

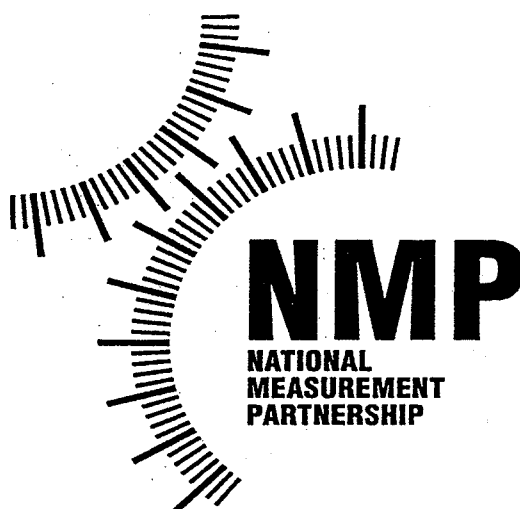
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High temperature superconducting devices for absolute noise thermometry

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Abstract: Josephson noise thermometry has provided a method of primary thermometry in the temperature region below 1K for a number of years [1]. An HTS Josephson noise thermometer extending the temperature range of application of such primary thermometers to as high as 50K has been proposed [2]. A Josephson junction is shunted by a resistor in series with an inductor L to form the RSQUID [3], which is inductively coupled to a nearby HTS readout dc SQUID. Measurement of the finite linewidth of the Josephson radiation due to thermal noise in the shunt resistor provides the absolute temperature.

In practice a large value of RSQUID loop inductance L is needed to ensure efficient coupling to the readout SQUID. We present calculations which indicate that, for practical design parameters, the amplitude of the circulating RSQUID current measured by the readout SQUID is seriously reduced and its frequency spectrum distorted such that the linewidth cannot be related accurately to temperature, using the proposed read-out technique.

We are now extending our work to use the directly-coupled two-junction RSQUID, as has been successfully used at LHe temperature [4]. Simulations show that this device avoids the effects due to high loop inductance, and in this case the Josephson linewidth should be determined only by the thermal noise in the shunt resistor.

A two junction R-SQUID is shown schematically in Fig.1. The bias currents are independently adjusted such that each junction oscillates at a relatively high Josephson frequency (10's of GHz), whereas the heterodyne (difference) frequency at a much lower value (kHz-MHz) is determined by the dc voltage across R .

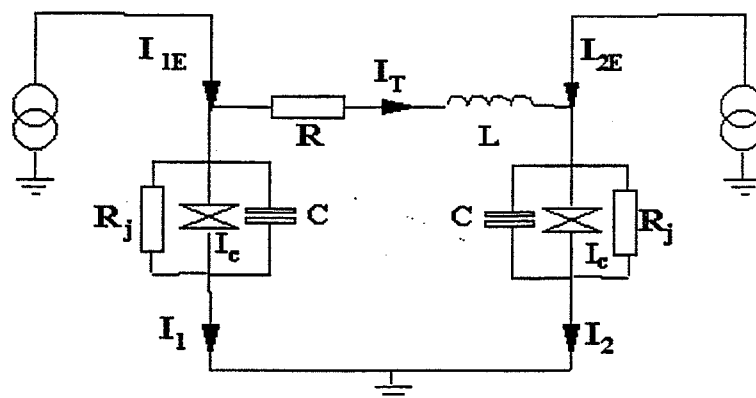


Fig.1 Circuit diagram of 2-junction R-SQUID showing shunt resistor R , loop inductance L , intrinsic junction resistance R_j and capacitance C .

We assume that both junctions have identical critical currents I_c and shunt resistance R_j . (Slight differences in a real device can be compensated by adjustment of the bias currents). The shunt capacitance C , as discussed above, can be neglected. The currents are related by the two equations:

$$I_1 = I_{1E} - I_T ; \text{ and } I_2 = I_{2E} + I_T$$

The voltages are given by

$$V_1 = \frac{\Phi_0}{2\pi} \cdot \frac{d\theta_1}{dt} = R_j(I_1 - I_c \sin \theta_1) ; \quad V_2 = \frac{\Phi_0}{2\pi} \cdot \frac{d\theta_2}{dt} = R_j(I_2 - I_c \sin \theta_2)$$

$$\text{It follows that } V_1 - V_2 = \frac{\Phi_0}{2\pi} \cdot \frac{d(\theta_1 - \theta_2)}{dt} = RI_T + L \frac{dI_T}{dt}$$

