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A THIN-FILM DC SQUID GRADIOMETER

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ABSTRACT

1. CONFIGURATION AND FABRICATION

A thin-film dc SQUID gradiometer has been fabricated on a single planar substrate. The superconducting pick-up loops consist of a lead strip in the form of a 48- μ m rectangle with a niobium strip bisecting the rectangle. A tunnel junction dc SQUID is symmetrically located on the niobium strip. If there is a spatial gradient in the magnetic field applied to the gradiometer so that the magnetic fluxes threading the two pick-up loops differ, a supercurrent is induced in the niobium strip that is detected by the SQUID. The noise power spectrum of the SQUID is white down to a frequency of about 3×10^4 Hz with a rms flux noise of 8×10^{-3} Φ_0 Hz $^{-1/2}$, corresponding to a gradient sensitivity of 2×10^{-10} G cm $^{-1}$ Hz $^{-1/2}$.

1. INTRODUCTION

Superconducting gradiometers that measure time varying spatial derivatives of magnetic fields have been used for a number of years. The gradiometer consists of a superconducting flux transformer coupled to a SQUID. The flux transformer has two pick-up loops that are (in principle) balanced so that a change in a uniform magnetic field induces no supercurrent in the transformer, whereas a gradient change generates a proportional supercurrent. This supercurrent in turn produces a flux that is detected by a flux-locked SQUID. The highest sensitivity quoted in the literature appears to be that achieved by Wynn et al.¹, about 1×10^{-12} G cm $^{-1}$ Hz $^{-1/2}$, although a much higher noise level at low frequencies was observed. A balance against uniform field fluctuations and angular variation in the position of the gradiometer of 1 part in 10^7 was achieved by adjusting the positions of small pieces of superconductor.

Possible disadvantages of this type of gradiometer include microphonic noise, and loss of balance with thermal cycling of the device. In an attempt to overcome these problems, we have constructed and tested a prototype integrated thin-film gradiometer in which the pick-up loops and SQUID are deposited on a single substrate. The device is sensitive to off-diagonal gradient changes of the form $\partial H_x / \partial y$. In principle, this device should be insensitive to magnetic field changes in the plane of the pick-up loops, and should require balancing only in one dimension. Our prototype gradiometer has a length of 48 μ m, and a sensitivity of about 2×10^{-10} G cm $^{-1}$ Hz $^{-1/2}$. We achieve a balance of 1 part in 10^5 or better against uniform fields applied at right angles to the plane of the pick-up loops. The intrinsic balance (i.e. with no adjustment) against fields applied in the plane of the loops is better than 1 part in 10^7 . Although this preliminary design of the gradiometer clearly does not compete with state-of-the-art devices in either sensitivity or balance, we feel that larger versions based on the same principles may well do so.

In this paper, we briefly describe the fabrication and testing of the gradiometer, and give projections for the expected sensitivity and balance of a larger version.

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The configuration of the thin-film gradiometer is shown in Fig. 1. A uniform magnetic field H , applied at right angles to the plane of the rectangular pickup loops produces zero current in the Nb strip, since the loops are balanced. On the other hand, the application of a gradient $\partial H / \partial y$ produces a proportional supercurrent in the Nb strip that is detected by the planar dc SQUID. Details of the SQUID are shown in Fig. 2.

Fig. 1. Configuration of thin-film gradiometer.

Fig. 2. Configuration of planar dc SQUID.

The gradiometer is constructed as follows. A PbIn (52 wt.%) strip 150 μ m wide and 0.5 μ m thick is evaporated as a 48- μ m rectangle on an 80- μ m $\times$ 120 μ m over substrate. Next, 0.01 μ m thick Au shunts (for the tunnel junctions) and contacts are evaporated. A niobium strip 100 μ m wide and 0.1 μ m thick is then sputtered; the Nb makes superconducting contacts with the PbIn strips. The niobium is thermally refined. Two tunnel junctions are formed by evaporating two 10- μ m-wide PbIn cross strips 1.5 μ m apart over the Nb film and the Au shunts. An insulating disk, consisting of a 0.1 μ m thick film of SiO $_2$ with a 0.05 μ m thick overlay of Ge is evaporated over the mid-point of the Nb strip. The SQUID is completed by evaporating the remaining PbIn strips as shown in Fig. 2. The finished gradiometer is coated with a thin layer of Duco cement to protect the metal film/insulator structure.

The gradiometer is balanced along the y -axis by moving two pyrex blocks onto each of which has been sputtered a 0.1 μ m thick Zn film. The Zn film is pressed against the substrate on which the gradiometer is fabricated, so that the gradiometer and balancing film are as co-planar as possible. The gradiometer substrate is mounted vertically on a fiberless dewar insert, and the balancing blocks are assembled on a