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Superconducting Magnetic Sensors (SQUID, QFP) and Their Application

Hideaki NAKANE *

Abstract

Superconducting magnetic sensors such as SQUID's and QFP are extraordinary sensitive detectors of magnetic flux. Thin film and bulk devices are used at 4.2K in numerous high resolution magnetometer. High sensitivity of these sensors lead the applications of neuromagnetics and non-destructive evaluation. The present status of the device technology and the future subjects on these magnetic sensors are described in conjunction with recent high Tc superconductors.

1. Introduction

Electronic applications of superconductors have a wide technology field in both digital and analog. Superconducting magnetic sensors including SQUID's are major application fields of superconducting electronics. The superconducting devices exhibit unique performances in sensitivity and accuracy, comparing the other devices. There unique feature of the superconducting devices come from the macroscopic quantum effect including the Josephson effect. Recently, the superconducting device technology has been much progressed by a new microfabrication technology based on Nb or NbN junctions. This technology has been mainly developed in the course of Josephson computer researches. The present status of the device technology focused on the magnetic sensors and discuss the future subjects for these devices are described in conjunction with recent high Tc oxide superconductors.

2. SQUID magnetometer

SQUID are currently the most sensitive detectors for measuring magnetic flux and are used in a wide variety of applications of which neuromagnetism is a very remarkable one. SQUID consists of a superconducting loop including one (rf-SQUID) or two (DC-SQUID) Josephson junctions. DC-SQUID are nowadays often fabricated as a washer type SQUID ring with a planar input coils on top. In these SQUID, the equivalent flux noise at 4.2K is about $3 \times 10^{-6} \Phi_0 / \sqrt{\text{Hz}}$ (Φ_0 : flux quan-

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tum), which corresponds to a noise energy of a few 100h. In order to deduce the position of the flux source accurately, it is very important to construct a multi-channel SQUID system which is very useful to search nervous activity in human brain. The development of the multi-channel SQUID system is now in progress in a number of laboratories in the world, e.g. the Low Temperature Laboratory in Helsinki (24 channels)(1), BTI (37 channels)(2) and Siemens (37 channels)(3). These DC-SQUID have analog feedback circuits as in Fig.1. The analog feedback circuits make the periodic output signal of DC-SQUID to a linear signal which is proportional to the magnetic flux. The multi-channel SQUID system needs large number of analog feedback circuits that causes integration difficult. A digital feedback circuit has been proposed to make the superconducting feedback circuit on the SQUID's chip. The digital feedback circuit should have functions as a counter and a D/A converter as shown in Fig.2. The magnetic flux coupled the digital feedback SQUID was as low as $1.0 \times 10^{-3} \Phi_0 / \sqrt{\text{Hz}}$

