JOSEPHSON JUNCTION ARRAY VOLTAGE STANDARD AT THE ETL

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Abstract

A system based on the Josephson junction array of 1 V has been used to maintain the primary voltage standard at the Electrotechnical Laboratory (ETL) since January 1, 1990. The configuration and performance of the system are described. The uncertainty of 1.8 x 10^{-8} is obtained at least for the calibration of a Zener voltage reference performed in a run of 45 minutes.

Introduction

Several national standard laboratories and institutions (including industries) are already using 1 volt Josephson junction array voltage standard to calibrate their secondary standards [1-3]. Here we report on the 1 volt Josephson junction array voltage standard developed at the ETL. It has been used in place of the previous 10 mV Josephson system for the maintenance of the primary voltage standard of the ETL since January 1, 1990.

Although we have demonstrated [4] that a Weston cell can be calibrated with an uncertainty of 7x10^{-9} by utilizing a junction array, the system we used at that time was not automated and involved 3 cryostats (one for junction array, one for SQUID galvanometer, and one for SQUID constant current source). Hence it took a whole day for the measurement including preparation and data analysis.

In the new system design, we took into account to reduce time and physical consumption required for measurement. That is to automate the system, to use a digital volt meter (DVM) for a null detector, and to use a Zener voltage reference as a buffer for the ETL secondary standard of the Weston cells. Configuration of the new system is illustrated in Fig. 1. Details of the components are described in chapter two, and the operation and the performance of the system evaluated in November 1989 are described in chapter three.

System Components

Junction Array The junction array consists of 2400 Nb/AlOx/Nb Josephson junctions. The critical current of the junctions is 600 µA, and the junction array generates constant voltage steps up to 1.4 volt when irradiated by 94 GHz millimeter wave provided from a 60 mW output Gunn oscillator. The current width of the steps at 1 volt is typically 100 μA_{p-p}.

Millimeter Wave Source The Gunn oscillator (Millitech GDM-10-4-18) has an output power of 60 mW, and its frequency is mechanically tunable at the range of 94 GHz ± 1 GHz. The driver (i.e. a combination of a dc power supply and an amplifier to feedback signal from a phase lock controller) is custom-made to acquire sufficiently low phase noise performance. The frequency is stabilized by a counter/phase-lock controller (EIP 578B). The frequency of the Gunn oscillator can be set to desired value with 0.1 ppm resolution with this equipment. The reference frequency for the phase-lock controller is provided from a rubidium frequency standard via a synthesizer (HP 3335A). The synthesizer has a resolution of 1 mHz, and can adjust the 10 MHz reference frequency slightly with 0.0001 ppm resolution. By this configuration, the frequency of the Gunn oscillator can be adjusted to 0.0001 ppm with an accuracy better than 1 x 10^{-10}. Electrically tunable range of this system is ± 20 MHz, which corresponds to ± 1 step range of array's voltage at 1 volt. Thus the step number of the array that must be biased onto has an allowance of ±1, and electrical frequency tuning adjusts the array voltage exactly to the desired voltage.

Bias and Monitor Bias circuit is custom-made. It is computer-controlled to automate the step selection sequence. Circuit insulation from the ground is carefully accomplished. Two DVM's and an oscilloscope are also connected to monitor the current, voltage, and the I-V characteristic. Isolation amplifiers are used to isolate these monitoring circuits from precise voltage lines to avoid ground loop effect which causes an voltage measurement error.

Null Detector A digital volt meter (Advantest R6561), which has 10 nV resolution, is used as a null detector. We determined to use this model by testing several DVM's to find the best model with low radiation noise and high resolution.

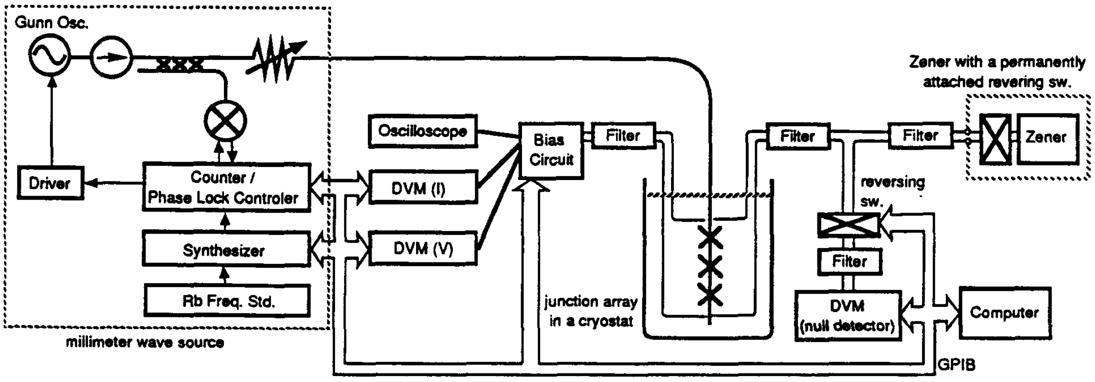

Fig. 1 Configuration of a new 1 volt Josephson junction array voltage standard.

