A Digital-to-Analog Converter with a Voltage Standard Reference

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***Abstract* — Commercially available 20-bit digital-to-analog converters (DACs) have the potential to impact the field of low-frequency voltage metrology. We measured a linearity of ±6 μV (±0.6 μV/V full scale) over the 10 V range for such a DAC with a Zener voltage standard in use as its external 10 V reference. This result is a first step toward implementing such a DAC as an ac synthesized source, whose accuracy and stability could be established by a dc voltage standard reference.**[1]

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

I. Introduction

Commercially available digital-to-analog converters (DACs) have reached 20 bits of resolution combined with excellent linearity characteristics (less than 1 part in 10^6 or ppm) [1]. We are interested in such devices as accurate voltage sources for metrology. The AD5791 DAC from Analog Devices that was used in this research[2] was developed mainly for industrial and medical applications. In order to meet the requirements of accuracy and stability for metrology applications, a dc voltage reference can be provided externally. DACs have been implemented in the past for precision voltage and power metrology [2-3], but the availability of commercial DACs with ppm performance provides new opportunities for precision measurements.

Recent developments in DAC architecture [1] allow a shorter settling period in comparison with the more complex and costly DACs on the market having a similar resolution. We hope to use these DACs to produce an ac source for frequencies up to 1 kHz that is metrologically accurate and stable by incorporating a primary or secondary voltage standard reference. Such a source would meet the high stability characteristics needed for low-frequency voltage metrology and electric power applications [3-5]. Moreover, if the gain of such a device is easily controlled and stabilized with a metrology-grade dc voltage reference, this ac source could avoid the use of complicated and time-consuming ac voltage measurements for routine low-frequency ac metrology calibrations.

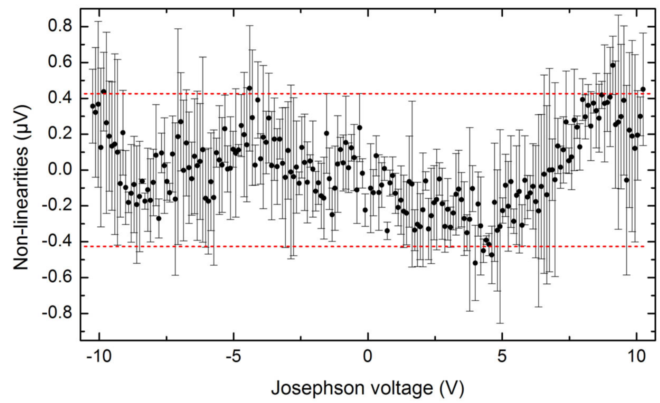

Fig. 1. Deviation from linearity curve of the DVM for the 10 V range versus the reference Josephson voltage.

II. Measurement Setup

Before attempting integration of the 20-bit DAC into an ac source, we first evaluated its dc gain and linearity performance. The measurement setup consists of a commercially available evaluation board including the 1 ppm resolution DAC, a Zener secondary standard as the voltage reference, a superconducting programmable Josephson voltage standard, and a high-resolution digital voltmeter (DVM) to measure the accuracy of the DAC output voltages.

The 20-bit DAC device generates any integer level (D) between 0 and 1,048,576. The corresponding output voltage (V_{OUT}) depends on the positive (V_{REFP}) and negative (V_{REFN}) voltage references applied.

$$V_{OUT} = (V_{REFP} - V_{REFN}) \cdot (D/2^{20}) + V_{REFN}. \quad (1)$$

V_{REFP} was connected to a 10 V Zener secondary voltage standard. The value of the Zener (9.999,960,5 V), was measured with a 10 V programmable Josephson voltage standard (PJVS) [4]. The Zener voltage uncertainty is 0.3 μV (k=2). A short was used for the negative voltage reference (V_{REFN}=0 V). In this unipolar configuration, a least-significant bit (LSB) voltage is equivalent to 9.54 μV.

The high resolution DVM was calibrated beforehand with a 10 V PJVS. Figure 1 shows the measured nonlinearity characteristics. The two horizontal lines (± 0.42 μV) highlight the typical (k=2) nonlinearity of the instrument. The gain error of the DVM (-0.772 μV/V) is used to correct measurements of the 20-bit DAC.

