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STABILIZATION OF MAGNET CURRENT USING JOSEPHSON VOLTAGE STANDARD

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I. Introduction

A stable reference source with a high current capability is useful for many metrological applications. Unlike the conventional Josephson voltage standard, one can couple the programmable Josephson voltage standard (PJVS) to a current source below mA range to stabilize the current. For higher current ranges, we tested a feedback method which allowed us to stabilize the 0.1 A output current of a commercial current source to within a standard deviation of $2\text{x}10^{-8}$ A/A.

A programmable Josephson voltage standard (PJVS) can generate a large and well-defined Shapiro step [1].Unlike the conventional Josephson voltage standard, the output voltage (V_J) of a PJVS can definitely be controlled by the selection of bias lines to the binary divided sections of the PJVS Josephson junction series array.

$$V_J = \sum_{k=1}^{n} b_k 2^{k-1} f/K_J \tag{1}$$

where bk is the k-th digit's binary number 1 or 0,depending on whether the bias current is flowing or not through the corresponding section containing 2^{k-1} Josephson junctions, f is the driving microwave frequency, and $K_J = 2e/h$ is the Josephson constant. Fig.1 shows the typical current-voltage characteristic of a PJVS array of 2^{13} SINIS (Superconductor-Insulator-Normal metal-Insulator-Superconductor) junctions fabricated at PTB. The current width of the Shapiro step is about 1 mA with 65 GHz irradiation. When adjusting the bias current to the optimum, i.e. the middle of the Shapiro step corresponding in this case to about 3.6 mA, one can obtain maximum stability of the output voltage V_J against external noise. This stability and easy controllability of any desired voltage allow various DC and low-frequency (LF) measurements, such as the precise determination of the resistance ratio [2] and the LF and Fast Reversed DC waveform synthesis for the evaluation of the AC-DC transfer standards [3,4,5,6]. However, so far the PJVS has only been used for zero or small current applications. Here, we would suggest that it could also be used for the stabilization of current sources. We will describe the principle of the proposed stabilization method and the result of an experimental demonstration. This will be followed by a discussion and finally by the conclusion.

II. Principle of the Current Stabilization

For the application to the higher current ranges we would suggest a feedback stabilization method as shown in Fig. 2, where the current to the load resistor is mostly suppliedby a main current source and where an additional small, fine-tuning current is supplied by a voltage-to-current converter in such a way that the change of the voltage drop across the current sensing resistor is compensated in accordance with the detector reading. The detector compares the voltage drop with a reference voltage and sends its analogue output to the voltage-to-current converter. The use of several ranges of current-sensing resistors in the circuit facilitates the proper combination of the current-sensing resistance with the output voltage of the reference, enabling multi-range operation. By using the PJVS as the voltage reference and a pre-calibrated standard resistor as the current sensing resistor, one can accurately control any high current through the arbitrary load resistor. The compliancevoltage to the load depends only on the compliance voltage of the main current source and the voltage-to-current converter, regardless of the output voltage level of the PJVS.

III. Measurement

We set up a simple voltage-to-current converter with a single op-amp to test 0.1 A stabilization by means of the feedback circuit of Fig. 2. We chose a 10 Ω standard resistor as current sensing resistor, a shorting cable as load resistor and a nanovoltmeter as the detector. We supplied 0.1 A from the calibrator which was intentionally put on the 1 A range to simulate a poor current source. At the same time we measured the voltage difference between the current sensing resistor and the PJVS and the voltage across the resistor by means of the nanovoltmeter (10 mV range and filter time constant of 2.5 s) and the $8^{1/2}$ digit DVM, respectively. Fig. 3(a) shows the measurement result when the feedback loop is disconnected, where the voltage difference (open circles) and the voltage (solid diamonds) are shown. Typicalstandard deviations of the voltage difference and the voltage were 1.4 mV and 1.5 mV, respectively. Fig. 3(b) shows the samemeasurements, this time, however, with feedback stabilization. The typical standard deviations of the voltage difference and the voltage were 21 nV and 70 nV, respectively. The direct reading of the PJVS output of 1.1 V with reversed output polarity was also recorded (not shown here), which showed a typical standard deviation of about 50 nV. Thus, the voltage fluctuation of 70 nV is largely to be attributed to the DVM on its 2 V range. This experiment demonstrates that a current of 0.1 A from a calibrator having a stability of 10^{-5} A/A to 10^{-6} A/A can be stabilized within a standard deviation of $2\text{x}10^{-8}$ A/A. For comparison, Fig. 3(c) shows the measurement result with feedback stabilization using a Zener voltage standard (1.018 V) instead of the PJVS array. The typical standard deviation of the voltage difference and the voltage was 21 nV and 100 nV, respectively. The difference instability observed in Fig. 3(c) was similar to that of Fig. 3(b), but the voltage instability was larger due to the instability of the Zener voltage standard.

IV. Discussion

The feedback method can be used for many applications of the Josephson effect. One example is the calibration of DC current meters. Here, one can use a PJVS as a voltage reference and a pre-calibrated resistor as current sensing resistor. This configuration will give an accurate current value based on the Josephson and the quantum Hall effect for the current through any arbitrary load. Another example is the calibration of 10 V using the 1 V PJVS and a 10:1 resistive divider. The feedback method allows the external current to the 10:1 divider to be stabilized with respect to the 1 V PJVS by using any resistor out of the divider as current sensing resistor, making the total voltage of the divider nearly 10 V. By comparing the 10 V output of the 10:1 divider with an unknown 10 V source under test, and repeating the comparison for all ten current sensing resistors, one can determine the 10 V/1 V ratio and the unknown 10 V output under test simultaneously. Further details of the 10 V calibration method using the 1 V PJVS is outside the scope of this paper and will be published elsewhere. In addition, we would like to point out that the feedback method using the Zener voltage standard gives good result and would also be useful for many practical applications.

V. Conclusion

We have investigated three current stabilization methods that use a PJVS. We have also suggested a feedback method allowing the stabilization of a high current source by using the PJVS voltage reference, and have demonstrated that a current of 0.1 A from a calibrator with an inherent stability of 10^{-5} A/A to 10^{-6} A/A can be stabilized within a standard deviation of $2x10^{8}$ A/A. The advantage of the feedback method is that in principle any high current can be stabilized effectively if the appropriate current sensing resistors are available, Also then the compliance voltage of the stabilized current to the load depends only on the compliance voltage of the main current source and of the voltage-to-current converter, regardless of the output level of the PJVS array. In conclusion, it is expected that the current stabilization method using the PJVS array willprovide possibilities for a more extensive use of the Josephson effect in precise DC and LF measurements including for high current ranges.

References

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Acknowledgement

This research was supported by a grant from KRISS project 04-0502-020, Republic of Korea.