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The cover design depicts the microwave planar near-field scanner being developed at NPL.

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Automation of the NPL 1 V Josephson array voltage standard

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1. Introduction

In recent years, Josephson array voltage standards[1] have become an indispensable part of the maintenance of DC voltage in the majority of the world's national standards laboratories, and in an increasing number of industrial standards laboratories (mainly in the USA to date). Although the operation of a Josephson standard has been greatly simplified since single and dual junction systems gave way to Josephson arrays over the last 6 or 7 years, it is still a measurement best performed by specialist operators. Clearly, automation of the measurements would further simplify the process and reduce the likelihood of errors by inexperienced operators.

Some national laboratories have automated their Josephson array systems to a large degree[2], [3]. In such an automation it is sufficient to obtain results adequate to characterise the behaviour of available voltage reference standards, often Zener diode-based references, measured with an accuracy of a few parts in 10^8 . A Josephson array voltage standard is capable of much better accuracies, typically around 5 parts in 10^{10} [4],[5], when measuring another Josephson standard.

The NPL Josephson array standard has undergone a gradual programme of automation since last reported[6]. At that time, a computer was used only to take readings of a DVM and frequency counter, and subsequently to calculate results. This paper will report the options now incorporated for routine use and will describe the progress to date on the automation of the voltage step selection process - the most difficult part of the full automation of the complete Josephson system.

2. Control of the measurement process

The NPL Josephson junction array voltage standard in routine use relies on manually selecting the required Josephson constant voltage step using a "training" voltage generated by passing a variable current through a fixed resistor. Once the required millimetre-wave electromagnetic radiation is applied to the array, the training voltage can be disconnected, leaving the array unbiased on a constant voltage step given by

$$V_J = nK_J^{-1}f$$

where n is the total number of constant voltage steps produced by the junctions in the array, K_J is the Josephson constant $2e/h$ and f is the applied millimetre wave frequency.

The operator selects options from an equipment list including which type of DVM monitors the total array voltage (used to calculate the value of n), which detector is to be used to

monitor the difference in voltage between the Josephson array and the voltage reference being measured, and which type (from a selection of two) of millimetre-wave source is being used. Depending on the detector selected, the computer either reads and corrects the difference voltage, or proceeds to change the source frequency, thus changing the Josephson array voltage, to reduce the difference voltage to less than 1 part in 10^7 of the nominal voltage. A further change of 1 part in 10^7 in voltage passing through the null of voltage difference, allows the exact null to be calculated. The readings are corrected to the null to allow the standard deviation of the measurement to be assessed. To remove the effect of thermoelectric emfs from the measurement, the process is repeated with the array voltage being reversed manually and a reversing switch connected to the reference being reversed automatically.

A typical set of results of the measurement of a commercial Zener diode-based reference is shown in Figure 1.

Polarity	Frequency	Deviation	No. rdgs	Time	
Set number 1					
+	87.49892151	0.000010	20	17.34	
-	87.49958315	0.000010	20	18.34	
+	87.49892457	0.000008	20	20.26	
-	87.51513662	0.000011	20	22.50	
+	87.51447688	0.000010	20	24.63	
Measurement of 5785002 on 1.9.1993					
Times are given in minutes after 15.00 hours					
Polarity	Step no	Measured voltage	Polarity average	Result	Time
Set number 1					
+	5627	111.186	111.186		
-	5627	118.884	118.884		
+	5627	111.221	111.221	115.044	18.82
-	5626	118.893	118.893	115.055	20.47
+	5626	111.218	111.218	115.056	22.48
Mean of results is 115.052 μ V above 1.018V at 20.59 mins					
with standard deviation of +/-0.006 μ V					

Figure 1 Typical measurement results

3. Automation of the step selection

The requirements for automation of the step selection process rely on identifying parameters which control the generation of the constant voltage steps and can be operated and monitored under computer control. The parameters are the "training" voltage and the millimetre-wave power level applied to the array, thus a commercial IEEE-programmable voltage source and a variable attenuator operated by an IEEE-controllable stepper motor have been purchased.

The voltage noise generated by the programmable voltage source exceeds that of the previous battery-driven current source and resistor, giving a requirement for extra L-C filtering in the bias connections. Another difference from the manual process is that the voltage source remains connected to the array during the measurement, making assessment of the step quality more critical (an unbiased step has zero resistance, a biased step may show a resistive slope

causing a measurement error). The existence of constant voltage steps can be shown by the frequency to voltage conversion in the array; if no steps are present changing the frequency will not effect the monitored voltage. Alternatively, a predictable change in voltage will be measured.

The limit to the measurement of the resistance of a voltage step is the voltage noise present in the measurement, dominated by the voltage noise of the voltage reference to be measured. Whilst the array is biased on a voltage step, the biasing voltage is changed by a few microvolts. Any difference in voltage between the bias voltage and array voltage causes a small current to flow, giving a non-zero bias current to the array but, for a zero resistance step, no change to the step voltage. A current monitor with a sensitivity of 1 mV/1 μ A connected to an oscilloscope shows the bias current. There should be no change to the difference voltage between the array and the voltage reference, with the limit of the measurement being the resolution of the balance.

Using the indicators above, it is possible to arrive at an algorithm for stable generation of constant voltage steps. However, should stable operation not be attained, small adjustments or even removal and re-application of the millimetre-wave power to the array is included in the algorithm. The present state of the process shows that by manipulating the equipment manually through these processes, it is possible to achieve constant voltage steps and to regenerate them in the opposite polarity when required by reversing the polarity of the biasing voltage.

4. References

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