SQUID DEVELOPMENT FOR APPLICATIONS IN FUNDAMENTAL PHYSICS AND ASTRONOMY

Interim Report

JPL Task 1024

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A. OBJECTIVES

Future experiments in many areas of physics and astronomy will require extraordinarily sensitive detectors, which in turn require very low noise amplifiers for their readouts. The goal of this task is to develop low-noise amplifiers based on superconducting quantum interference devices (SQUIDs) which are suitable for many of these applications. The principal improvement required over commercially available systems is larger bandwidth, but that larger bandwidth cannot be gained at the expense of noise performance.

In order to design a SQUID that is both fast and low-noise, we have adopted the two-stage architecture developed originally by Welty and Martinis. In this architecture, a "preamplifier" SQUID is followed by an array of, typically, one-hundred SQUIDs wired in series. If the series array can be modulated coherently, the signals from the individual SQUIDs add, amplifying the signal from the preamp SQUID to a level compatible with a room-temperature amplifier stage.

One application of these SQUID amplifiers is to Nuclear Magnetic Resonance (NMR). It is our objective to supply these devices to the Low-Temperature Physics group at USC headed by Professors Hans Bozler and Criss Gould, for use with NMR measurements on helium films at millikelvin temperatures.

B. PROGRESS AND RESULTS

1. Fabrication Process Development

We have developed a seven-layer process for the fabrication of SQUIDs and SQUID arrays. The process includes three separate superconducting niobium wiring layers, three silicon monoxide dielectric layers, a resistor layer, and aluminum oxide Josephson junctions. The first layer is the first niobium wiring layer. To enable this layer to withstand subsequent etch steps, a technique of sandwiching aluminum etch-stop layers inside the niobium was developed. The aluminum is not etched by the fluorine chemistry used for the niobium etch, but it is vulnerable to ion milling, so must itself be protected with layers of niobium. The second layer is the PdAu resistor layer. This alloy was chosen because it is non-superconducting at any temperature and for its moderately high resistivity. The third layer is the first SiO dielectric layer used for insulating the resistor and first wiring layers. The forth layer is the niobium-aluminum oxide-niobium trilayer from which the junctions are made. The oxidation pressure and times for making the comparatively low critical current junctions used for SQUIDs were investigated. The fifth layer forms the junctions from the trilayer, using a self-aligned liftoff technique (that was developed for SIS mixers), where the top layer of the trilayer is etched away and replaced with SiO. The sixth layer is an additional SiO layer, added to avoid problems with short circuits. The final layer is the topmost wiring layer. A picture of a fabricated two-stage SQUID amplifier is shown in fig.1.

2. SQUID amplifier design

The two-stage amplifier shown in figure 1 incorporates a transformer-coupled input stage. This design allows for a much smaller SQUID loop because the multi-turn transformer is on a separate washer. There has been some indication that this separation of the input coil and SQUID loop can lead to better noise performance because the parasitic resonances associated with the large input coil have less of an effect on the SQUID. The second stage is an array of one hundred SQUIDs in series. A 7-turn input coil is placed on top of the array in a way that is intended to minimize the uncoupled flux.

3. SQUID amplifier test results

We obtained modulation depth of up to 1.2mV and a maximum transfer function slope of 5000V/A, which are comparable to the best reported results in the literature. A scope trace of the transfer function is shown in figure 2. The SQUID noise is 1 micro-phi0 for a 1-second bandwidth, corresponding to 1 pico Amp for the input coil used. A lower limit on the bandwidth is 600kHz, but that value may be limited by emi filters in the test system.

4. NMR results

One of these devices was mounted in a dilution refrigerator system at USC and used to measure NMR signals from a sample cell containing a helium film. Signals from the helium film and carbon substrate could be observed simultaneously for the first time, as illustrated in figures 3 and 4.

C. SIGNIFICANCE OF RESULTS

This task developed high-bandwidth SQUID amplifiers with noise performance exceeding commercially available devices.

The results indicate that such devices, which have application to astrophysical instrumentation, can be reliably fabricated at JPL's Microdevices Laboratory.

D. FINANCIAL STATUS

The total funding for this task was \$115,000, of which \$85,000 has been expended.

E. PERSONNEL

No other personnel were involved.

F. PUBLICATIONS AND PRESENTATIONS

[1] Zhang J., Fink B.R., Bozler, H.M., Gould C.M. and Day, P.K., SQUID NMR at Millikelvin Temperatures, presented at the 2003 March APS Meeting, Austin Texas.

G. REFERENCES

[1] Welty R.P. and Martinis J.M., IEEE Trans. Appl. Supercond. 3, 1808 (1993).

