Josephson Arbitrary Waveform Synthesizer as a Reference Standard for the Measurement of the Phase of Harmonics in Distorted Signals

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***Abstract* — We use the Josephson arbitrary waveform synthesizer to provide traceability for the phase of the harmonics, relative to its fundamental, of a distorted waveform. For distorted waveforms with rms values in the range from 0.154 V to 0.2 V and harmonic magnitudes from 5% to 40 % of the fundamental, our system can generate odd harmonics up to the 39th with phase uncertainties from 0.002° to 0.010° (*k*=2.0), depending on the harmonic number and harmonic magnitude.**

***Index Terms* — Josephson junction array, measurement standards, measurement techniques, phase measurement, quantum voltage standards, spectrum analysis.**

I. Introduction

Harmonic analysis is used in electricity networks, communications, characterization of systems and materials, acoustics and vibration. While the traceability of harmonic magnitude measurements to ac-dc transfer measurement standards is well established (see for example Ref. [1]), there is a gap in the traceability for the phase of harmonics relative to the fundamental.

Budovsky [2] proposed the use of a Josephson arbitrary waveform synthesizer (JAWS) for the calibration of the phase of harmonics of a distorted signal relative to the fundamental. Based on [2], we use the JAWS to generate precisely distorted waveforms that contain harmonics of known magnitude and phase. The primary application of this work is to provide traceability for the phase of the harmonics for power analyzers used in power systems. Target uncertainties for this application range from 0.002° to 0.010°, depending on the relative harmonic magnitude and the harmonic number.

II. System Description

The JAWS system (Fig. 1) contains a continuous wave generator, a tertiary pattern generator, two broadband radio frequency (rf) amplifiers, two arbitrary waveform generators (AWGs), two voltage-to-current converters and two NIST Josephson junction arrays (JJAs) [3]. The inputs and outputs of the rf amplifiers are connected through a combination of dc-blocks and attenuators (shown as capacitors in Fig. 1), optimized for the maximum step current margins of the JJAs.

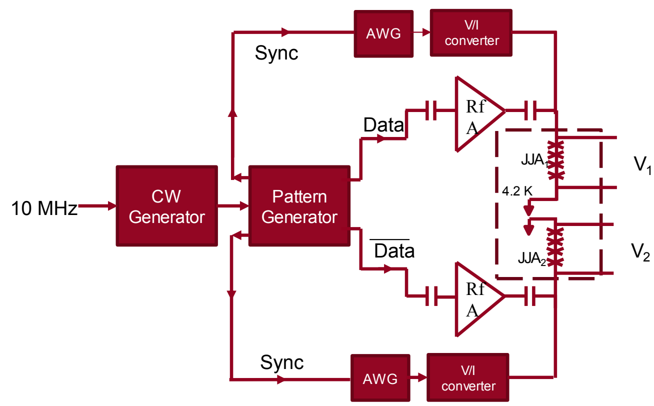

Fig. 1. Block diagram of the JAWS system

A 24-bit flexible resolution digitizer is used to check the quantization of the JJAs.

The JJAs are programmed to produce two arbitrary waveforms of the same harmonic content and rms values with a relative phase difference of 180°. The memory size of the pattern generator limits the lowest fundamental frequency to approximately 56 Hz.

III. Experimental Results

In view of the errors that can occur in a practical realization of a JAWS [4,5], to evaluate the performance of the JAWS as a harmonic phase standard it is important to show that (a) the phase of the generated signals is independent of the specific JJA, (b) that the biasing electronics do not affect the operation of the system, and (c) that the phase of each generated harmonic does not depend on the total harmonic content. In this section we present several experiments aimed at proving that these conditions are met. In these experiments we used two digital sampling systems as transfer standards – one based on two precision digital sampling multimeters [6] (Digitizer1) and the other based on the National Instruments PXI5922 (Digitizer2).

First, we generated two single-frequency sine waves of 0.158 V rms with a nominal phase difference of 180° and used Digitizer1, whose internal phase shift was nulled prior to the

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measurement, to measure the phase difference between these two sinewaves. The disagreement was 0.00003° at 60 Hz and less than 0.0003° up to 1 kHz.

