Calibration System for AC Measurement Standards Using a Pulse–Driven Josephson Voltage Standard and an Inductive Voltage Divider

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***Abstract* — A pulse-driven ac Josephson voltage standard (ACJVS) has been set up at the National Measurement Institute, Australia (NMIA) with the assistance from the National Institute of Standards and Technology (NIST). The ACJVS forms the basis of a high precision calibration setup for ac measurement standards at audio frequencies. The ACJVS can presently produce up to 100 mV. A precision inductive voltage divider increases the measurement range to 100 V at frequencies from 57 Hz to 1 kHz. Preliminary measurements conducted on a thermal transfer standard and a voltmeter show agreement with the conventional calibration within its uncertainties.**

***Index Terms* — Ac voltage standard, ac voltage measurement, inductive voltage divider, Josephson arrays, Josephson junction, pulse-driven Josephson voltage standards.**

I. Introduction

Quantum ac voltage sources based on a pulse-driven ac Josephson voltage standard (ACJVS) [1] have been successfully used for low-voltage ac-dc transfer calibrations [2], [3]. The ACJVS uses an array of Josephson junctions, driven by delta-sigma modulated radio frequency pulses, to create precisely known voltages with a defined harmonic content. Since the maximum voltage achievable by the ACJVS is presently several hundred millivolts, its main application for metrological purposes has been calibration of thermal transfer standards (TTS) on their millivolt ranges [2], [3].

At the National Measurement Institute, Australia (NMIA), in collaboration with the National Institute of Standards and Technology (NIST), we have developed an ACJVS system based on the NIST design [1] and are working towards increasing its calibration capability by three orders of magnitude in voltage by means of a precision three stage inductive voltage divider (IVD), developed at NMIA [4]. This will extend the application of the ACJVS to the calibration of ac voltage measurement standards (ac voltmeters).

II. Calibration Setup

Figure 1 shows a simplified schematic diagram of the calibration setup. A lock-in amplifier is used to compare two voltages, a quantum reference voltage provided by the ACJVS and the voltage across the instrument under test, generated by a commercially available ac voltage source and scaled down to the reference voltage level using a precision IVD. The ratio uncertainties of the IVD range from 1×10^{-8} to 5×10^{-7} at frequencies from 40 Hz to 1 kHz.

The ACJVS is based on a series array with 6400 Nb-Nb_xSi_{1-x}-Nb Josephson junctions operating in a liquid Helium Dewar. Both the array and the cryoprobe were made at NIST. The array is driven by a commercial ternary code generator (TCG) with 256 Mbit memory after amplification through a 60 GHz bandwidth amplifier. At 15 GHz TCG clock frequency, ACJVS voltages up to 125 mV rms can be generated by a single array at frequencies down to 57 Hz. By reducing the clock frequency to 10 GHz, frequencies down to 38 Hz with proportionally reduced amplitude can be obtained. In order to maximize operating margins with these electronics, the ACJVS was operated at two output pulses for each input pulse and with waveforms having code density less than 50%.

The low-frequency part of the TCG code is filtered by a dc block and re-applied through an arbitrary waveform generator (AWG), to reduce the voltage across the on-chip radio frequency termination resistor. TCG and AWG are frequency-locked to a 10 MHz reference signal and the phases of their outputs are synchronized using the TCG's trigger signal. A floating differential amplifier between the AWG and the ACJVS removes potential ground loops.

The electronic ac source that supplies the instrument under test must be phase-locked to the ACJVS. Both its amplitude and phase must be adjustable to bring the output voltage of the IVD close to the ACJVS voltage and thus minimize comparison errors from the lock-in amplifier. A second AWG, locked to the 10 MHz signal and triggered from the TCG, is used for this purpose.

