Digitizer Linearity Measurement with a Josephson Arbitrary Waveform Synthesizer

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***Abstract* — This article examines the non-linearity and gain error of a commercial digitizer on the 100 mV range with a Josephson Arbitrary Waveform Synthesizer (JAWS) as a reference. Different digitizer input filter settings were studied, and the shortest aperture of the digitization window was chosen to maximize the processing speed. The results revealed a maximum non-linearity of 0.3 µV on the 100 mV range with the digitizer filter frequency set to 100 kHz. A gain stability over 12 hours was determined to be 0.92 µV/V.**

***Index Terms* — Digital-analog conversion, Measurement uncertainty, Josephson junction arrays, Standards, Superconducting integrated circuits, Voltage measurement.**

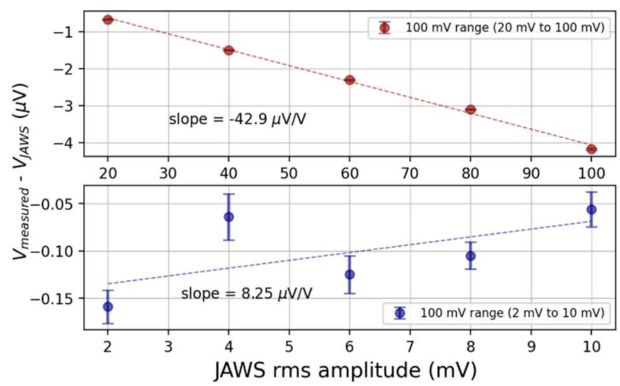
I. Introduction

Josephson Arbitrary Waveform Synthesizers (JAWS) provide high spectral purity, intrinsic linearity, and direct realization to the International System of Units for ac voltage metrology applications [1]. This study focused on a detailed evaluation of the linearity of a commercial digitizer using the JAWS. By subjecting the digitizer to rigorous testing and utilizing the minimum aperture time to evaluate its performance at the highest digitization rate, this research evaluated its non-linearity and gain error at small voltage amplitudes. Our end goal is to determine the performance of the digitizer for use in differential measurements between a JAWS reference and an ac voltage source as the device under test. This differential approach plays a crucial role in ensuring the precision and accuracy of measurements, especially in applications like the comparison protocol for ac voltages established by the BIPM [2].

II. Setup

In these measurements, the JAWS provided a reference voltage that was directly sourced to a commercial digitizer (Fluke 8588A[1]). All instruments shared a common 10 MHz reference and were synchronized through a trigger signal provided by the JAWS system. The JAWS system consisted of one 2 V JAWS chip mounted in a cryogenic package. This package was mounted on the cold stage of a cryocooler and operated at a temperature of 4.5 K (further details can be found in [1]). Each digitizer measurement consisted of 2 million samples acquired with an aperture time of 200 ns. Correction for the aperture time was applied in each measurement [3]. The number of periods of the signal acquired varied depending on the frequency being measured. A Fast Fourier Transform (FFT) was applied to the entire set of samples to extract the rms voltages at the waveform fundamental frequency. Each voltage measurement was repeated ten times, and the average value was calculated ($V_{measured}$).

Fig. 1. Voltage difference measured at 1 kHz on the digitizer 100 mV



range with the digitizer 100 kHz filter for two different voltage spans: 20 mV to 100 mV (top) and 2 mV to 10 mV (bottom). All uncertainties have a coverage factor of $k = 1$.

III. Gain and Linearity Results

Commercial digitizer linearity measurements were conducted at rms amplitude ≤100 mV at various signal frequencies (100 Hz, 400 Hz, 1 kHz, 10 kHz, and 20 kHz). Three different configurations of the digitizer input filter were used: 3 MHz, 100 kHz, and none (OFF). The gain error is extracted from a linear fit (slope) of the voltage difference ($V_{measured} - V_{JAWS}$) versus the JAWS rms amplitude (V_{JAWS}) as shown in Fig. 1. The gain error was determined for two different voltage spans on the digitizer's 100 mV range: (1) from 20 mV to 100 mV in 20 mV increments, and (2) from 2 mV to 10 mV with 2 mV increments. In Fig. 2, the measured gain error is reported as a function of the signal frequency for two filter settings and two different voltage spans. The more

[1] Certain commercial instruments are identified in this paper 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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significant frequency dependence of the gain error, shown in Fig. 2b), is imputable to the bandpass cutoff effect of the digitizer 100 kHz filter.