Results of the two junction R-SQUID simulation

The first derivatives of each of the 5 unknown quantities are expressed in terms of the 5 (undifferentiated) variables I_1, I_2, I_T, θ_1 and θ_2 thus

$$\frac{dI_T}{dt} = -\left(\frac{R}{2L}\right)(I_{1E} - I_{2E} - I_1 + I_2) + \left(\frac{R_j}{L}\right)(I_1 - I_2 - I_c(\sin \theta_1 - \sin \theta_2))$$

$$\frac{dI_1}{dt} = -\frac{dI_T}{dt} = -\frac{dI_2}{dt}$$

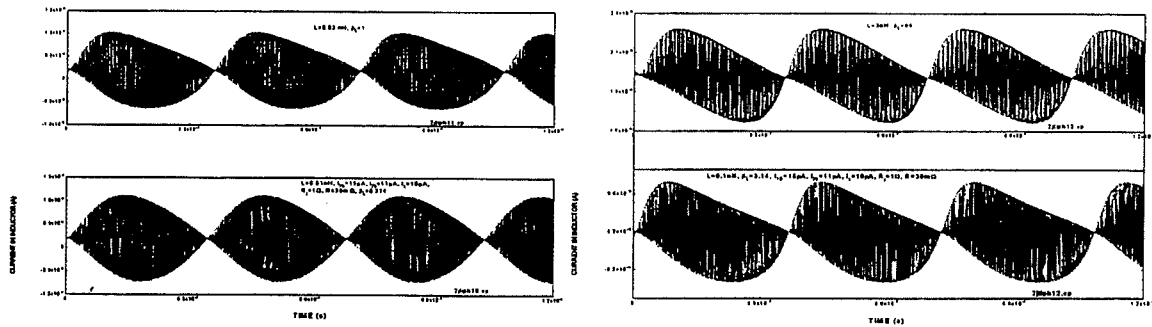


Fig. 2 Simulation of circulating supercurrent in 2-junction R-SQUID for inductance values 0.01, 0.03, 0.1 and 3 nH. The Josephson oscillation is modulated at a frequency corresponding to the voltage across R .

The results of the numerical simulation of these differential equations describing the circuit (fig. 2) are shown for a range of β_L values in fig. 2. Note that **even for very large β_L values the amplitude of the inductor current is not significantly reduced and its essentially sinusoidal character is maintained.**

EXPERIMENT

A two junction R-SQUID of the type shown in Fig.3 has been fabricated using thin-film YBCO bi-crystal junctions. The resistor R is formed by a Au film 400 nm thick, which bridges a gap in the underlying YBCO film. Deposition and fabrication techniques were optimised such that resistor values of a few 10s of micro-ohms were achieved with negligible Au-YBCO interface resistance [4]. Currents I_{1e} and I_{2e} are applied from external stable current supplies such that the voltage difference (~ 20 nV) between the junctions determines the frequency of the heterodyne signal (~ 10 MHz) which is amplified and recorded. The Josephson linewidth can then be measured.

RESULTS

The device was installed in a helium-flow cryostat and carefully shielded against magnetic and radio-frequency interference. Its temperature was controlled within 10 mK between 19K-90K. A cryogenic co-axial cable coupled the R-SQUID to a room temperature amplifier. When both junctions were biased slightly above their respective critical currents, Josephson oscillations were readily observed at heterodyne frequencies between 5 and 35 MHz, in the temperature range 19K - 74K. The oscillations were stable over periods of several hours, and could be reproduced following temperature cycling of the device. An example of the signal recorded on a spectrum analyser for the device temperature near 26K is shown in Fig.3.

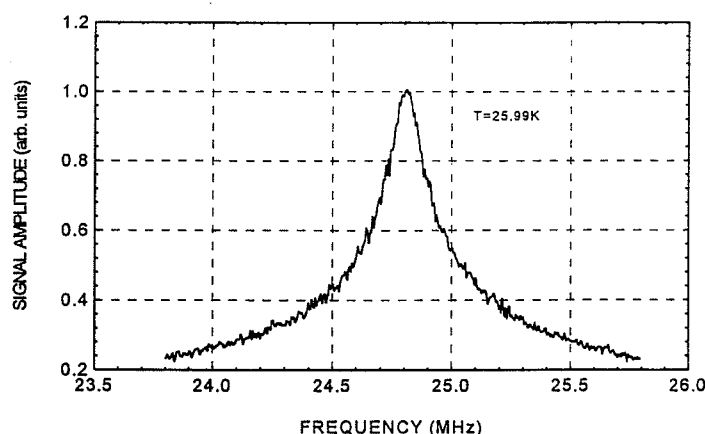


Fig. 3 Spectral recording of Josephson heterodyne oscillation generated by a 2-junction R-SQUID.

CONCLUSION

Mathematical simulations of the single-junction and 2-junction R-SQUIDs have been done for a range of inductance values. In the former type of device, large inductance values ($L \sim 1$ nH) which are necessary for efficient coupling to a read-out SQUID cause severe attenuation and distortion of the Josephson signal. In the 2-junction R-SQUID, however, the heterodyne Josephson signal is not similarly affected. First experimental observations of heterodyne Josephson oscillations in a 2-junction HTS R-SQUID are reported in the temperature range 19K-74K. Ongoing work is directed at the measurement of the linewidth

as a function of temperature and resistance, and accurate comparison with the theoretical dependence.

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