Improvement of Leakage Resistance of PJVS for NIST-4 Watt Balance Experiment

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Abstract[1] **— A Programmable Josephson Voltage Standard (PJVS) system is used for the voltage measurements in the NIST-4 watt balance experiment. In order to achieve the uncertainty of voltage measurements better than 1 part in 10^9, it is critical to increase the leakage resistance of the PJVS to ground. This paper describes how to modify the watt balance PJVS system to isolate the bias electronics and quantify its resistance to ground. Direct comparison between the watt balance PJVS (WPJVS) and NIST Volt Lab PJVS (VPJVS) was carried out to verify the performance of WPJVS with improved isolation resistance.**

Index Terms **— bias electronics, isolation transformer, leakage resistance, programmable Josephson voltage standard, uncertainty.**

I. Introduction

A fourth generation watt balance experiment at the National Institute of Standards and Technology (NIST-4) has been constructed in preparation for the redefinition of the International System of Units and the realization of mass through an exact value of the Planck constant [1]. The total relative uncertainty goal for this instrument of a few parts in 10^8 requires that the relative uncertainty of voltage measurements in velocity mode or force mode is on the order of one part in 10^9. This paper describes the leakage resistance measurement related to the watt balance Programmable Josephson Voltage Standard (WPJVS) and its improvement by using an isolation transformer for the WPJVS bias electronics. A direct comparison between the WPJVS and a second PJVS maintained in the NIST Volt Lab (VPJVS) was carried out to assure the uncertainty contribution to the watt balance uncertainty budget is within the allowance.

II. WPJVS Leakage Resistance

The conventional Josephson Voltage Standard (CJVS) uses zero-current voltage step and voltage bias electronics. When the bias electronics is disconnected from the Josephson junction array as is often the case in many CJVS applications, the array is floating from the ground. With the bias lines disconnected, the CJVS leakage resistance is given by just the cryoprobe and the wiring, which tends to be very high in the order of 100 GΩ range, and as such does not have a significant error contribution. In contrast, PJVS uses current bias to establish quantized voltage steps and the current bias electronics must remain connected to the array for the duration of the measurements. Thus, the leakage path to ground through the current bias electronics and its dedicated power supply has to be taken into account. The NIST-4 WPJVS uses a commercial instrument, a National Instruments NI PXI-1042Q chassis with 6 PXI-6230 multifunction cards[2] along with custom-designed voltage-to-current converters to provide the bias currents to each cell on the array.

The leakage resistance to the ground of PJVS is defined as the electrical resistance of one side of the measurement leads to ground. If the low side of the array is grounded in a direct comparison measurement with another JVS, then the leakage resistance will reduce the PJVS output voltage U by a systematic voltage error, e, based on the following equation:

$$e = U \times r_m / R_L \qquad (1)$$

where r_m is the resistance of the precision leads and R_L is the PJVS leakage resistance to ground [2]. For the watt balance experiment, the voltage on a 100 Ω resistor in the force mode or the voltage generated by a moving coil with 100 Ω resistance in the velocity mode is measured against the WPJVS at 1 V, therefore r_m would include the resistance of 100 Ω resistor in the force mode or 100 Ω of moving coil resistance in the velocity mode. As a first-order approximation the WPJVS requires a leakage resistance larger than 100 GΩ for a 1 part in 10^9 uncertainty contribution to meet the requirement of total uncertainty budget of a few parts in 10^8 for the watt balance experiment.

III. WPJVS Leakage Resistance Measurement and its Improvement

Specific details concerning the measurement of PJVS leakage resistance to ground is described in reference [2]. A resistance r is connected from one side of the array to ground. The other side of the array, at a potential U, is left open so that the only path to ground is through the leakage resistances R_L, where R_L includes the isolation resistance of the leads and the leakage to ground of the bias source through the digital-to-analog converter (DAC) voltage cards PXI-6230, as well as the amplifier board power supply. After multiple measurements at r = 500 kΩ, the WPJVS leakage resistance to ground was determined to be 48 GΩ with standard deviation of 4 GΩ.

Two options are available in order to further improve the WPJVS leakage resistance. One common method is to use, for example, batteries as a power supply for the PXI chassis. An

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[2] Certain commercial equipment, instruments, or materials are identified in this report to facilitate understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment that are identified are necessarily the best available for the purpose.

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alternative is to use a commercial air gap isolation transformer to increase the isolation of NI PXI-1042Q chassis to ground as shown in Figure 1. The secondary winding is completely galvanically isolated from the primary winding and the transformer core. Figure 2 shows the circuit of the isolation transformer. The isolation resistances between the primary and secondary windings and to their ground taps were measured using a teraohmmeter. The coupling capacitance between the windings and to their ground taps were also measured as listed in Table 1.

