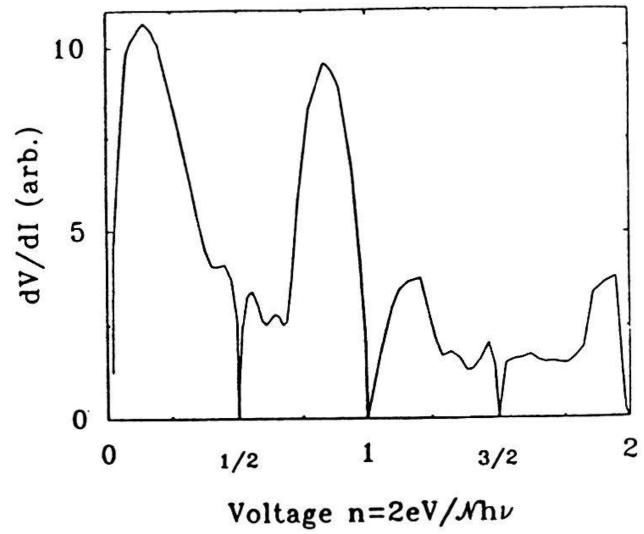

Figure 2 Simulated dynamic resistance vs. voltage for 9x5 array, with the self-field included. Subharmonic steps exist at n=1/2 and n=3/2.

We model each junction as a resistively-shunted junction and numerically solve the coupled nonlinear differential equations as others have[3]. A representative plot of the simulated dynamic resistance in the absence of an applied field is shown in Fig. 2. The subharmonic half-integer steps which appear are absent in simulations that don't include the self-field.

A better approximation to the self-field involves calculating the fields for each current element in the array. Preliminary data from simulations using this approach also show the half-steps, as well as subharmonics at 1/3, 2/3, and 3/4, as one might expect.

Acknowledgements

This research was supported in part by USAF Wright Research and Development Center through Acurex Corp. and the Ohio Supercomputer Center. Samples were provided by D. C. Harris and J. C. Garland.

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