Differential Sampling Measurement of a 7 V rms Sine Wave and a Programmable Josephson Voltage Standard

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***Abstract* — A 10 V programmable Josephson voltage standard has enabled sine waves with rms voltages up to 7 V to be accurately measured with differential sampling methods. This paper reviews the challenges and limitations of differential sampling that arise when rms voltages greater than a few volts are measured. Preliminary measurements confirmed the capability of the NIST 10 V Josephson array to perform this task and emphasize the need for highly stable and low-phase-noise ac sine wave voltage sources in order to further reduce the measurement uncertainty.[1]**

***Index Terms* — Differential amplifiers, digital-analog conversion, Josephson arrays, standards, voltage measurement.**

I. Introduction

NIST recently completed development of a 10 V programmable Josephson voltage standard (PJVS) [1] that allows rms voltage measurements to be extended up to 7 V. The differential sampling method was previously implemented for measuring 1.2 V rms amplitudes for a new electrical power standard [2-3]. This straightforward sampling method can characterize any sine wave source signal by use of a stepwise-approximated sine wave that is synthesized with the PJVS. Each step provides a quantum-accurate voltage reference for the different sample periods. The residual differential voltage is measured with a sampling voltmeter in a null-detector configuration. Particularly suited for waveform frequencies below 1 kHz, the differential sampling method avoids the limitations induced by the PJVS transients that occur when it switches between quantized levels [4-5]. Increasing the sine wave source's rms voltage up to 7 V opens new options for the direct calibration of instruments such as ac calibrators and ac digital voltmeters, without the use of a thermal transfer standard [2], [6].

II. Differential Sampling

For all the measurements reported in this summary paper, a Datron 4808 calibrator[2] was used as the sine-wave source. The sampling voltmeter (time integrator), an Agilent 3458A, was modified to be locked with an external 20 MHz frequency reference. The overall measurement scheme is described in detail elsewhere [2]. The wait delay and the aperture period of the sampling voltmeter are selected in order to match the PJVS waveform. The sampling aperture period is expressed in terms of the ratio relative to the duration of one PJVS step $(Nf)^{-1}$, where N is the number of PJVS steps per period and f is the waveform frequency. The measurement procedure begins by aligning (or centering) the sampling windows with the quantized steps of the PJVS waveform. Next, the phase of the sine wave is adjusted with respect to the PJVS waveform (see Fig. 1a) in order to minimize the differential voltage (Fig. 1b). The sine-wave amplitude is then reconstructed based on the measured differential voltage and the voltages of the PJVS reference waveform. A fitting algorithm is used over multiple periods of the waveform to determine the rms contributions of the fundamental, the first harmonics, and the power-line frequency. Note that the entire procedure is fully automated.

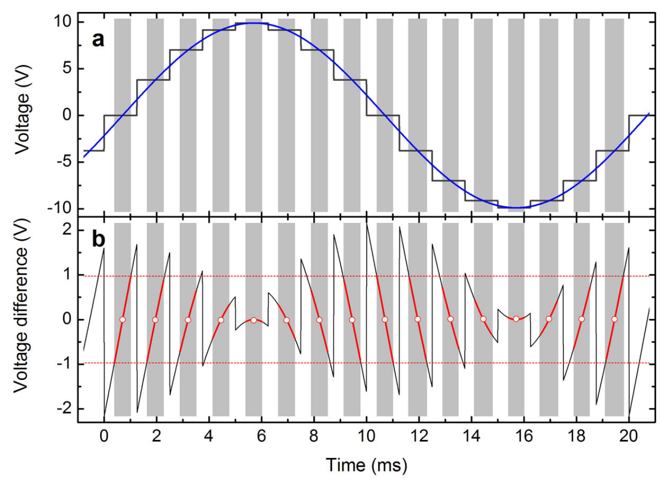

Fig. 1. (a) Alignment of a stepwise approximated PJVS sine wave (N=16) with a 7 V-rms-amplitude sine wave. The gray boxes indicate the sampling windows of the DVM (aperture period ratio = 0.5). (b) Differential voltage (line) versus time; the open dots represent the integrated voltage value for each sampling bin. The two horizontal dash lines indicate the maximal voltages measured by the sampling voltmeter.

III. Limitations

For a fixed N, increasing the waveform amplitude increases also the resulting differential voltage. Even if, after the phase alignment procedure, the values given by the sampling DVM

[2] The commercial instruments are identified in this paper only in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment identified is necessarily the best available for the purpose.