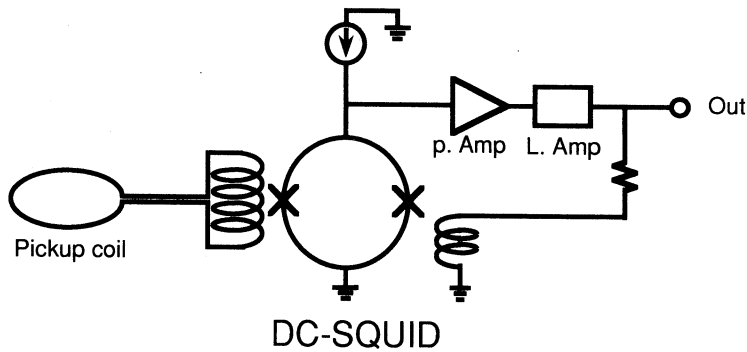


Fig.1. Equivalent circuit of SQUID magnetometer with analog feedback circuit

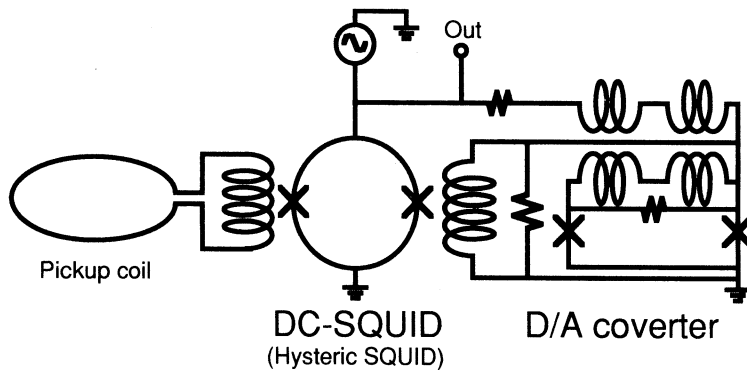


Fig.2. Equivalent circuit of SQUID magnetometer with digital feedback circuit.

3. OFP magnetometer

The Quantum Flux Parametron circuit (QFP) is a cryogenic circuit which has higher current gain and much lower power dissipation than other cryogenic circuits. The QFP consists of a superconducting loop having two Josephson junctions, two inductors L1 and L2, and a load inductor Ld as shown in Fig.3. An excitation line coupled magnetically with inductors L1 and L2. A small signal input current flows into the QFP and it is amplified by the excitation current. The QFP does not operate as a conventional analog amplifier, because the amplification gain of the QFP is not linear with the input signal. The QFP can be used as high gain current comparator. The output current of the QFP is detected by a conventional DC-SQUID instead of a Josephson sampler circuit. The QFP magnetometer consists of a sensing coil, the QFP, DC-SQUID current detector and a feedback circuit. The feedback circuit consists of a pre-amplifier, a lockin-amplifier. A sensitivity of the QFP magnetometer will be expected to be $6.4 \times 10^{-6} \Phi_0 / \sqrt{\text{Hz}}$ (5). It is same order as the

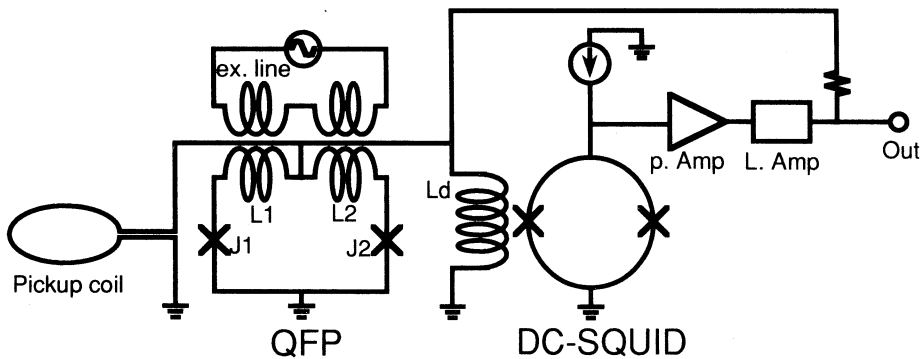


Fig.3. Equivalent circuit of QFP magnetometer

4. Oxide superconducting magnetic sensor

Recently, much interest has been generated by the discovery of superconducting properties in copper oxide materials at temperatures in excess of 100K. There is now a very substantial effort directed toward developing fabrication techniques which would enable the community to exploit the unique properties of these materials. In particular, several high Tc SQUID's have been fabricated and operated at liquid nitrogen temperatures and above (6-9). However, the two key structures which have been essential to the operation of high resolution low Tc SQUID have not yet been fabricated out of the new materials. These elements are a high quality Josephson junction and

a low noise, multi-turn transformer or input coil structure. At the present time, the non-linear behavior which occurs at grain boundaries in the material. In thin film SQUID, the film is patterned into a loop which crosses one or more grain boundaries. Josephson-like tunneling at these boundaries then produces a modulation of the screening current in an externally applied field. Noise levels of these SQUID's were still several orders of magnitude higher than the expected value.

In order to realize reliable devices, it is needed to establish technologies for thin films, tunnel junction and microfabrications, all of which are the future subjects.

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