The NPL 10 V Josephson junction array voltage standard

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Introduction

All the major national standards laboratories now maintain their DC voltage standards with reference to a Josephson junction array which, when cooled to 4.2 K and irradiated with electromagnetic radiation f, between 75 and 95 GHz, produces a constant DC voltage V, according to the equation

$$V = n\frac{h}{2e}f$$

where n is an integer and h and e are fundamental physical constants.

For many years, NPL has operated Josephson junction arrays comprised of around 3000 junctions and capable of producing voltages up to 2 V[1]. Recent work has been to develop a measurement system based on commercially-available Josephson junction arrays with over 20000 junctions and with the capability of producing voltages around 10 V.

The system

The measurement system can be considered in four parts: the establishment of the millimetre-wave source with sufficient power to drive the Josephson array to achieve 10 V, the construction of the cryostat hardware which houses the Josephson array, the connection of the DC measurement circuitry and the automated control of the measurements.

Millimetre-wave sources covering two operating frequencies have been established. A klystron-based source operating at 75 GHz did not produce adequate stability in the array voltage as this is at the lower end of the intended array operating frequency. Some improvement has been achieved by using a Gunn oscillator at 77 GHz, the frequency of which is stabilised to ±1 Hz using a Gunn oscillator driver made by ETL. Further increases in frequency are difficult to achieve with adequate power for stable array operation.

The array is housed in a liquid helium cryostat and is routinely kept at 4.2 K as this has advantages both for the operation of the array and for the stability of the thermoelectric potentials developed in the DC measurement leads between the cryogenic and room temperature environments.

The selection of specific constant voltage steps is performed by using a programmable voltage source. Fine adjustment is made to the millimetre-wave power reaching the array to maximise the stability of the constant voltage steps. References to be measured are selected by using a scanner to connect the reference in series opposition to the array voltage and a suitable detector is used both to calculate the value of n in the Josephson equation and to monitor the voltage difference between the array and the reference.

Results and discussion

Preliminary measurements have been performed on a commercially-available electronic voltage reference since June 1995. The results show the short-term stability of the reference over 50 - 60 minutes to be typically around 3 parts in 10^8 as given by the standard deviation of 3 or 4 measurements over this period. This value is used to obtain the random or type-A uncertainty for the measurement.

Preliminary assessment has been made of the four major components of systematic or type-B uncertainty for this system. The leakage resistance in the cryoprobe, dominated by the leakage resistance of rf feedthrough filters, effects the array voltage by less than 1 part in 10^{10}. The accuracy and traceability of the applied frequency are also of that magnitude. The two most significant components are those components of the thermoelectric potentials which are not compensated by performing reversals of the controllable voltages in the measurement circuit, and the effect of the detector on the measurement. Depending on the selection of detector, the limitation to the measurement may either be due to the resolution or to the calibration of the detector.

Conclusion

A system has been established which extends the capability of DC Josephson voltage measurements at NPL from 1 V to 10 V. As with the 1 V system, the achievable accuracy of the system will far exceed[2] that required for the measurement of available voltage reference standards at 10 V. However, the existence of the new system will remove the dominant source of uncertainty in present 10 V measurements which comes from relating the value of 10 V references to the 1 V array[3],[4]. This will allow an eventual improvement in the uncertainties offered on calibrations at 10 V.

The versatility of Josephson array voltage systems also allows the production of voltages at other than nominal voltage levels. Work in the future will look into extending the use of the 10 V Josephson array voltage standard for calibrating state-of-the-art digital voltmeters.

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References

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