Next the JAWS was used to generate a number of precisely distorted waveforms with a fundamental frequency of 60 Hz and an rms value of 0.158 V. These precisely distorted waveforms contained the 3rd, 5th, 7th, 9th, 11th, 23rd, 31st and 39th harmonics. These harmonics were selected as a compromise between (a) using the harmonics commonly found in power systems and referenced in power quality documentary standards and (b) keeping the signal-to-noise ratio of the harmonics relative to the noise floor of the spectrum analysis high enough to allow phase resolution better than 0.001°. Relative to the fundamental, the magnitude of each harmonic was 10 % and the phase was 90°. Digitizer1 was first used to measure waveforms containing the fundamental and one of the above harmonics, and then a waveform with the fundamental and all of the above harmonics (Fig 2). The difference between the two sets of measurements did not exceed 0.001°.

Several measurements were performed to study the influence of the biasing electronics, which includes the continuous wave generator, the pattern generator, the rf amplifiers, the voltage-to-current converters and the arbitrary waveform generators. First we calibrated Digitizer2 with two different JJAs from the same chip, driven by the same biasing electronics, using the all-harmonics waveform specified above. The results of the two measurements agree within 0.001° and the measured errors of the digitizer are within 0.001° of nominal (Fig. 3a). Then the two JJAs were used to generate the same waveform, but driven by different biasing electronics (Fig. 3b). For all the harmonics up to the 23rd, the results agree within 0.001°. As the harmonic number increased the disagreement increased as well but was still within the uncertainty of the measurement. The error bars in Fig. 3 indicate the standard deviation of the measurement.

Finally, a number of measurements were conducted with varying distortion, phase angle, helium level, and JJA output cable length. These results and the uncertainty analysis will be reported at the conference.

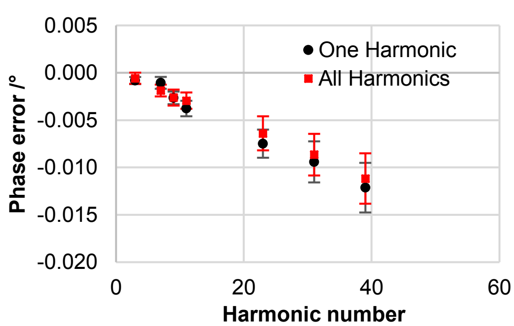

Fig. 2 Phase error of Digitizer1 measured with one harmonic at a time and all harmonics simultaneously. The error bars indicate the standard deviation of the measurement.

III. Conclusion

The results presented in this paper show that the JAWS gives consistent results as a standard for the phase of harmonics of a distorted signal for different JJAs and the biasing electronics. The uncertainty analysis, to be presented at the conference, suggests that the system can generate distorted signals with phase uncertainty of the harmonics from 0.002° to 0.010° (k=2.0), depending on the harmonic magnitude and harmonic number.

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(a)

(b)

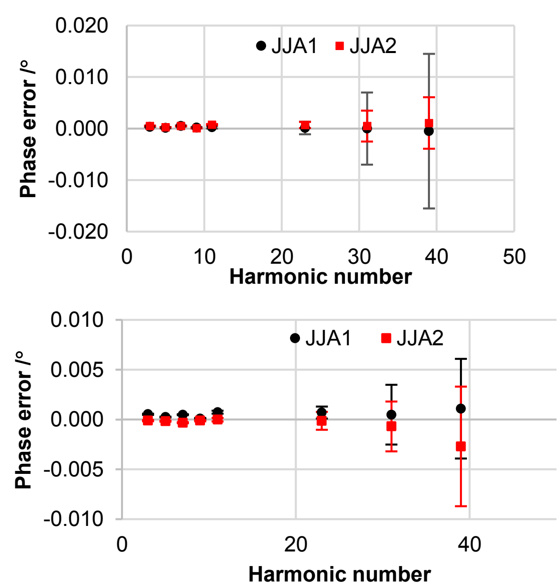

Fig. 3 Phase error of Digitizer2 measured using two different JJAs driven by (a) the same biasing electronics and (b) different biasing electronics.