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(open dots in Fig. 1b) are very close to zero, the maximum voltages (horizontal dashed lines in Fig 1b) might not be included within the lowest range of the DVM, as reported in previous work [2]. Measurements on the 1 V range of the DVM present a higher measurement noise compared with the 100 mV range. In order to maintain the lower range, the number of steps can be increased to above 200 (aperture period ratio=0.5 and 7 V rms waveforms). However, increase-ing N is not a perfect solution, because the noise will still increase due to the reduced aperture period of the sampling voltmeter. The dependence of the DVM noise on the aperture period has been described in reference [7]. Meanwhile, if the sine-wave source has good short- and long-term stability, then this effect can be compensated for with longer averaging.

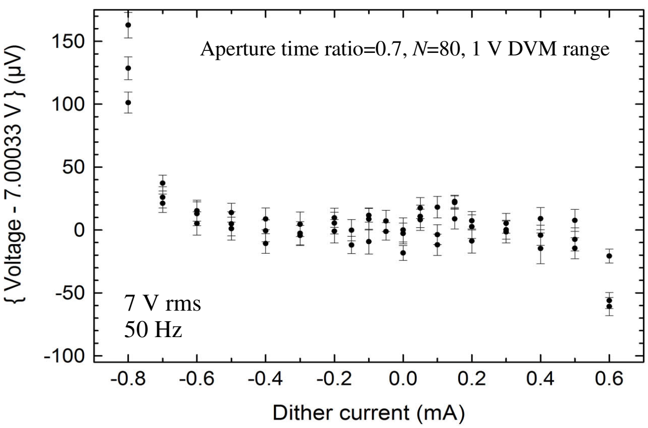

Fig. 2. Variation in the measured calibrator voltage vs. PJVS dither current.

IV. Preliminary results

The first measurements at 7 V rms allowed us to verify the quantization of the PJVS steps (Fig. 2). The loss of quantization in the PJVS reference at large dither currents is clearly observed outside of the ±0.4 mA range. The same minimum dither current range was found separately for the dc voltage steps. Another performance test of the measurement was to shift the sampling window with respect to the PJVS waveform (Fig. 3). The "0" and "1" values correspond respectively to the left and right alignment of the sampling window edges with the beginning and the end of each of the PJVS steps. No deviation is observed between 0.1 and 0.95, confirming the reliability of the automated alignment procedure. By default, the sampling window is adjusted to the middle of the PJVS step (value=0.5).

Complementary measurements performed for various N (from N=40 to N=200) at 7 V rms and 50 Hz produced the same rms amplitude and measurement uncertainty. Unfortunately, the uncertainty is dominated by the stability of the calibrator, U_c=33 µV (k=2) at 7 V rms, a relative uncertainty of 4.7 µV/V. The use of a more stable source is required in order for the measurement to be dominated by the noise of the sampling voltmeter. This was also the case in lower voltage measurements [2]. Sources with high voltage stability and low phase noise are being investigated and developed for this future application [3, 8]. If successful, they will be integrated with the PJVS system for ac measurements.

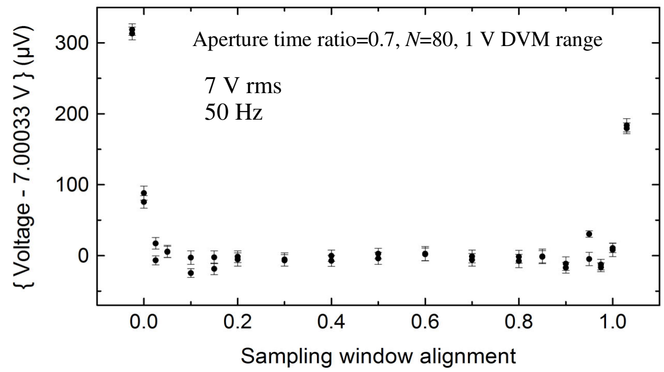

Fig. 3. Variation in the measured calibrator voltage vs. sampling window alignment position (see text for details).

V. Conclusion

The preliminary results obtained here confirm the capabilities of using the NIST 10 V PJVS system to measure sine-wave sources with rms amplitudes up to 7 V with the differential sampling method. Sources with better voltage stability and phase noise are critical for reducing the measurement uncertainty and implementing the differential sampling method for precise ac measurements.

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