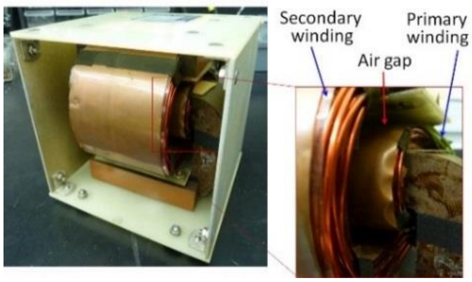

Fig. 1 An air gap isolation transformer

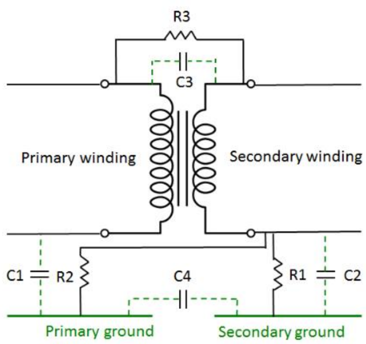

Fig. 2 Circuit diagram of the isolation transformer

Table 1 Characterization of the isolation transformer

Isolation resistance (TΩ)		Capacitance (pF)	
*R*1	2.5	C_1	343
*R*2	19.5	C_2	1060
*R*3	17.8	C_3	33
		C_4	37

We then used the isolation transformer to power the NI PXI-1042Q chassis and current bias electronics. The WPJVS leakage resistance was measured again using the same setup as for the WPJVS without the isolation transformer described above. Figure 3 shows the leakage measurement results with associated Type A uncertainty. The average leakage resistance was 120 GΩ ± 6 GΩ at the voltage of 0.99 V. The measurements were also carried out at a voltage of 2.31V with average leakage resistance of 128 GΩ ± 10 GΩ, indicating the leakage resistance does not change significantly within the typical range for watt balance experiment. Another leakage path between the center conductor and ground of the SMA DC block in the microwave path was also tested. The measured leakage resistance of the block was greater than 200 GΩ.

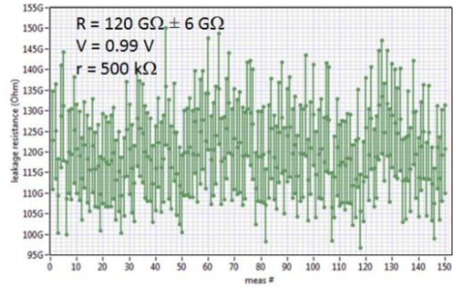

Fig. 3 WPJVS leakage resistance measurements with isolation transformer used to power PXI-1042Q and current bias electronics.

IV. Direct comparison between WPJVS and VPJVS

To assure that no systematic error is associated with the WPJVS a direct comparison between WPJVS and VPJVS was carried out at 0.991 V. The setup is shown in Figure 4. An automatic protocol was developed to perform the data acquisition. A digital nanvoltmeter (DVM) Keysight 34420A[2] was used to measure the difference between the two voltages generated by WPJVS and VPJVS. A total of four runs at 0.991 V were performed with the isolation transformer used to power PXI chassis and current bias electronics. An overnight run can collect 150 to 200 comparison points. We used the 1/*f* noise floor of the DVM to express the Type A uncertainty when the standard deviation of the mean of the data is smaller than the 1/*f* noise floor of the DVM. The difference between the WPJVS and VPJVS at 0.991 V was found to be 0.03 nV with an expanded combined uncertainty of 0.6 nV or 6 parts in 10^{10} (k = 2).

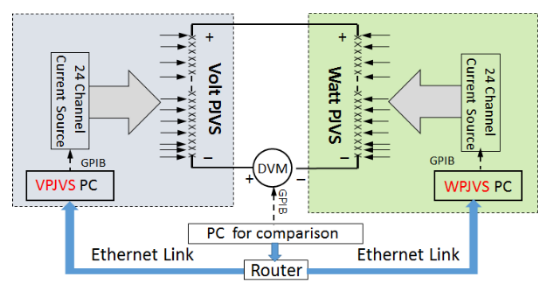

Fig. 4 Setup for automatic comparison between WPJVS and VPJVS.

V. Conclusion

By using an air gap isolation transformer to power the WPJVS PXI chassis and current bias electronics, the leakage resistance of the WPJVS is increased from 48 GΩ to 120 GΩ to meet the requirement for the NIST-4 watt balance experiment in its voltage measurement.

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