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TITLE: EXPERIMENTS ON SUPERCONDUCTOR IMAGING SURFACE MAGNETOMETRY

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EXPERIMENTS ON SUPERCONDUCTOR IMAGING SURFACE MAGNETOMETRY

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The recent development of a new concept in magnetometry has led to experiments to evaluate the performance of such systems. The superconductor imaging surface magnetometer employs superconducting plates and shells to deflect magnetic noise and to image nearby dipole sources while the SQUID pick-up coils are located in areas where the noise has been greatly reduced. The experiments herein reported confirm the principles of imaging magnetometry for detecting nearby dipole sources.

1. INTRODUCTION

London's analysis (1) of the superconducting sphere in a uniform magnetic field relates the current density, penetration depth and internal field to the external field and leads to an understanding of the Meissner effect. London's procedure can be extended to the analysis of the field of superconductors of various shapes such as cylindrical rods, plates with circular edges, and curved shells. Since the magnetic noise fields usually encountered in SQUID magnetometry are analogous to London's uniform field, one can adapt the principles involved in the deflection of bodies into a new concept for SQUID magnetometry. A first implication is that one should place the magnetometer pick-up coil at a location near the superconducting body where the noise field is a minimum. In some configurations, the noise may be reduced by as much as 1,000.

We show in Fig 1 a schematic of a magnetometer system in which a flat superconducting plate is in a noise field coming from 45° with respect to the plate normal (the z -axis). A weak magnetic field due to a nearby dipole source, such as m in Fig 1, may have an amplitude of only 10 fT to 1,000 fT, which is typical for brain waves and fields caused by flaws in materials. Meanwhile, the noise fields may have amplitudes of a million to ten million fT.

Since the superconducting plate of Fig 1 has essentially infinite conductivity, the target dipole m will exhibit an image m' behind the front face. Thus, the field at the pick-up coil $A-A'$ will be the sum of fields due to the source and its image. We have named the system the Superconductor Imaging Surface Magnetometer (2).

The purpose of this paper is to report on experiments done to test the performance of this novel magnetometer system in the uniform field of a Helmholtz coil and in the dipole field of a wire loop dipole that can be moved to arbitrary coordinate positions.

FIGURE 1

Schematic of one of many configurations of the superconductor imaging surface magnetometer. $A-A'$ denotes the location of signal pick-up coil in front of the front face. $B-B'$ is the noise cancellation coil the same distance behind the back face. Line of flux due to a distant source are deflected by superconducting plate as shown. For an ordinary wire loop dipole, the image m' is the mirror image of m .

2. EXPERIMENTAL DISCUSSION

The superconducting plate illustrated in Fig 1 was actually a 7.8 cm diameter by 0.95 cm thick plate of lead with edge rounding. The pick-up coil $A-A'$ was a 7-turn coil of NbTi wound on a 1.27 cm diameter form and had an

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inductance of $1.7 \mu\text{H}$. The identical coil at B-B' was connected in series opposition to the one at A-A'. The shielded pair of connecting lines was then attached to a B.T.L. hybrid rf SQUID located approximately 50 cm higher in the LHe dewar. The total circuit inductance was therefore

$$L(A-A') + L(B-B') + L(\text{leads}) + L(\text{SQUID}),$$

which was equal to about $5.5 \mu\text{H}$. The sensitivity was therefore reduced from the typical $17 \text{ fT}/\sqrt{\text{Hz}}$ for an rf SQUID magnetometer to approximately $49 \text{ fT}/\sqrt{\text{Hz}}$ for our system.

In an experiment to test the noise rejection capability of the system, we used a Helmholtz coil pair with a field factor of $31.5 \mu\text{T/A}$ to produce a 100 Hz uniform applied field. This was driven at 2 to 6 mA peak-to-peak. The resulting B_z values are shown in the first column of Table 1. The corresponding flux ratios are shown in the second column in ϕ_0 units. The rms signal voltage output of the SQUID is shown in the third column. This was determined accurately by using a PAR lock-in amplifier tuned to 100 Hz. The last column gives the ratio of signal received to field applied by the Helmholtz coil. These figures compare favorably with the goal of 10^{-6} for the second order gradiometer, a goal that is rarely achieved. The average of $1/330,000$ for the values in Table 1 can easily be improved. One obvious way is to increase the plate diameter, thereby reducing the noise field at the locations of coils A-A' and B-B'.

Table 1
The ratio of received signal in ϕ_0 units of coils A-A' and B-B' to the amplitude produced by the Helmholtz coil.

B_z (p-p) (units of $\text{fT} \times 10^7$)	ϕ/ϕ_0 rms ($\times 10^3$)	Signal ϕ_0 units	Signal/ drive
2.42	3.76	0.010	1/376,000
2.42	3.76	0.016	1/235,000
1.21	1.88	0.0055	1/342,000
2.42	3.76	0.011	1/342,000
3.64	5.66	0.016	1/354,000

SQUID output vs dipole position

FIGURE 2

Response of the image magnetometer to a loop dipole driven at 100 Hz and located 9.7 cm below coil A-A'. The x-position is varied from 12 to 31 cm, with the center position at $x = 21 \text{ cm}$.

We show in Fig 2 the response of the magnetometer to a wire-loop dipole driven at 100 Hz. The theoretical solid curve is the same for the image magnetometer and an ordinary first-order gradiometer with baseline $2d$, where d is the distance of the coil A-A' from the front surface. The experimental points (squares) are in good agreement with the theory.

3. SUMMARY

The Superconductor Imaging Surface Magnetometer is shown to be suitable for detecting weak near-source magnetic signals in the presence of overwhelming magnetic noise without requiring a magnetically shielded room.

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