NIST SAMPLING SYSTEM FOR ACCURATE AC WAVEFORM PARAMETER MEASUREMENTS

D. I. Bergman

National Institute of Standards and Technology†
100 Bureau Drive, stop 8172, Gaithersburg, MD, USA 20899, dbergman@nist.gov

Abstract

This paper summarizes efforts at the National Institute of Standards and Technology to develop a waveform sampling and digitizing system with accuracy comparable to that of an ac-dc thermal transfer standard for ac voltage measurements over the frequency range of 10 Hz to 1 MHz.

Introduction

Improvements in the determination of ac quantities at power frequencies using sampling and digitizing techniques have been reported in [1] and elsewhere. Toward this end as well as for higher frequency applications, NIST has recently improved its electronic voltage sampling and digitizing system, described previously in [2], for accurate determination of ac quantities over the frequency range of 10 Hz to 1 MHz. The work is motivated in part by the desire to verify ac-dc difference measurements with a method that is independent of thermal-voltage converters (TVC). Waveform parameters other than root-mean-square (rms) can be determined as well since the instrument produces a sampled data record of the measured signal with excellent dynamic linearity. In comparison with a NIST-calibrated commercial thermal transfer standard, ac-ac differences of the sampling system at 1 V differ from the thermal standard by no more than 7 µV/V ±5 µV/V (k=2) over the frequency range of 20 Hz to 10 kHz and 17 µV/V ±5 µV/V over the frequency range of 20 Hz to 100 kHz.

NIST Sampling Comparator System

The system consists of a mainframe unit, a remote sampling comparator probe, and software for command and data handling. The measurement scheme is that of a successive approximation analog to digital converter (ADC) that samples in equivalent-time. The sampling probe [3] forms the comparator portion of this ADC. The system topology [4] is illustrated in Figure 1. The comparator's simple track/latch circuit structure yields an inherently flat gain versus frequency response. In the frequency range from 1 kHz to 1 MHz, the sampler's flatness is better than that available from the best commercial digital multimeter (DMM).

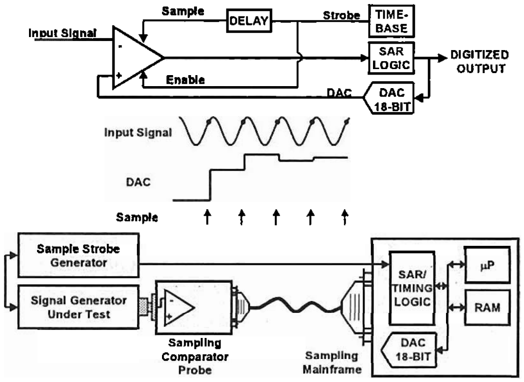

Figure 1: Equivalent-time, successive approximation digitization. Comparator probe connects to sampling mainframe through umbilical harness.

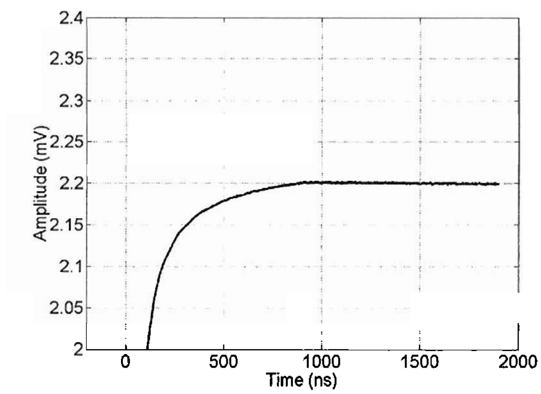

Figure 2: Settled region of the sampling probe step response. The reference-step generator had a pulse amplitude of -0.5 V and a transition duration of approximately 15 ps.

By design, the probe exhibits a finite impulse response through the use of an enabling switch that keeps the comparator's front-end circuitry powered off (no bias) until 800 ns prior to sampling. While minimizing signal-induced thermal errors, the enabling feature also limits the probe's memory to the

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duration for which the comparator is energized before each sample is taken. The effect is illustrated in Figure 2 in which the response to a step indicates a distinct knee at the enable time. Since this response is linear and time-invariant and since the impulse response is essentially zero for all time after 800 ns, a step response measurement of the probe over a waveform epoch of 800 ns is sufficient to characterize fully the probe's frequency response from dc to an arbitrary maximum frequency of interest. The sampling probe's frequency response can thus be characterized from its response to a step signal, the generation of which is achievable with a commercially available reference-step generator. Calibrating the probe in this manner provides a means to measure the root-mean-square (rms) value of an ac waveform accurately without the involvement of thermal converters.

Comparison with a NIST-Calibrated Thermal Transfer Standard

Sampling probe gain flatness at 1 V was measured against a commercial thermal transfer standard. The frequencies selected were those for which the transfer standard had corrections available. The result is plotted in Figure 3. The measurement was performed on the 2.2 V range of the transfer standard.

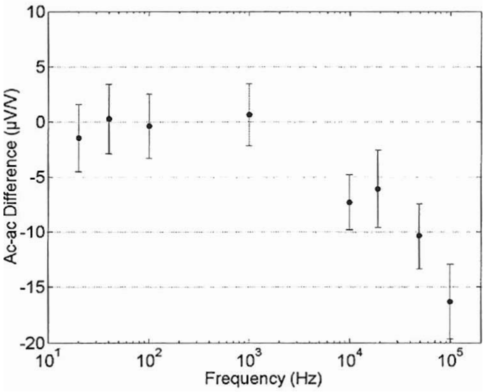

Figure 3: Ac-ac differences for the NIST sampling system measured against a commercial thermal transfer standard. The reference frequency was 1 kHz. The uncertainty bars indicate the Type A uncertainty (k=2) of the measurement. The transfer standard uncertainty (k=2) is 4 µV/V.

Dynamic Linearity

An example of dynamic linearity performance of the system is illustrated in Figure 4. The spectrum of a sampled data record for an input signal with a level of 1 V at 45 kHz is shown. The second harmonic power level is −100 dBc, and total harmonic distortion is −95 dB.

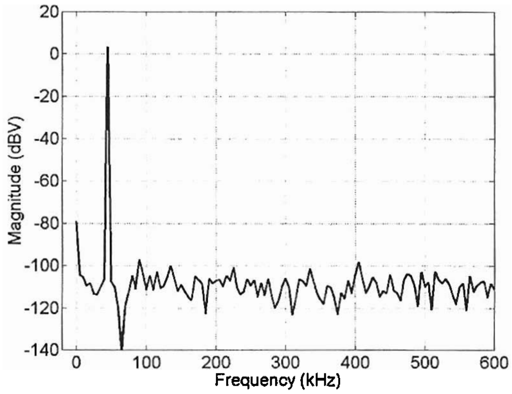

Figure 4: Magnitude spectrum of sampled data for an input signal of 1 V at 45 kHz.

Further Considerations

With an input impedance of 1 MΩ, the sampling probe is amenable to the use of a frequency-compensated resistive attenuator to allow operation at higher voltage levels. We have developed attenuators calibrated up to 100 V using a digital filtering process to achieve flatness within 20 µV/V from 100 Hz to 100 kHz.

Nonlinear error in the sampler has been investigated using phase-plane techniques [5]. An analytic error model that describes the sampler's nonlinear error behavior - harmonic distortion as well as zeroth (offset) and first order (gain and phase) distortion - has been developed. The model is used to correct nonlinear error in the probe when signal amplitudes exceed 2 V.

References

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