Highly Accurate Differential AC Voltage Measurements with a Single DC Voltage Reference

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***Abstract* —This paper describes a measurement setup employed to investigate differential voltage measurements to be done with a spectrally pure sine wave and a dc reference. The system enables adjustment, to a very high accuracy, the start phase of ac sampling. Repeatabilities of some 0.1 µV/V were obtained with the help of adaptive digital control.**

***Index Terms* —Ac voltage, chopped dc reference, digital signal processing, Josephson, measurement standards, sampling technique.**

I. Introduction

The system described in this paper was originally devised to help evaluating measurement errors when sampling differential signals with an integrating analog-to-digital converter of highest resolution (28 bits) [1] operating with a programmable step-driven Josephson ac standard (PJVS). The principle backing up this work relies on the fact that the root-mean-square (rms) value is numerically exactly located at integer multiples of π/4 on a pure sine waveform. 'Pure sine' waveforms, however, do not indeed exist in practice. Normally, the heuristic limit of -100 dBc to -110 dBc of residual harmonic content is employed to classify a sine approximation as spectrally pure. Our endeavor to synthesize sine waves with residual harmonic content much lower than -160 dBc still needs experimental proof for this claim, awaiting elaborate experimental verification [2]. A spectral purity of -120 dBc though is attainable by using highest-grade commercial sine generators (either digital or analog) aided by some additional filtering (if necessary). The limit of -120 dB seems to be a reasonable compromise to qualify a waveform as 'spectrally pure', since its harmonic content contributes to less than 1 part in 10^{12} of the total energy of the signal. Such spectrally pure sine waveforms seem to fulfill present requirements of analog-to-digital converters (ADCs) characterization and laboratory needs.

II. Obtaining Spectrally Pure Sine Waveforms

RC-Oscillators are one of the best ways to synthesize a pure sine signal [3]. Care must be devoted to the selection of proper passive components and amplifiers. It cannot however be taken for granted, that the best components will ultimately yield the very best results, although excellent audio amplifiers are in the market claiming harmonic distortions as low as -140 dBc. Voltage dependencies of passive components also play a role, and this information is seldom available from component manufacturers' data. The easiest way though is to use a commercial calibrator, which can deliver signals up to -100 dBc. Workbench oscillators are normally general purpose digital sources displaying spectral purity not better than -60 to -80 dBc. To reach distortions lower than -120 dBc, the output of these devices shall be cleaned up with the help of analog filters.

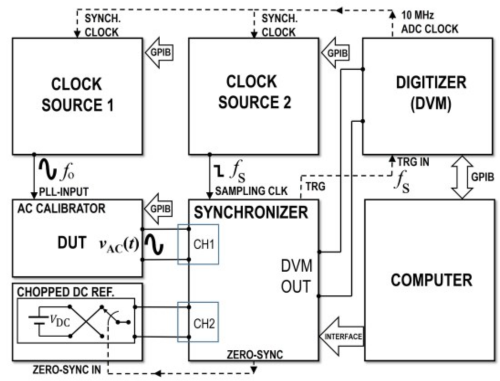

Fig. 1. Diagram of the measurement setup.

Reliable information on voltage dependencies of electronic passive components (capacitors of solid dielectric and metal film resistors) can be obtained at great cost, through very highly sensitive bridges and elaborated measurement techniques [2]. Good harmonic filter rejection demands high-quality capacitors, e.g., NP0 ceramic capacitors [2] and metal film resistors in, for instance, a 'biquad' or 'state variable bandpass filter' [4]. The resultant 'spectrally pure' sine needs to be sampled as is presented next.

III. System Operation

Fig. 1 shows the measurement setup. As in [1], The PJVS is programmed to synthesize a square wave, or a calibrated Zener reference V_{DC} is alternately switched to invert its polarity as can be done with an electronic switch (as depicted), according to the sign of the alternating voltage $v_{AC}(t)$. The direct-digital-synthesizer (DDS) based clock sources 1 and 2 run synchronously with the internal clock of the digitizer (the Agilent A3458 digital voltmeter - DVM) and synthesize the fundamental f_0 of $v_{AC}(t)$ (to phase-lock a calibrator) and the sampling frequency f_s respectively. The DVM is triggered by a synchronizer, which is described in more detail in [1]. The output of the calibrator is further filtered if necessary (not

