

The automated two Josephson array system for RVD calibrations

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Abstract

This paper describes the progress with the NPL Josephson junction array voltage standards. The JJAVS achieves a system uncertainty of 2 parts in 10^9 and an uncertainty for measurement of zener reference standards of 11 parts in 10^9 for a confidence level of $k=2$. The system is also capable of calibrating state-of-the-art digital voltmeters (DVMs). A two Josephson array system has also been developed for the calibration of resistive voltage dividers (RVDs) with the intention of simplifying the calibration process and enabling the calibration of any ratio that is capable of measuring the ratio to 1 in 10^7 .

Introduction

It is now the norm for national standards laboratories to maintain their DC voltage standards relative to a Josephson junction array voltage standard (JJAVS) so as to gain the advantage of accurate and straightforward traceability for DC voltage. Josephson junctions, made in arrays from niobium / insulator / niobium and held at a temperature around 4 K, produce a constant DC voltage V given by

$$V = nK_J^{-1}\nu$$

where n is an integer, $K_J = 2e/h$ is the Josephson constant where e and h are fundamental physical constants and ν is the frequency of electromagnetic radiation between 70 and 95 GHz applied to the junction. For these frequencies the difference in voltage between adjacent steps n and $n+1$ is 145 and 196 μV respectively.

Arrays of these junctions are used to produce voltages in excess of 1 V (3000 junctions) or 10 V (20000 junctions). The National Physical Laboratory has operated a 1 V JJAVS since 1987^[1] and a 10 V JJAVS since June 1995^[2]. The additional versatility gained from working up to 10 V allows measurements to be made, not only of zener-based voltage reference standards, but also of DVM characteristics such as gain and linearity up to their 10 V range.

JJAVSs at NPL

The NPL currently runs both a semi-automated 1 V and an automated 10 V JJAVS (fig 1). The Josephson arrays are housed in cryostats containing liquid helium at 4.2 K and can be either one purchased from Hypres Inc manufactured using technology transferred from NIST, or one made by PTB.

The millimetre-wave source used to produce the electromagnetic radiation is normally a phase-locked Gunn diode oscillator (86 GHz for the 1 V JJAVS and 70 GHz for the 10 V JJAVS) but can be produced using a klystron oscillator. The frequency used is dependent on the characteristics of the individual array. Traceability is provided from a 10 MHz signal produced by one of the two hydrogen masers used to maintain UTC(NPL) by the Time and Frequency section of NPL.

