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Study on bias reversal readout working at suppressing low frequency noise of dc SQUID with different β_c

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ABSTRACT

How to reduce of low frequency noise of low Tc DC superconducting quantum interference device (DC SQUID) has been an important problem and bias reversal readout scheme is an effective method to tackle it. However, the effect varies with the change of the parameter of sensors. Wang et al. found that DC SQUID with different ranges of β_c matches different readout circuits to gain the lowest white noise. It is regrettable that this study did not involve the discussion of low frequency. In this work, we compare the noise of SQUID with a large range of β_c measured by static bias and bias reversal. The preamplifier used is six parallel connected bipolar transistors (6 × SSM2220). Finally, we found that the bias reversal scheme is suitable to match SQUIDs with $\beta_c < 1$.

1. Introduction

The source and suppression scheme of low frequency noise (1/*f* noise) of DC Superconducting Quantum Interference Device (DC SQUID) has been an important research subject as its low frequency application in biomagnetism and long-wave communication. Several studies suggest that fluctuation of the junction critical current causes the low frequency noise of DC SQUID [1,2] and has been approved [3].

To suppress the low frequency noise of DC SQUID, R H Koch et al. [4] proposed bias reversal scheme and achieved some good results. As reported, bias reversal scheme has been used to measure different types of DC SQUIDs like high-Tc DC SQUID, SNS junction based DC SQUID and nano-SQUID, and the low frequency noise has been successfully reduced [5–9]. However, the result of bias reversal scheme presented little difference to that measured by static bias sometimes [10], which suggested that the effect of bias reversal is affected by the property of devices.

Conventionally, in order to avoid the hysteresis, SQUIDs should be operated in the range of $\beta_c < 1$, where β_c is the Stewart-McCumber parameter. Recently, Liu et al. extended the SQUID operating area to $\beta_c > 1$ due to a large noise parameter Γ* [11]. Therefore, noise matching between sensors with different β_c and readout electronics becomes an important problem. White noise matching between SQUID sensor and readout electronics with increasing β_c has been studied [12], however, low frequency is not involved in this study. In this work, we examine the low frequency noise matching between SQUID sensor and bias reversal readout scheme for SQUID with β_c varying in a large range. The noise spectral density measured by bias reversal is compared to that measured by static bias to verify the effect of bias reversal.

2. Electronic principle and realization

In the bias reversal readout technique, the SQUID is biased with a rectangular current which is switched between $+I_B$ and $-I_B$ at a frequency of f_b. The voltage-flux characteristics (VFC) of the SQUID are changed with the bias current as shown in Fig. 1. The position of the working point, where the flux-lock-loop (FLL) circuit works stably, is also changed (points A and B in Fig. 1). In order to provide proper operation of the FLL circuit, the VFC must be shifted in both directions (along V and Φ axis) until the points A and B coincide on the Φ axis. Therefore, an additional voltage V_B must be supplied to FLL circuit (bias compensation) and an additional flux (Φ_B) must be introduced to SQUID (bias flux). While the voltage amplitudes at both polarities are different, an offset voltage V_O should be supplied to circuit. As a result,

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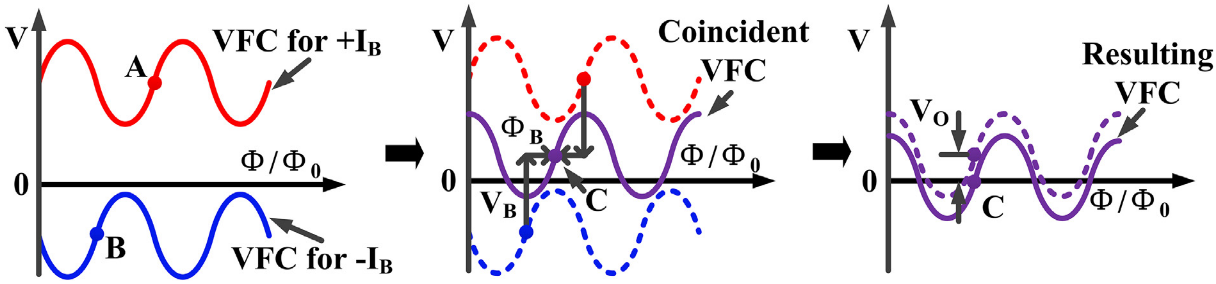

Fig. 1. Simplified evolvement diagram of SQUID voltage-flux characteristics (VFC) in the reversal bias scheme (introducing an additional flux Φ_B).

