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A SIMPLE ULTRA HIGH RESOLUTION SQUID RESISTANCE BRIDGE

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Résumé.— On décrit un pont de résistance simple et bon marché, capable de détecter des changements faibles de résistance avec une résolution allant jusqu'à $1/10^7$. Cette méthode représente une amélioration de deux ordres de grandeur par rapport à un circuit potentiométrique SQUID conventionnel. Elle égale la résolution obtenue par comparateurs de courants (une méthode coûteuse) et a l'avantage supplémentaire sur ces derniers de pouvoir être utilisée avec des échantillons de très faibles résistances.

Abstract.— A simple and inexpensive resistance bridge is described which can monitor small changes in resistance with a resolution of up to 1 in 10^7 . Its performance improves on that of the conventional SQUID potentiometric circuit by up to two orders of magnitude; its resolution equals that obtained with (expensive) current comparators, with the added advantage that, unlike the latter, it can be used with very small sample resistances.

The usual potentiometric circuit for the measurement of small resistances with a SQUID is shown in figure 1a: the SQUID electronics feeds back a current I_2 so as to maintain a null across the signal coil, and the sample resistance r_1 is obtained in terms of a comparison resistor r_2 and the ratio of the currents I_2/I_1 . The limitations of this circuit are set by the stability of the sample current supply, and the measurement of the currents which is usually done by measuring the voltage drop across high quality room temperature resistors R_1 and R_2 . With care a resolution of 1 in 10^5 can be achieved, but more commonly the performance is a factor of ten worse than this.

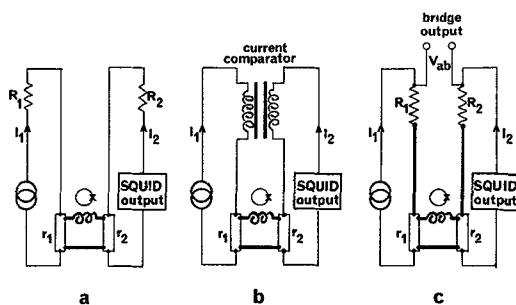


Fig. 1 : SQUID resistance measuring circuits. Heavy lines represent superconducting wires. (a) the usual potentiometric circuit (b) potentiometric circuit with a room temperature current comparator (c) the new bridge circuit.

Recently two groups /1,2/ have overcome these pro-

blems by measuring the current ratio directly with a room temperature current comparator (figure 1b); these devices have very high accuracy and resolution (~ 1 in 10^7) and, because the SQUID feedback loop itself maintains I_2/I_1 steady, drifts in the sample current supply are unimportant. However not only are current comparators extremely expensive, but in addition, if the sample resistance is small, the AC modulated flux gate magnetometer that is used for sensing current balance affects the SQUID operation; this interference limits the circuit of figure 1b to sample resistances greater than about 10^{-5} ohm. Our interest /3,4/ is in the low temperature behaviour of the resistivity of pure metals and dilute alloys; it appears that surface scattering and crystal defects have a confusing influence on the resistivity, so that ideally the sample should have as large a cross-section as possible, compared with electronic mean free paths that can approach 1 mm in these circumstances. So, for example, for a material of residual resistivity 10^{-9} to 10^{-10} ohm cm formed into a sample a few mm in diameter, the sample length would need to be 10 m or more for the circuit of figure 1b to be usable.

Our circuit (figure 1c) is essentially a resistance bridge. Because the SQUID feedback loop ensures that $I_1 r_1 = I_2 r_2$, V_{ab} can be made zero by choosing $R_1/r_1 = R_2/r_2$, irrespective of any drift in I_1 . In general (with $R_1 \gg r_1$, $R_2 \gg r_2$)

$$V_{ab} = I_1 R_1 - I_2 R_2 = I_1 R_1 \left[1 - \frac{r_1}{r_2} \frac{R_2}{R_1} \right] = I_1 R_1 \alpha \quad (1)$$

where $\alpha (= 1 - r_1 R_2 / r_2 R_1)$ is a measure of the degree to which the bridge has been balanced.

The bridge is sensitive to changes in sample resistance r_1 :

$$\Delta V_{ab} = - \frac{R_2}{r_2} \Delta r_1 I_1 \quad (2)$$

but the effect of any drift in I_1 is reduced by the factor α . The bridge is, therefore, suitable only for looking at small changes in resistance.

Clearly the bridge depends for its performance on the stability of the ratio arm resistors R_1 and R_2 , and of the comparison resistor r_2 . We have achieved this by winding R_1 and R_2 from phosphor-bronze wire and immersing them in liquid helium at 4.2 K. Because of the symmetry of the circuit the effects of the temperature and power coefficients of the two resistors are greatly reduced. The comparison resistor r_2 , which dissipates little power, is also held at 4.2 K, but within a vacuum can. In order to maintain thermal isolation of r_1 the superconducting interconnecting leads are made from Niomax CN; because the Cu-Ni coating of this wire has a large thermopower we have been extremely careful to maintain thermal symmetry of the SQUID input circuit.

Typical data obtained with a sample of moderately high resistivity are shown in figure 2 : the resolution is of order 1 in 10^7 . The smallest resistance sample we have looked at so far resistance 5×10^{-8} ohm. On a sample of resistance 4×10^{-7} ohm we have made a careful analysis of the noise : In a 0.1 Hz bandwidth the measured noise, referred to the input, was 6×10^{-15} V. r.m.s. Johnson noise in the same bandwidth for a total input circuit resistance of 1.0×10^{-6} ohm (including 2×10^{-7} ohm contact resistance) is 4.5×10^{-15} V. r.m.s. At this level we have not had any difficulty from thermal EMFs. We have used both a digital voltmeter of 0.1 μ V resolution and a nanovolt amplifier to monitor the bridge output. Neither appears to interfere with the SQUID operation. As far as the SQUID itself is concerned, no more than the usual screening precautions were taken. The sample current supply delivers a maximum of 120 mA, and is stable to 1 in 10^5 . The maximum temperature at which the bridge can be used is, at present, 9 K, the superconducting transition temperature of the Niomax CN leads.

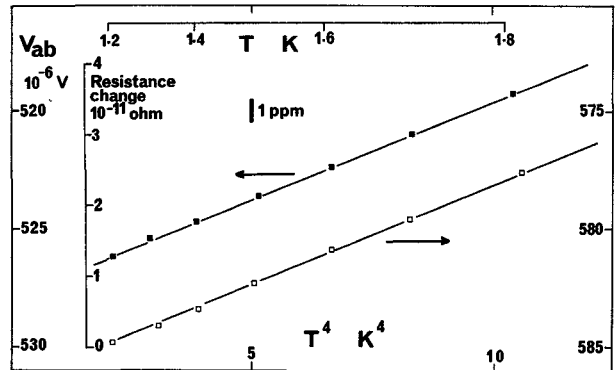


Fig. 2 : Typical data on the temperature variation of the resistance of a silver 0.2 % gold alloy below 2 K; at higher temperatures thermometric uncertainties contribute a larger experimental scatter. $r_1 = 3.48 \times 10^{-6}$ ohm, $r_2 = 3.49 \times 10^{-6}$ ohm, $R_1 : 9.74$ ohm, $R_2 = 9.76$ ohm, $\alpha = 5 \times 10^{-4}$, $I_1 = 100.0$ mA. Effective bandwidth about 0.1 Hz. Calculated Johnson noise, referred to the bridge output, is 1.5×10^{-8} V r.m.s. The two sets of data points represent two runs with an intervening period of four weeks at room temperature, during which the bridge balance shifted by about 60 ppm.

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