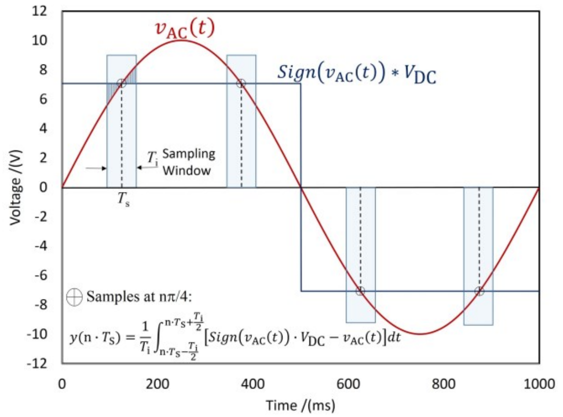

Fig. 2. Measurement method employed. The small differential voltage is represented by the hatched area inside the first sampling window of length T_i.

shown in Fig.1). The sampling frequency f_s is adjusted according to the same procedure as described in [1], which asks for a target phase of exactly $\pi/4$, wherein the sampling window is centered.

The alternating signal $v_{AC}(t)$ is sampled with four or more samples per period equally spaced in time over many periods. The phase ϕ_{AC} of $v_{AC}(t)$ is computed by fast-Fourier transform. The deviation of phase from the target phase of exactly ($\pi/4$) is fed to a digital proportional integrating regulator, whose output is a new sampling frequency $f_s(1+\xi_s)$ (maintained over a time span Δt and thereafter set to its original value f_s to cause precise phase increments as in [1]). The fractional dimensionless change ξ_s of frequency f_s is calculated according to

$$\xi_s = \frac{\phi_{AC} - \pi/4}{2\pi f_s \Delta t}. \quad (1)$$

Fig. 2 shows illustratively this process after approaching the target phase ($\pi/4$) by a negligible threshold (defined by the user). Afterwards, differential voltages to compute the rms of $v_{AC}(t)$ are sampled according to the relation in the insert of Fig. 2. The differential voltages at each sampling point n, i.e., $y(nT_s)$ tend to zero when the peak value of $v_{AC}(t)$, i.e., V_{ACm} satisfies the following relation (due to the frequency response of the integrating digitizer):

$$V_{ACm} = \frac{V_{DC} \cdot \sqrt{2}}{\mathrm{sinc}(\pi f_0 T_i)}, \quad (2)$$

where the sinc function stands for the sine cardinalis $(\sin(x))/x$, f_0 for the fundamental frequency in hertz of $v_{AC}(t)$ and T_i for the aperture time (in seconds) of the DVM. The smaller the differential voltages are, the smaller is the effect of inaccuracies of the digitizer in the determination of the rms value of $v_{AC}(t)$. The 'Sign' function is realized by the commutating switch and is 1 when $v_{AC}(t) >= 0$ and -1 when $v_{AC}(t) < 0$. This function is generated by a zero-synch output of the in house made synchronizer.

IV. Measurement Results

First investigations were done with filtered sources with expected spurious harmonic distortions below -120 dBc. Measurement repeatability is excellent ranging from 1×10^{-7} to 1×10^{-6}, dominated by noise of the sampler and sources. Although any integration time can be chosen, charging up of the internal filters of the DVM is responsible for a considerable spread of values. At present, investigations are being done to evaluate the metrological feasibility of the method including measurement uncertainties. A piece of hardware is under construction to avoid saturation of the DVM input-circuitry when lower ranges (as the 100 mV range) shall be employed to measure differential voltages. More information will be presented at the conference.

VI. Conclusion

An efficient method for calibrating 'spectrally pure' sine waveforms was presented. In this case, a Zener reference can substitute an expensive PJVS. The setup can also represent a secondary standard, and the low sampling rate allows extension of frequency up to the audio range. Very accurate rms values and small sine distortion are prerequisite to characterize ADCs, what can also be done with this system.

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References

[1] W. G. Kürten Ihlenfeld and R. P. Landim, "An automated Josephson based ac-voltage calibration system," CPEM2014 Conf. Digest, this issue, Aug. 2014.

[2] W. G. Kürten Ihlenfeld and R. T. B. Vasconcellos, "On the nonlinear voltage dependence of passive electronic components," CPEM2014 Conf. Digest, this issue, Aug. 2014.

[3] B. L. Stevens and R. P. Manning, "Improvements in the theory and design of RC oscillators," *IEEE Trans. Circ. Theory*, vol. 18, no. 6, pp. 636-643, Nov. 1971.

[4] R. A. Pease, *Analog Circuits – World Class Designs,* Newnes Oxford, 2008.