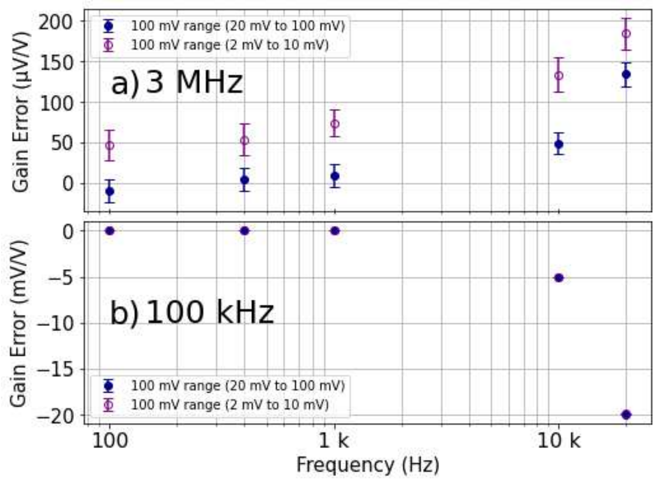

Fig. 2. Gain error analysis as a function of frequency for a) 3 MHz and b) 100 kHz digitizer filters. All uncertainties have a coverage factor of $k = 1$.

The non-linearity was defined as the residual (deviation) from the linear fit shown in Fig. 1. All waveform frequencies reported in Fig. 3 show a similar non-linear profile for each voltage span investigated (a) from 20 mV to 100 mV and (b) from 2 mV to 10 mV. Over the 100 mV voltage span, all data points are within 0.3 µV of the gain-corrected value, while over the lesser 10 mV span, all data points are within 0.09 µV of the gain-corrected value.

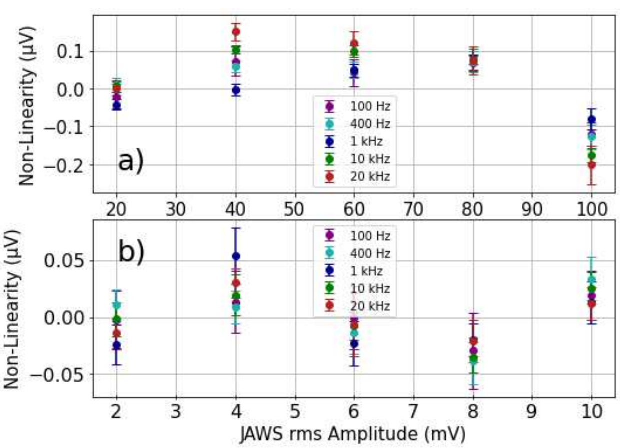

Fig. 3. Non-linearity measurement of the commercial digitizer 100 mV range, covering a) a voltage span from 20 mV to 100 mV and b) a voltage span from 2 mV to 10 mV. These data were acquired using the 100 kHz filter. All uncertainties have a coverage factor of $k = 1$.

Gain stability measurements were conducted over multiple hours at a signal frequency of 1 kHz, for the three input filters of the digitizer (Fig. 4). The best stability was achieved with the 100 kHz filter, maintaining a stable gain within 0.92 µV/V over 12 hours.

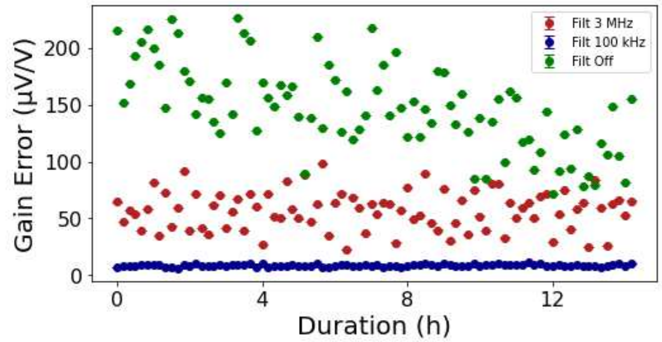

Fig. 4. Gain error extracted from the data with a 2 mV to 10 mV voltage span on the digitizer 100 mV range using input filters at 100 kHz (Blue), 3 MHz (Red), and OFF (Green).

IV. Conclusion

Our experimental results demonstrated the use of a JAWS system to characterize the linearity and gain performance of a commercial digitizer. The results demonstrated that the linearity performance of the commercial digitizer's 100 mV range with the 100 kHz filter is adequate for measurements in differential mode, which is crucial for obtaining accurate measurements between JAWS reference signals and an ac source under test [4]. The data acquisition process, executed with finer voltage increments, also demonstrated good non-linearity performance at all frequencies. The results presented in Fig. 3 and 4 demonstrated the effectiveness of the applied corrections, emphasizing the importance of these adjustments for ensuring precise and reliable measurements, especially within the domain of metrology.

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