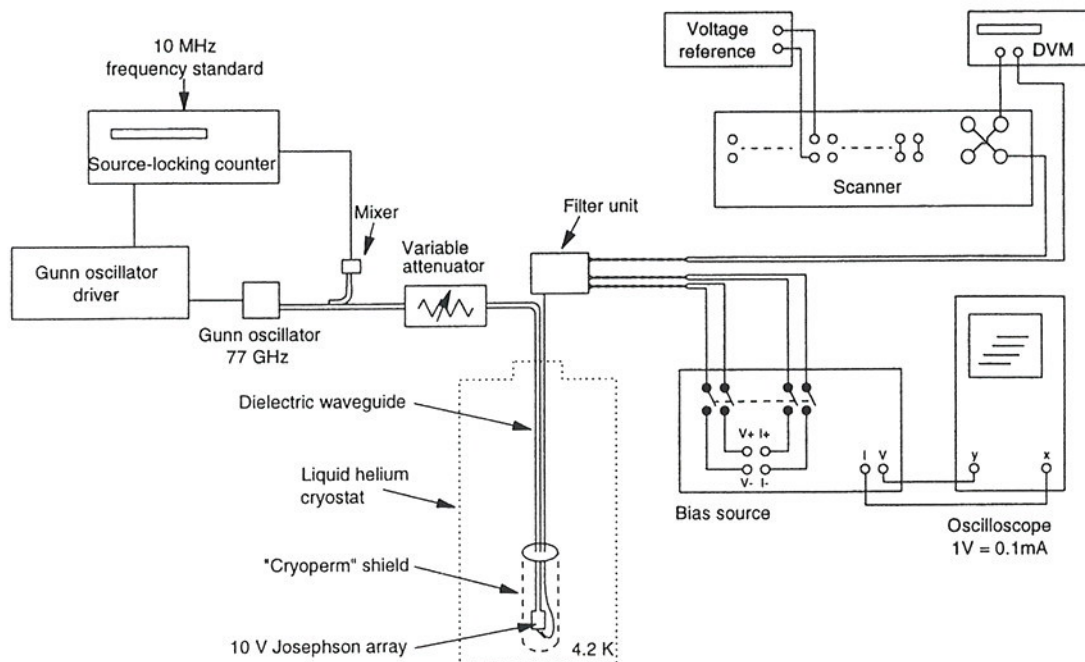


Figure 1 Block diagram of the NPL 10 V JJAVS

On the 1 V JJAVS, the device under test (DUT) is placed in series opposition to the array voltage and a manual bias source is used to train the array onto the step nearest the voltage of the DUT. The bias source is then disconnected and the frequency applied to the array is adjusted so that its voltage is the same as that of the DUT. The polarities are then reversed and the measurement repeated to eliminate any thermals. However on the 10 V JJAVS the step stability is not quite as good, so the array is trained on to a step within 10 mV of the DUT and a difference measurement is performed using a calibrated nanovoltmeter. Again full reversals are performed, using the NPL low thermal switch system, to eliminate any thermoelectric emfs. Regular comparisons between the two systems are performed at 1 V using a zener-based transfer standard.

During the commissioning and early use of the 10 V JJAVS problems were observed with interference which was traced to the programmable bias source being used. This was modified to use the NPL fibre optic ring interface and the 50 Hz isolated power supply developed at NPL.

Two array measurements of an RVD

This method has been developed to simplify the measurements by avoiding the lengthy traditional build up processes using series parallel networks and eliminating the problem of having to use combining networks to balance the two RVD's in a bridge measurement. The systematic uncertainties of the system should also be reduced to produce more accurate measurements.

For initial testing of the feasibility of an RVD calibration using two Josephson, a prototype was constructed using two 10 V arrays and components from the two existing systems. A simple sampling program to record all the information was also written so that the results could then be analysed.

Two different measurement configurations were used in making measurements of the RVDs. The first configuration (fig. 2) uses the two arrays to measure the input and the output voltages on the RVD (method 1). The second method (fig. 3) was to measure the voltage drop between the input and output terminal and the output terminal (method 2). The second method had the advantage that a Wagner circuit could be used to hold the output terminal close to screen potential removing any concerns about leakage across the detector. This was not possible with method 1 because one of the bias sources has a permanent screen connection.

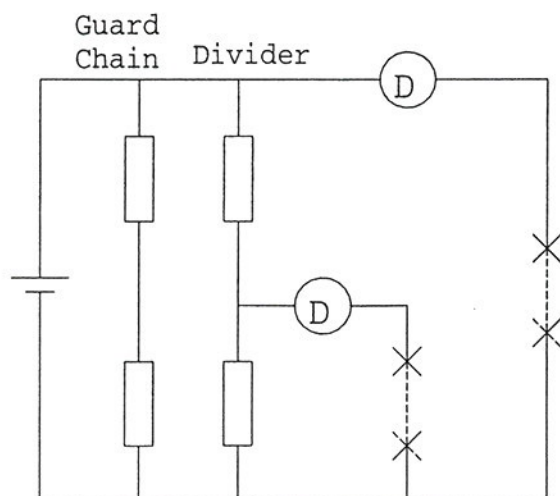


Figure 2 Block diagram of method 1

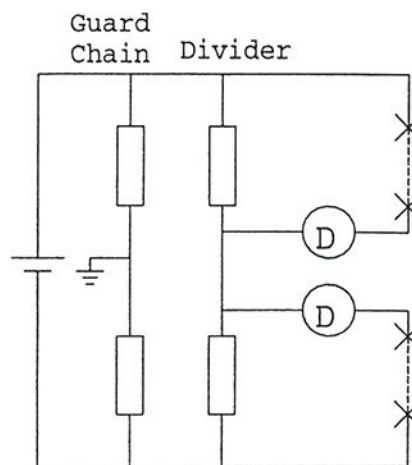


Figure 3 Block diagram of method 2

The RVD was energised using a 10 V zener reference with a low thermal reversing switch and the input and output voltages measured using the two JJAVSs. Each JJAVS consisted of a bias source, a DVM to monitor the array voltage and a nanovoltmeter to measure the difference between the array voltage and the relevant voltage to be measured.