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[2] This commercial chip is 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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III. GAIN AND LINEARITY MEASUREMENTS

Figure 2 presents the voltage difference between the measured and expected DAC voltages over the entire digital code range. The inferred gain error of the tested 20-bit DAC is -5.2 μV/V. This value is within the gain uncertainty specified by the manufacturer (±10 μV/V for V_{REFP}=10 V and V_{REFN}= 0 V). The measured voltage offset of -13.7 μV (DAC voltage setting = 0 V) can be due either to some thermal voltage in the various connectors of the 20-bit DAC evaluation board, or inherent to the DAC itself.

Figure 3 presents the linearity of the 20-bit DAC. The measured ±0.6 LSB integral nonlinearity (INL) of this curve agrees with the specifications given by the manufacturer as having an INL value smaller than ±1 LSB. No particular anomaly appears in the INL when every single bit of the DAC code is tested. However one can observe a code dependent repetition pattern in the INL, particularly visible at every multiple of 512 and 2048 (Fig. 3 inset).

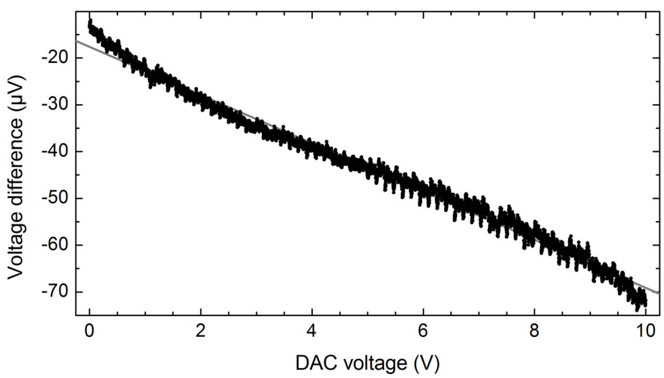

Fig. 2. Difference between the measured and expected DAC voltage versus the expected DAC voltage. The grey line behind the data represents the measured gain correction factor of -5.2 μV/V.

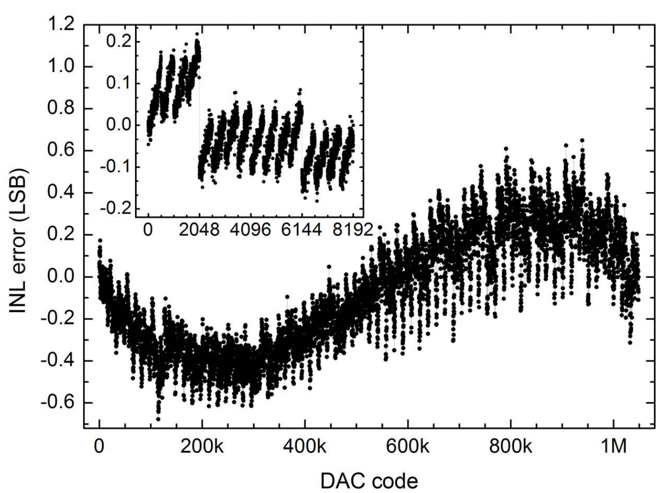

Fig. 3. Measured integral nonlinearity error over the entire DAC range (bit code increment = 128). Inset shows INL for every bit between DAC levels 0 and 8192.

IV. RESULTS AND FUTURE APPLICATIONS

The results obtained for the 20-bit DAC gain and INL are limited neither by the stability of the Zener voltage reference nor by the gain error and nonlinearities of the DVM. Excellent linearity of the DAC is the first requirement fulfilled to develop new voltage sources for metrology applications. However, Fig. 2 shows that both the gain correction value and the zero offset of the DAC must be precisely determined before it can be used for dc or ac metrology. The use of a voltage standard to provide the DAC voltage reference is a very interesting potential approach that might improve both the short- and the long-term stability of the DAC output voltages. Future measurements will evaluate this potential.

Ultimately, the external dc voltage reference can be provided by a programmable Josephson voltage standard. This more complex approach has the advantage that the source would be directly traceable to a primary standard. However, a Zener voltage reference is sufficient for the measurements that are possible with the manufacturer's evaluation board.

V. CONCLUSIONS

The results obtained for the 20-bit DAC gain and INL measurements by use of a quantum voltage standard for traceability agree with the performance specified by the manufacturer. Such a device could be implemented as an ac source in which the voltage stability is provided by a dc voltage standard. This approach could potentially simplify and improve low-frequency voltage-metrology applications.

ACKNOWLEDGEMENT

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