CHARACTERIZATION OF A HIGH-RESOLUTION ANALOG-TO-DIGITAL CONVERTER WITH AN AC JOSEPHSON VOLTAGE SOURCE

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Abstract

An alternating current (ac) Josephson voltage source [1] was employed to characterize the dynamic behavior of a high-resolution 28-bit ($8^1/_2$-digit) integrating analog-to-digital converter (ADC) of a digital sampling voltmeter (DSV), which is widely used in ac metrology at the Physikalisch-Technische Bundesanstalt - PTB. Extensive measurements were carried out to validate previous mathematical models of the DSV [2]-[5] when sampling ac signals. Some measurement methods and results thereof are presented.

Introduction

ADCs became common in ac metrology more than 30 years ago. Despite of many developments in sampling techniques, a significant and rather recent proposal in this field was made by Ramm et al. [2], suggesting the use of regularly spaced samples [3] of two ac voltage signals generated synchronously with the internal clock of a high resolution ADC (DSV). Since then, much effort at the PTB was concentrated on validating uncertainty evaluation models [4] based mainly on comparisons with PTB primary thermal converters (the standards for ac-dc transfer measurements).
Although the theoretical predictions hitherto agreed with experimental results under sinusoidal conditions, further investigations on the dynamic behavior of the high-resolution 28-bit ADC in the PTB system [2,3] remained essential for assuring the traceability of ac power under nonsinusoidal regime. Thorough investigations were carried out with an ac voltage source employing a digital-to-analog converter (DAC) based on Josephson arrays [1]. This source was operating synchronously with the ADC under test (DSV) [2] -[5] as described next.

Description of the system

As depicted in figure 1, a Josephson ac source (on the left) synthesizes an ac signal $u_{DAC}(t)$ (in this case a step-approximated triangle wave coherent with the DSV clock f_{CLK}), which is optionally amplified (by A2) and sampled on its quantized plateaus over a time-frame that encompasses an integer number of periods of $u_{DAC}(t)$.

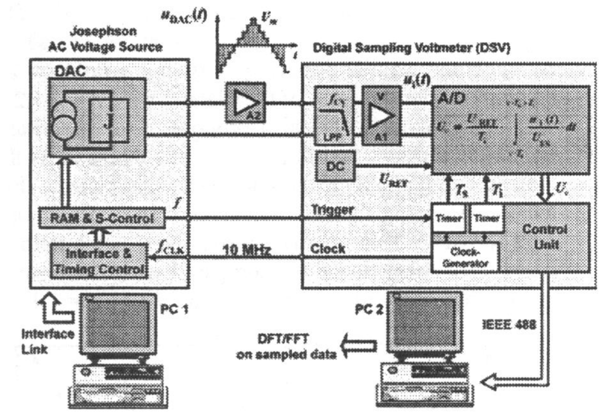

Fig. 1 – Block diagram of the system with the ac source represented by a Josephson array biased by a DC current source at the left [1] (controlled by its own computer PC 1), and the DSV at the right. The quantized ac signal $u_{DAC}(t)$ is coherent with the clock frequency f_{CLK} of the DSV, which is triggered by the f signal at each period of $u_{DAC}(t)$. U_{REF} and U_{FS} stay for the internal reference and full-scale values respectively (see text for further details.)

Leakage on the spectral lines after a discrete Fourier transform (DFT or fast Fourier transform - FFT) on the sampled data U_v (collected and processed by PC2) is thus prevented [2]-[5]. The DSV contains the ADC with its control unit for timing (for setting the sampling and aperture times T_S and T_i respectively), the analog low-pass input filter (LPF with cutoff frequency f_{CV}) and the signal conditioning amplifier A1 that embodies the ADC's imperfections (gain errors with T_i and its non-linearities resulting $u_i(t)$) [4]-[5].
Many methods and procedures for characterizing ADCs have been reported [6]-[7]. Those based on the DFT/FFT on sampled data are more compatible with the PTB system and were thus preferred [8, 9].
The step-approximated triangle wave with quantized steps contains multi-tones [10] (odd harmonics). Since the PTB sampling system is used primarily for the determination of effective values (or root-mean-square values) and ratio of DFT/FFT spectral lines (for the measurement of impedances and ac power), the evaluations of the experimental data were directed toward these needs. In fact, only a short portion of this work can be presented in this paper.

