IMPROVEMENTS FOR AUTOMATING VOLTAGE CALIBRATIONS USING A 10-V JOSEPHSON ARRAY[*]

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Abstract

With three novel improvements, a voltage standard system based on a 10-V Josephson array is totally automated. A commercial standard cell scanner controls switching for calibrating either Zener references or digital voltmeters, a programmable attenuator helps in obtaining voltage steps, and measurements of DVM noise help in verifying array stability.

Introduction

For the past three years, a Josephson array [1-3] has been used here as a voltage standard [4], directly calibrating Zener references for transferring the Volt at a fixed-value of 1.018 V. A second system was recently developed for 10 V capabilities based on a 19,900 junction Josephson-array [5]. This system is applied to more general measurements, such as calibrating Zener references at 1.0, 1.018 and 10 V, and digital voltmeters (DVMs) over many voltages from 0.0 to ±10 V. Most significantly, this array system operates completely unattended. A technician, who may be unfamiliar with Josephson array physics, only need perform a basic setup sequence for operation. We accomplish this by (1) incorporating a commercial standard cell scanner as an automated, low thermal emf switch, (2) engaging a programmable millimeter wave attenuator to generate voltage steps, and (3) verifying the stability of these steps by analyzing the standard deviation of array voltages relative to the background noise level of the DVM and Zener reference.

Summary

System Scanner Connections

The switching flexibility necessary for a multipurpose system is provided by a DataProof[†] standard cell scanner. Under normal operation, two different voltages references are connected as inputs so the scanner can switch them into series opposition while a DVM, attached to the output, completes the circuit as a differential voltmeter. The scanner also reverses the orientation of the references relative to the DVM in a method for eliminating DVM offsets and wiring thermal emfs. But unlike voltage references, an array must not be physically reversed within the circuit, though it can be electrically reversed. So an alternate approach is possible. Instead of placing the DVM at the output, we attach the array, as in Figure 1. The DVM is wired to two scanner "input" channels, one with the leads reversed relative to the other.

In this manner, selecting a Zener reference and the DVM+ channel joins them in series opposition via the array. Interchanging the A/B channels reverses the reference but also the DVM, thus necessitating the second DVM− channel. Using both DVM channels at each array polarity provides an advantage; the thermal emf in the cryogenic wiring and the DVM offset are calculated separately. Variations only in DVM offsets indicate worn switch contacts, while other thermal emf increases indicate problems in wiring caused by the severe thermal cycling.

Our Zener reference calibration is an average of four independent points, derived from sixteen DVM readings and four array polarity changes, patterned

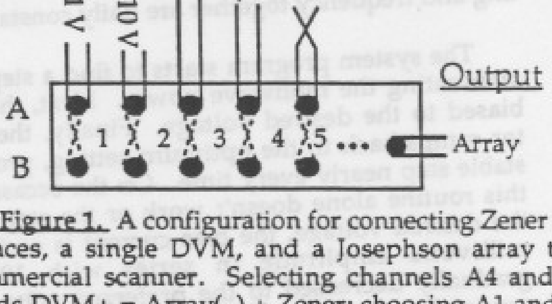

Figure 1. A configuration for connecting Zener references, a single DVM, and a Josephson array to a commercial scanner. Selecting channels A4 and B1 yields DVM+ = Array(−) + Zener; choosing A1 and B5 yields DVM− = −[Array(+) − Zener]. Our measurements average over both DVM channels.

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[†] Brand names are used only for purposes of identification. Such use implies neither endorsement by the National Institute of Standards and Technology nor assurance that the equipment is the best available.

(+--++--+). This procedure provides a straightforward calculation of the standard deviation of the mean. The Type-A random uncertainty is about 0.004 ppm at 10 V over a measurement period of 14 min, and about 0.008 ppm at 1.018 V. Note the signal/noise ratio is better at 10 V than at 1 V, but not tenfold better, because the noise level increases with voltage.

The same connection scheme works just as well for DVM calibrations. For this case, one input channel is shorted so the scanner links the DVM directly to the array. No further switching is needed. Using voltages at roughly regular values read by the DVM, the system calculates a proportionality constant (gain error) for each polarity and deviations from this linear fit at each measured value (linearity errors). Test calibration curves have included 83 points recorded in less than 2 h with 0.02 ppm resolution.

Generating Josephson Steps

Obviously in any measurement, generating array steps is an integral process, requiring sensitive adjustments of the voltage bias and millimeter wave power. Previously this meant complicated manipulations for an omnipresent operator. Some programmed routines using only electronic biasing have limited successes but must be tailored to specific voltage values, power levels, and individual array characteristics. Arbitrary voltages generated this way are often unstable and voltage-dependent attenuation levels are not predictable, especially at voltages lower than some optimum for a particular array. Using a programmable, 0-50 dB, rotary vane attenuator, we have found a reliable method of automated step selection, general enough for use with any array (1500-19,900 junctions) and at any voltage (0.0 to ±10 V). It is limited only in that an optimum power level must be set for each array, i.e., driving an array to its highest stable voltage and using just enough power to initiate a small decrease in the step current. Although this power level depends on the specific array design and drive frequency, the attenuator setting and frequency together are daily constants.

The system program starts to find a step by fully attenuating the milliwave power. Next, the array is biased to the desired voltage. Finally, the attenuator ramps back to the optimum setting, producing a stable step nearly every time. On the occasion when this routine alone doesn't work or the step is not at the desired voltage, the bias current is oscillated by millivolts amplitude in series with 10 Ω and gradually decreased to the preferred voltage. This routine loops until a good step is found. Failures of this combined routine within the last year were all from correctable problems: low liquid helium levels, insufficient power due to waveguide obstructions, excessive rf noise from poor bias cable shielding, Zener reference power supply noise, or in one case, a physically deteriorating array.

Verifying Array Steps

Verifying array steps is of major importance. Since multiple DVM readings are always involved, the standard deviation of each series is used as the vital parameter to monitor step quality. A step is effectively checked twice; once quickly while dithered with 1-2 µa and then again using the crucial measurement data to make sure there was no step jump. If the standard deviation is more than about 1.5 times greater than the background noise, the computer repeats the measurement or a new step is generated. We place great reliance upon the DVM to read precise voltages as high as 10 V, so at least 7 digits resolution in less than 30 s integration time is desirable. In this way the automation successfully guarantees good, stable, Josephson voltage steps. In normal operation, no oscilloscope is used.

We are testing DVM and Zener references from various manufacturers for the instrument noise levels incorporated into the programming. Through these studies we are also investigating algorithms and procedures for DVM calibration in hopes of using DVMs at accuracies better than 0.1 ppm in experiments where automation is desired and it is difficult or impractical to use an array [6].

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