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Table 1 Possible Uncertainty Sources and Estimated Uncertainties

1) Type A uncertainty (1σ estimation for a mean of 3 values obtained in one-run measurement.)	1.0×10^{-8}
2) Type B uncertainty (max. estimation)	
2-1) Leakage resistance	1.5×10^{-8}
2-2) Frequency instability of the millimeter wave	$< 1 \times 10^{-10}$

In order to evaluate and compensate the offset of the DVM, a computer-controlled reversing switch with low parasitic e.m.f. is used. The reproducibility of the parasitic voltage against switching operation is better than 1.5 nV.

Zener voltage reference Zener voltage references (John Fluke 732A) are used as equipments under test. To prevent an effect caused by unremovable parasitic e.m.f. generated at output terminals of the Zener (as parasitic e.m.f. may vary each time that wires are connected to the binding posts), a reversing switch and a connector were permanently attached to each Zener. Hence "the e.m.f. of a Zener" is defined by including the parasitic e.m.f. at the binding posts and the reversing switch.

Filters In order to bias stably the junction array on a desired step, noise emitted from the DVM and the Zener should be reduced. For this purpose, filters are inserted in the lines connecting these components. Details of the filters as well as the phase lock system is described elsewhere [5].

Computer Most of operating sequences are carried out by a computer (HP 300). GPIB is used for the interface in this system.

Operation and Performance

Operation

After setting a cryoprobe into a cryostat and connecting the leads, the Gunn oscillator is mechanically tuned to the frequency where millimeter wave couples optimally to the junction array. This tuning is carried out by monitoring the I-V characteristic on the oscilloscope. Next, the bias voltage is adjusted to about 200 μV larger than the Zener's voltage, and the pre-adjustment is finished. These operation are carried out manually.

Each measurement starts from selecting a desired step. Extra voltage of 9 V is added to and taken away from the bias voltage. By this operation, the bias point is moved up above the gap voltage of the array, and is successively returned back to 1 volt. The nature of the junction array makes the bias point successfully rest on the desired step (or one step upper or lower), but it may also make it accidentally rest elsewhere on a quasi-particle characteristic. A computer can judge whether this step selection trial turned out as a success or a failure by monitoring the bias current. The bias circuit is computer controlled and repeats this trial until junction array is successfully biased on a desired step. The time required for this procedure is typically a few minutes.

Next, the voltage difference between the array and the Zener is measured by the DVM. The computer calculates and adjusts the Gunn's frequency so that array's voltage balances with the Zener's.

Then small voltage difference is measured. In order to evaluate and compensate the offset of the DVM's zero, polarity reversal procedure (using computer controlled switch just before the DVM) is involved in this sequence.

In order to evaluate and compensate thermal e.m.f. in the circuit, polarities of the array and the Zener are reversed, and the measurement described above is performed twice again. Then polarities are reversed and voltage is measured again so that linear drift of the thermal e.m.f. against time should be evaluated and compensated. The polarity of the Zener is reversed at the switch attached to the Zener, while array's polarity is reversed by changing the polarity of the bias.

All these procedure are accomplished typically within 10 to 15 minutes. We usually make this measurement three times and calculate the mean to obtain the final voltage of the Zener.

Performance

Table 1 lists uncertainty sources and uncertainties estimated in November 1989. Several improvements are under progress, and final evaluation will be reported at the conference.

A long-term behavior of a Zener output of nominal 1.018 V measured with this system is shown in Fig. 2.

It shows a linear drift against time. Radius of the solid circles corresponds to about three-sigma estimation of uncertainty.

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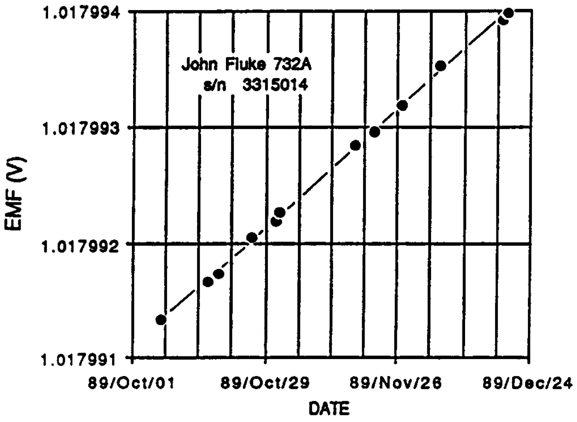

Fig. 2 Long-term behavior of a Zener's 1.018 volt.