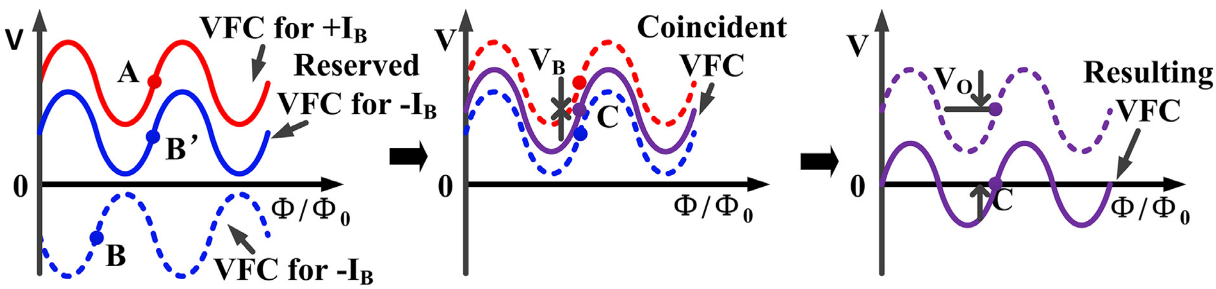

Fig. 2. Simplified evolvement diagram of SQUID VFC in the reversal bias scheme (reverse VFC for C-I_B without additional flux Φ_B).

the points A and B are shifted to point C on the Φ axis.

The usual method to introduce the bias flux is adding the rectangular sign from the generator of the bias current to the feedback coil. It is hard to maintain the rectangular shape of bias flux after transformation between inductors. In our circuit design, a modulator is added to reverse the VFC for C-I_B and the point B is changed to another edge to point B. The changed simplified diagram of SQUID VFC is shown in Fig. 2. As a result, the bias flux becomes unnecessary.

The functional diagram of the readout electronics is shown in Fig. 3. In the FLL circuit, the SQUID are amplified by the preamplifier (6 × SSM2220) [13], integrated (C_{INT}) and coupled back via the output voltage to the feedback coil through the feedback resistors R_F, thus compensating the external flux change in the SQUID. Consequently, the voltage at the output of the FLL circuit is proportional to the magnetic flux threading in the SQUID.

The bandwidth of the FLL circuit is about 530 kHz and the gain is about 10000. To measure the noise of circuit, we set a source resistor R_{source} at the input of the preamplifier and obtain the output voltage noise by spectrum analyzer. The equation will be

$$V_{no}^2 = G^2(V_{ni}^2 + I_{ni}^2 R_{sourse}^2)$$

in which V_{no} is the output voltage noise, G is the gain, V_{ni} is the input voltage noise and I_{ni} is the input current noise. V_{ni} and I_{ni} can be calculated by changing the value of R_{source}. The voltage white noise level of circuit with respect to the input is 0.65 nV/Hz$^{1/2}$ with a corner frequency of 3 Hz. The current white noise level is about 20 pA/Hz$^{1/2}$ and the corner frequency for the $1/f$ noise is 30 Hz. The noise spectral density is shown in Fig. 4.

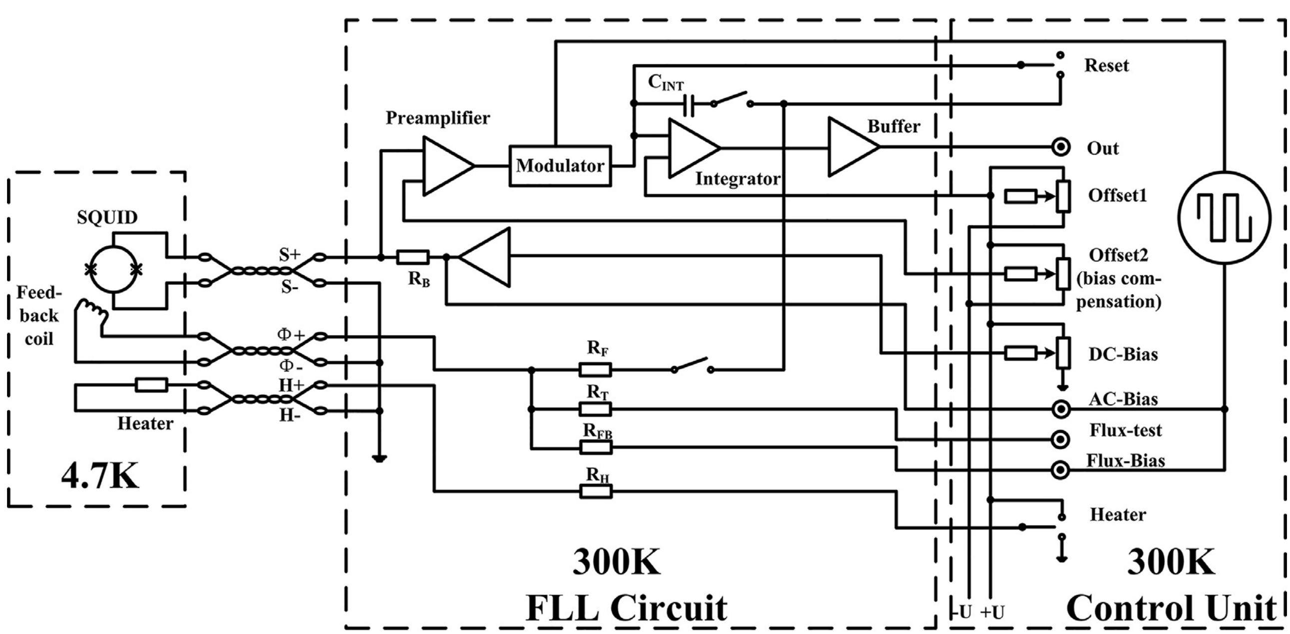

Fig. 3. Functional diagram of the readout electronics with ac bias.