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Publisher’s version / Version de l'éditeur:
https://doi.org/10.1109/CPEM.2012.6250646
2012 Conference on Precision Electromagnetic Measurements, pp. 36-37, 2012-07-30

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Investigation of Systematic Errors of an AC Josephson Voltage Standard

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***Abstract* — This paper presents results of experiments quantifying two systematic errors associated with the calibrations by use of an AC Josephson Voltage Standard: the change in the voltage leads error with the change in the level of probe immersion in the liquid helium, and the effect of the internal inductance of a Josephson array. The measurements were performed at frequencies 100 kHz and above, however, they can be used in evaluating an error budget at lower frequencies.**

***Index Terms* — Digital-analog conversion, Josephson arrays, measurement uncertainty, quantization, signal synthesis, standards, voltage measurement.**

I. INTRODUCTION

The AC Josephson Voltage Standard (ACJVS) established at the NRC closely follows the NIST design, [1], [2]. At the heart of the standard is a superconducting Josephson junction array (JJA) generating quantum-accurate voltage pulses when energized by a train of high frequency current pulses, clocked at 10 GHz. The energizing current pulses are modulated by a low frequency sinewave and the same low frequency component appears in the output voltage pulses. This component is in principle quantum-accurate, and can be calculated solely from the number of junctions in the array, the frequency of the current pulses and fundamental constants. At the present level of technology, the ACJVS rms output voltage is limited to 300 mV, the lowest frequency to a few tens of hertz and the highest frequency to 1 MHz.

To implement the ACJVS as the primary standard of the ac-dc transfer difference, the ACJVS instrumentation errors have to be identified and quantified. Several systematic errors have been discussed previously, [3]-[5]. This summary presents results of tests quantifying two components; one intrinsic to the output voltage leads error and the second to the internal inductance of the JJA.

II. VOLTAGE LEADS ERROR

The transfer of the ACJVS voltage value to a secondary standard is degraded by the voltage drop/rise on the relatively long leads (1.3 m) between the quantum-accurate voltage source, the Josephson array immersed in the liquid helium, and the room-temperature secondary standard. This error can be corrected to a certain degree with the correction calculated from the parameters of the leads and the load, [6], the experimental measurements, [7], or both [8].

Table I. ac-dc difference TTS calibration change due to 0.1 m liquid He probe immersion change, μV/V.
TTS range: 22 mV, test voltage - 10 mV.

	Frequency MHz			dc reversal
Leads	0.1	0.5	1	μV
#1	+5	+8	+4	-47
#2	-5	-105	-341	+19
#3	-2	-37	-101	+117
#4	-2	-59	-196	+20
#5	-1	-27	-115	+92
#6	-5	-50	-115	+20

Microcoax and twisted pair line voltage leads: #1 microcoax H Ø 1 mm, #2 Ø 0.25mm, magnet wire, #3 Ø 0.25 mm, solid wire PVDF insulated, #4 Ø 0.32 mm, stranded wire, Teflon insulated, #5 microcoax L Ø 1 mm, #6 Ø 0.64 mm solid wire, Teflon insulated.

Table II. Change in cryoprobe voltage leads resistance, Ω.
Position: Bench – probe at the room temperature, Dewar top – probe installed in the Dewar but not immersed in the liquid He, immersed – probe fully immersed.

	Leads					
Position	#1	#2	#3	#4	#5	#6
Bench	1.6	1.1	0.94	0.60	1.1	0.18
Dewar top	1.1	0.65	0.63	0.40	0.78	0.11
Immersed	0.46	0.37	0.36	0.26	0.16	0.06

The accuracy of the leads correction is limited by the changes in the leads parameters with the level of the probe immersion in the liquid He, [9]. To test the magnitude of these changes, a series of tests was performed for six different lead types: two flexible microcoax cables and four twisted-pair lines. For every type of leads a commercial Thermal Transfer Standard (TTS) was calibrated twice, with the test probe fully immersed in the liquid He and then raised by approximately 0.1 m from the lowest point. The differences in both calibrations at three frequencies are shown in the Table I, columns 2 to 4. Column 5 shows the dc reversal, the difference in the input voltages of the TTS when equal positive and negative dc voltages were generated by the ACJVS. This difference is an indicator of the thermal voltages generated at the contact points of voltage leads.

The RLC parameters of the probe leads were also measured in the function of the level of immersion. Only the probe prepared from the PVDF insulated wire has shown a significant change in the parallel capacitance between the lead wires (decrease by approximately 50% when fully immersed), none of the leads has shown a significant change in the series inductance. As expected, all leads have shown a significant change in the series resistance, as shown in Table II.

