Improved Readout Scheme for SQUID-Based Thermometry
Flux-unit-counting ambiguities would be eliminated.
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An improved readout scheme has been proposed for high-resolution thermometers, (HRTs) based on the use of superconducting quantum interference devices (SQUIDs) to measure temperature-dependent magnetic susceptibilities. The proposed scheme would eliminate counting ambiguities that arise in the conventional scheme, while maintaining the superior magnetic-flux sensitivity of the conventional scheme. The proposed scheme is expected to be especially beneficial for HRT-based temperature control of multiplexed SQUID-based bolometer sensor arrays.

SQUID-based HRTs have become standard for measuring and controlling temperatures in the sub-nano-Kelvin temperature range in a broad range of low-temperature scientific and engineering applications. A typical SQUID-based HRT that utilizes the conventional scheme includes a coil wound on a core made of a material that has temperature-dependent magnetic susceptibility in the temperature range of interest. The core and the coil are placed in a DC magnetic field provided either by a permanent magnet or as magnetic flux inside a superconducting outer wall. The aforementioned core is connected to an input coil of a SQUID. Changes in temperature lead to changes in the susceptibility of the core and to changes in the magnetic flux detected by the SQUID.

The SQUID readout instrumentation is capable of measuring magnetic-flux changes that correspond to temperature changes down to a noise limit of 0.1 nK/Hz^{1/2}. When the flux exceeds a few fundamental flux units, which typically corresponds to a temperature of ~100 nK, the SQUID is reset. The temperature range can be greatly expanded if the reset events are carefully tracked and counted, either by a computer running appropriate software or by a dedicated piece of hardware.

While adequate for many applications, the conventional scheme has drawbacks: If the temperature is changed rapidly or the temperature noise is high, the counting hardware and/or software loses flux count. In the case of a software counter, the temperature reading is lost entirely if the software is reset or restarted. In the case of a multiplexed SQUID controller, these drawbacks become more severe because flux readings are taken less frequently.
The proposed scheme is intended to eliminate these drawbacks. The scheme calls for including a secondary SQUID and its readout instrumentation that would register a small fraction of the magnetic flux passing through a primary SQUID. The scheme includes the following elements:

- Winding a secondary coil of fewer turns around the core to a second readout; or
- Forming a circuit branch parallel to the main coil with the secondary SQUID input coil in series with a large (compared to the SQUID input coil inductance) inductor; or
- Forming a circuit branch parallel to the main coil with a large inductor in series with a SQUID input coil shunted by a small inductor (see figure).

The goal is to avoid having to reset the secondary SQUID in the temperature range of interest, while maintaining the capability of determining the flux state of the primary SQUID unambiguously. If the secondary SQUID readout were monitored by a 16-bit data-acquisition board and the digitization effected by the board determined the readout accuracy, then the dynamic range afforded by this scheme could be optimized by designing the secondary SQUID readout to be about \(1/32,000\) as sensitive as is the primary SQUID readout. In a typical application, this level of secondary-SQUID sensitivity would correspond to a temperature range \(\approx 3\) mK. In this temperature range, there would be no need to actively track the flux state to maintain fidelity of the readout. To avoid the need for counting hardware altogether, a tertiary readout could be added.

This work was done by Konstantin Penanen of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
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