The bias sources were manually trimmed to within 10 mV of the voltage to be measured and then disconnected. The phase-locked frequencies of the two arrays were recorded and the sampling program then took a set of measurements of the time, array voltage and difference measurement of both the required voltages so that a mathematical software package could be used to calculate the ratio.

Results

Ratio	Traditional (V)	Method 1 (V)	Method 2 (V)	MEAN (V)	Std Dev (uV)	Std Dev ppm
10:1	0.9999878	0.9999881	0.9999876	0.9999878	0.18	0.18
10:2	1.9999788	1.9999790	1.9999782	1.9999787	0.29	0.15
10:3	3.0000305	3.0000303	3.0000298	3.0000302	0.25	0.08
10:4	4.0000143	4.0000136	4.0000133	4.0000137	0.36	0.09
10:5	5.0000104	5.0000094	5.0000108	5.0000102	0.51	0.10
10:6	6.0000173	6.0000139	6.0000161	6.0000158	1.22	0.20
10:7	7.0000415	7.0000384	7.0000402	7.0000400	1.10	0.16
10:8	8.0000240	8.0000207	8.0000228	8.0000225	1.18	0.15
10:9	8.9999968	8.9999939	8.9999941	8.9999949	1.15	0.13

Table I Comparing the results against the JJAVS with a traditional method using build up techniques.

Current Status of Development

In conjunction with the European Provolt project NPL has developed an isolated fully automated bias source based on the fibre optic ring interface controlled ADC/DAC^[3] board that can also monitor the array characteristics. A LabVIEW driver to control the bias source has also been developed. Figures 4 & 5 show the characteristics of a 1V array being driven using the new bias source.

A new suite of software is under development to take the Voltage and Resistance section into the 21st century to give the operator the ability to perform a greater range of measurements using the apparatus available.

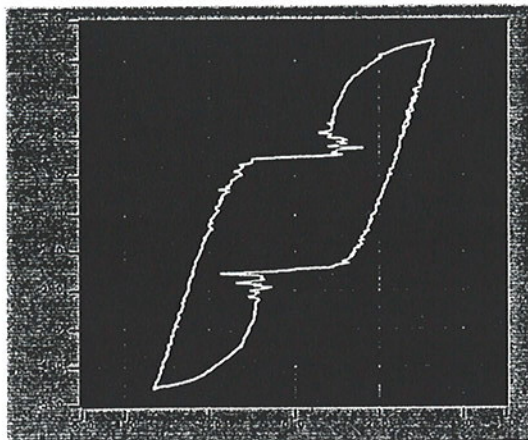


Figure 4 Array characteristics with microwaves applied using the new software.
y axis = 1 V/division and
x axis $\approx 20 \mu\text{A}/\text{division}$

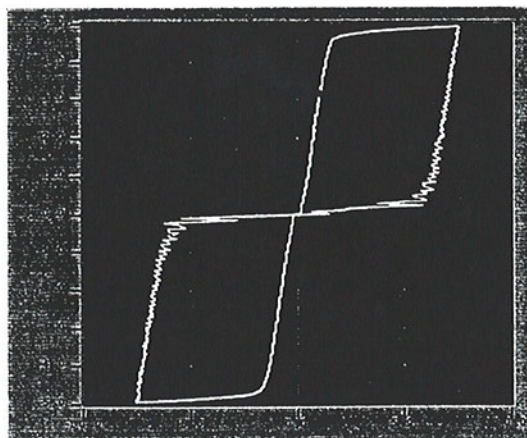


Figure 5 The DC Josephson characteristic of a 1 V JJAVS
y axis = 1 V/division and
x axis $\approx 50 \mu\text{A}/\text{division}$

Conclusions

The NPL JJAVSs have now reached a stage of development allowing for routine measurements of a variety of voltage instruments and devices. Further development of the systems will enable the NPL to perform a wider variety of tasks with greater ease than is currently available.

Acknowledgements

The authors would like to thank Jürgen Nemeyer of PTB, Germany for the Josephson arrays used for much of the work presented here, to Haruo Yoshida, Yasuhiko Sakamoto and Tadashi Endo of ETL, Japan for the Gunn oscillator driver used to stabilise one of the frequency sources and to Ian Robinson and Robin Buller for the design of the isolated bias source. This work was supported by the Electrical Programme of the National Measurement System Policy Unit of the DTI, UK.

References

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