III. Calibration Procedure

After loading of the code and parameters into the TCG and its associated AWG, the reference voltage from ACJVS appears at input A of the lock-in amplifier. The lock-in amplifier internal reference is adjusted to be in phase with the ACJVS voltage by minimizing the quadrature component of the measured voltage. The same is then done for the IVD output voltage at input B, but this time using the AWG that provides the synchronization signal for the ac source. Finally, the in-phase component of the difference between the two input voltages is minimized by changing the amplitude of the ac source. The voltage at the ac voltmeter is now known in terms of the ACJVS voltage and the IVD ratio. Presently the

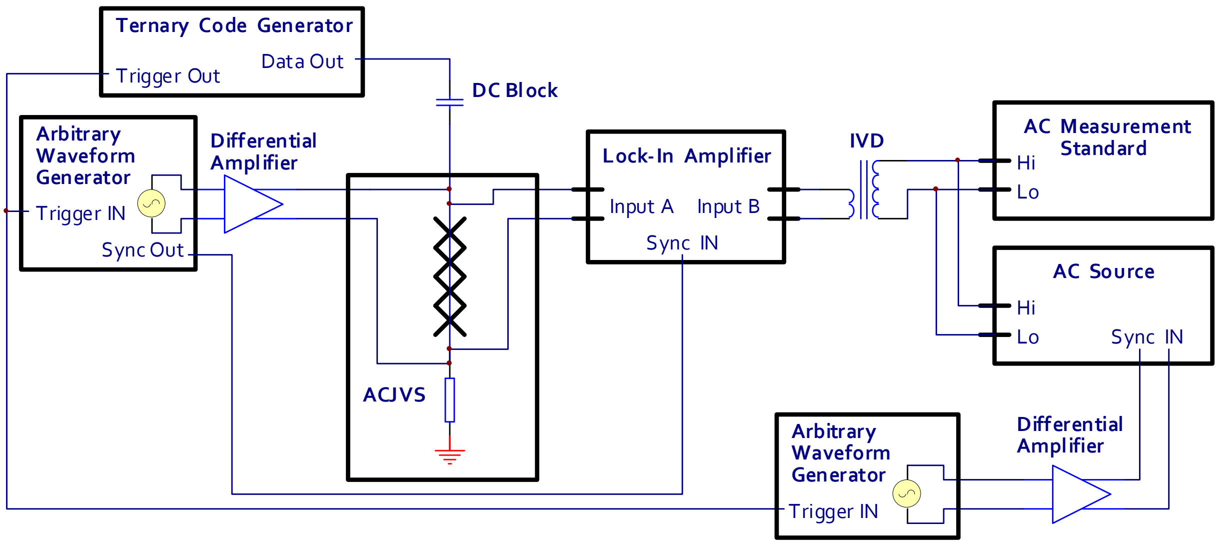

Fig. 1. Schematic diagram of the calibration setup. The Arbitrary Waveform Generators and the Ternary Code Generator are locked to a traceable 10 MHz reference signal.

measurement takes less than 5 minutes as opposed to more than 1 hour required for ac-dc transfer.

IV. Performance Evaluation

The performance of the ACJVS was first verified in ac-dc transfer mode. A commercially available thermal transfer standard (TTS) with an input impedance of 10 M• in parallel with less than 50 pF was calibrated at voltages from 20 mV to 100 mV and a frequency of 1 kHz. Table 1 shows a comparison of the results against those determined using a conventional ac-dc calibration setup based on micropotentiometers (µPots) [5]. The agreement is well within the uncertainty of the calibration against µPots. At 1 kHz, corrections for leads and loading by the TTS were small and were not applied.

Table 1. Ac-dc difference of a TTS at 1 kHz measured using the ACJVS and a micropotentiometer based ac-dc system.

Voltage Level (mV)	TTS Ac-dc Difference ACJVS (µV/V)	µPot (µV/V)	Uncertainty µPot (µV/V)
20	- 11	+ 8	± 44
30	+ 7	+ 7	± 35
50	+ 5	+ 22	± 23
100	- 5	0	± 12

An NMIA reference ac voltmeter was calibrated using the complete system at voltages from 6 V to 100 V and a frequency of 1 kHz. The results agree well with those of conventional calibration using thermal voltage converters and a dc reference.

Earth loops have significant impact on the measurement, especially due to IVD ratios down to 1:1000, and cause high sensitivity of the lock-in amplifier readings to different earth arrangements. Acceptable results could be achieved by using the lock-in amplifier with floating inputs, disconnecting its earth from mains and connecting it to the common earth of the ACJVS system and also by using isolated outputs of the IVD.

V. Conclusion

A calibration setup for ac measurement standards based on a quantum ac standard is presently under development. The setup uses a precision IVD to extend the voltage measurement range by a factor of 1000 at frequencies from 38 Hz to 1 kHz. The calibration procedure is quicker and potentially more accurate than ac-dc transfer.

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