The numerical data presented in Table I are only valid for comparison purposes. The voltage drop on the leads changed very significantly with the actual loading. The reported data were obtained with a 6 MHz first order RC filter and a coaxial cable (0.9 m) between the cryoprobe output and the TTS. The lowest change observed in these conditions was with the coaxial leads #1, however the same leads also show an increase in the reversal error. A large reversal error can degrade accuracy of ac-dc calibrations even at frequencies when the voltage leads error is negligible.

III. INTERNAL INDUCTANCE VOLTAGE DROP

The low-frequency-modulated energizing current pulses create a voltage drop on the internal inductance of the JJA, [4]. Ideally, a low frequency component of this voltage drop is much smaller than, and orthogonal to the quantum-accurate low frequency JJA voltage, so the sum of these two voltages, the ACJVS output voltage, remains quantum accurate. In the actual instrumentation, the low and high frequency components of the energizing pulses are delivered to the array separately; the two voltages are no longer exactly in quadrature. This quadrature phase defect, together with the value of the internal inductance of the array, and the magnitude of the low frequency component of the current pulses, can be used to estimate the ACJVS systematic error arising from the internal inductance voltage drop.

The internal inductance of an array was measured by applying a known low frequency ac current and measuring a voltage drop. The measured inductance was 6.9 nH, for an array containing 5120 Josephson junctions, 10.1 nH for a 6400 junctions array. The phase defect from the quadrature was measured by a method described in [4]. Table III show measurement results for two 6400-junction arrays, situated on the same chip (designated Left and Right). It is interesting to note that the phase defects for these two arrays are not identical and of the opposite signs. The last two rows show a calculated systematic error when these arrays are used in calibration of a 100 mV ac-dc transfer standard. The opposite sign of the errors suggest that the error can by averaging results from the Left and Right arrays.

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Table III. Phase defect, in electrical degrees, and the associated ac-dc transfer difference error at 100 mV, μV/V.

	Frequency kHz					
Array	50	100	150	200	250	300
Array Left	0.0	-0.3	-0.8	-1.2	-1.7	-2.3
Array Right	0.6	1.6	2.4	3.4	4.4	5.2
	ac-dc transfer difference error					
Array Left	0	-2	-6	-12	-22	-35
Array Right	1.6	8.2	18	34	56	79

SUMMARY

The ACVJS instrumentation errors increase with the output voltage frequency. Magnitudes of two such errors are discussed in this paper, one related to the change in the resistance of the voltage leads with the level of liquid He immersion and second, due to the internal inductance of the JJA. The experiments were conducted at frequencies 100 kHz and above, the presented results can be extrapolated to estimate these errors at lower frequencies.

ACKNOWLEDGEMENT

The author would like to thank Dr. Sam Benz and the NIST Quantum Voltage Project for providing the JJ array and the collaborative support.

REFERENCES

[1] S.P. Benz and C.A. Hamilton, “A Pulse-Driven Programmable Josephson Voltage Standard,” *Appl. Phys. Lett.*, vol. 68, no. 22, pp. 3171-3173, May 1996.

[2] S.P. Benz,.P.D. Dresselhaus, A Rufenacht, N.F. Bergren, J.R. Kinard, R.P. Landim, "Progress Toward a 1 V Pulse-Driven AC Josephson Voltage Standard," *IEEE Trans. Inst. Meas.*, vol. 58, No. 4, pp. 838-842, April 2009.

[3] C.J. Burroughs, S.P. Benz, P D. Dresselhaus, “AC Josephson voltage standard error measurements and analysis,” *IEEE Trans. Inst. Meas.*, vol. 52, no. 2, pp. 542-544, April 2003.

[4] R. P. Landim, S. P. Benz, P. D. Dresselhaus, and C. J. Burroughs, “Systematic-error signals in the ac Josephson voltage standard: measurement and reduction,” *IEEE Trans. Inst. Meas.*, vol. 57, no. 6, pp. 1215-1220, June 2008.

[5] T.E. Lipe, et al. “Thermal Voltage Converter Calibrations Using a Quantum AC Standard,” *Metrologia,* vol.45, no.3, pp.275-280, June 2008.

[6] P.S. Filipski, J.R. Kinard, T.E. Lipe, Y.H. Tang and S.P. Benz, “Correction of Systematic Errors due to Voltage Leads in AC Josephson Voltage Standard,” *IEEE Trans. Inst. Meas.*, vol. 58, No. 4, pp. 853-858, April 2009.

[7] H. E. van den Brom, E. Houtzager, “Minimizing Voltage Lead Corrections for a Pulse-Driven Josephson Voltage Standard,” in *Proc. CPEM 2010*, Daejeon, Korea, June 2010, pp. 6-7.

[8] P. S. Filipski, M. Boecker, S. P. Benz, and C. J. Burroughs, “Experimental Determination of the Voltage Lead Error in an AC Josephson Voltage Standard,” *IEEE Trans. Instrum. Meas.*, vol. 60, July 2011, pp. 2387-2392.

[9] J.R. Kinard, (private communication, NIST, May 2010).