Measurement Method

The ac Josephson source is capable of generating signals with peak values U_m of about 1 V with a resolution of 13 bits. In order to test the DSV (a commercial digital multimeter model HP3458A operating in the direct DC sampling mode) not only on the 1 V but also on the 10 V range, the ac voltage signal was amplified by a DC coupled amplifier with a closed-loop-gain of 11 (a highly linear double-stage DC amplifier - A2 in figure 1 - with settling time to 0.1% smaller than 2 μs.) Triangle and sinusoidal waves of different frequencies (from 11 Hz up to about 400 Hz) were synthesized with 28 steps, which can be considered "absolutely" accurate (i.e., with negligible uncertainty) for this purpose. To avoid transients and errors due to the DSV internal low-pass filter (with f_{CV} = 150 kHz) each quantized step was sampled 40 μs after it was set. Each sample (at each quantized step) corresponds to the mean of 12 measurements (taken over 12 periods) repeated 10 times totalizing 120 single measurements. This procedure was repeated for DSV integration times (or aperture time T_i) varying from 10 μs to 3 ms.

Results

The true effective values are easily calculated from the quantized plateaus (determined by Planck's constant, the elemental charge and microwave frequency). The effective values determined from the DSV samples (or from the DFT spectral lines from samples) display deviations between the 1σ-limits predicted by previous modeling [4] for optimal aperture times at all frequencies of interest as figure 2 demonstrates.

The ratios of spectral lines (up to the 13th harmonic) were determined from a DFT of both the quantized steps and the DSV samples. The deviations of the DFT from samples in respect to the DFT of the quantized steps were smaller than the predicted 1σ-limits [5] and will be presented during the conference.

Besides many other findings, it is worth mentioning that the DSV presents an hysteretic behavior which is dependent on the amplitude of the input signal and aperture time. It is suspected that this effect is caused mainly by remaining charges in the integrator that are not totally discharged before a new conversion cycle starts (to be presented more fully at the conference.)

Conclusions

The ac Josephson source allows the dynamic characterization of a high-resolution ADC to be made. The experiments conducted with the ac Josephson

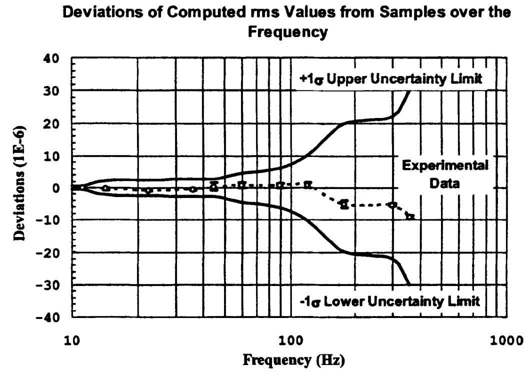

Fig. 2 – Deviations in the 10 V range of the computed effective value determined from samples in respect to the true root-mean-square value determined from the quantized steps.

source yielded valuable information about many dynamic ADC error sources and corroborate theoretical models for uncertainty evaluations of the PTB ac sampling technique. This work is to be continued aiming the development of more reliable ADC models and to improve uncertainty evaluations.

References

[1] J. M. Williams et al.,"Synthesis of precision ac waveforms using a SINIS Josephson junction array," Conference on Precision Electromagnetic Measurements, Digest, pp. 434-435, Canada, June 2002.

[2] G. Ramm, H. Moser, and A. Braun, "A new scheme for generating active, reactive and apparent power at power frequencies with uncertainties of 2.5 x 10^{-6}," *IEEE Trans. Instrum. Meas.*, Vol 48, pp. 422-426, Apr. 1999.

[3] F. J. J. Clarke, J. R. Stockton, "Principles and theory of wattmeters operating on the basis of regurlarly spaced sample pairs," *J. Phys. E.: Scientific Instruments*, Vol. 15, No. 6, pp. 645-652, June 1982.

[4] W. G. K. Ihlenfeld, "Maintenance and traceability of ac voltage by synchronous digital synthesis and sampling," Braunschweig, Germany, PTB Report E-75, 2001.

[5] W. G. K. Ihlenfeld, "Maintenance and traceability of ac voltage ratios and ac power by synchronous digital synthesis and sampling," Braunschweig, Germany, PTB Report E-76, 2001.

[6] W. G. K. Ihlenfeld et al.,"Evaluation of the synchronous generation and sampling technique," *IEEE Trans. Instrum. Meas.*, Vol. 52, No.2, pp. 371-374, Apr. 2003.

[7] T. M. Souders, "Data converter test methods," Nat. Bur. Stand. (U.S.), *NBS Special Publication 707*, 1983 .

[8] B. E. Peetz, " Dynamic testing of waveform recorders," *IEEE Trans. Instrum. Meas.*, Vol. IM-32, No.1, pp. 12-17, Mar. 1983.

[9] C. Clayton, J. A. McClean, and G. J. McCarra,"FFT performance testing of data acquisition systems," *IEEE Trans. Instrum. Meas.*, Vol. IM-35, No.2, pp. 212-215, Jun. 1986.

[10] M. Benkais, S. Le Masson, and P. Marchegay, "A/D converter characterization by spectral analysis in "dual-tone" mode," *IEEE Trans. Instrum. Meas.*, Vol. IM-44, No.5, pp. 940-944, Jun. 1995.