H. FIGURES

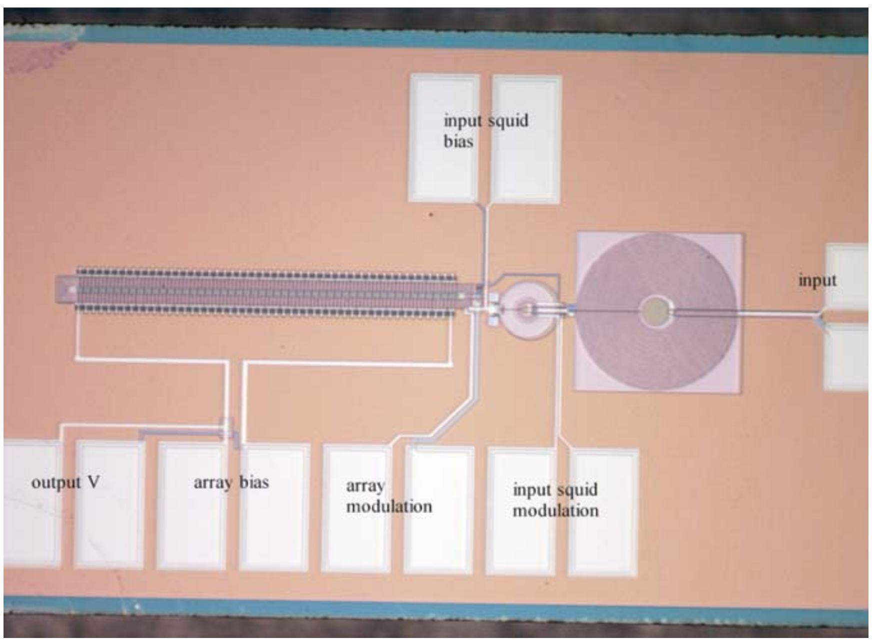

Figure 1. Picture of a fabricated two-stage SQUID amplifier.

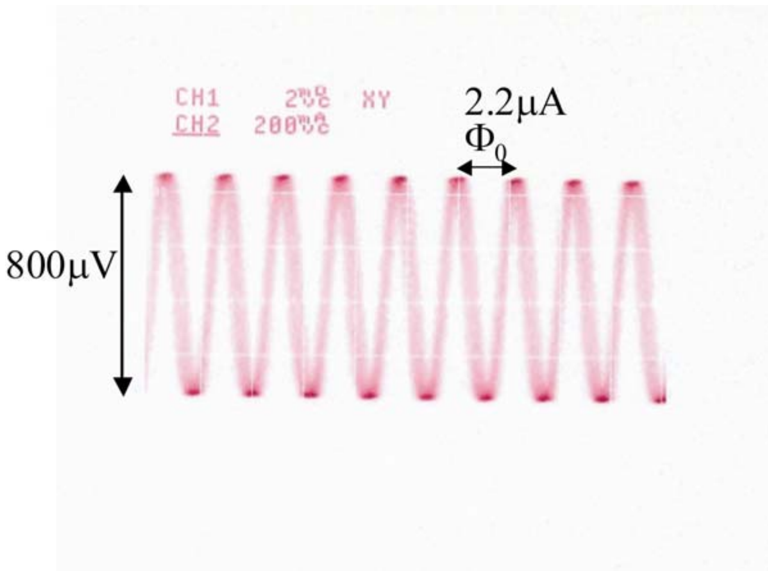

Figure 2. Scope trace showing a transfer function through the amplifier. (Courtesy of H. Bozler).

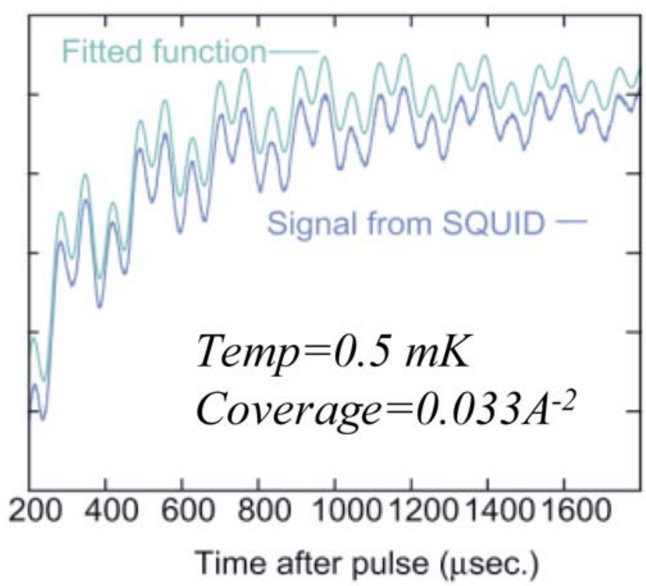

Figure 3. NMR signal from a sample cell at millikelvin temperature. (Courtesy of H. Bozler).

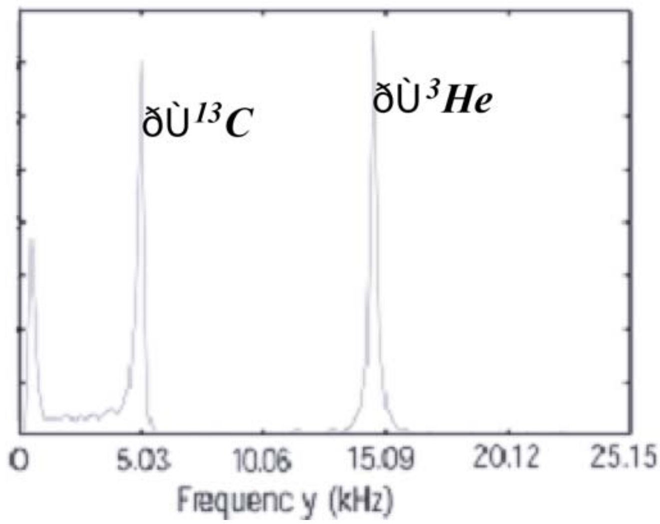

Figure 4. Fourier transform of the NMR data showing the signals from the helium sample and the carbon substrate. (Courtesy of H. Bozler).