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A Method for the Measurement of Digitizers' Absolute Phase Error

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Abstract. A lot of engineering applications, from telecommunications to power systems, require accurate measurement of phase angles. Some of them, like synchrophasor measurement and calibration of instrument transformers with digital output, in order to reach high phase measurement accuracy, require the knowledge of phase error of digitizers. Therefore, in this paper a method for the measurement of digitizers' absolute phase errors is proposed. It adopts a sinewave and two square waves, that are the digitizer sample clock and a phase reference signal. Combining the measurements of the relative phase differences between the adopted signals it is possible to accurately evaluate the absolute phase error of a digitizer.

1. Introduction

The knowledge of phase angles of signals is at the base of many engineering applications, from telecommunications to power systems ([1]-[5]). In particular, in most measurement applications, electronic instrumentation is based on digitizers, to convert analog signals to digital samples, and digital signal processors, to get the desired measurement value. However, every digitizer has its own phase frequency response which introduces a phase deviation between the analog input and its digital output samples. In some applications this phase deviation can be considered negligible, with respect to the measurand, and in others one could be interested only in the phase delay of two channels of the same digitizers, such as in energy or power measurement. Generally speaking, measuring the relative phase delay between two different channels of the same digitizer, or two channels of two different digitizers that have synchronized sampling clocks, is an issue solved in a number of scientific papers ([6]-[8]). However, there are special applications, such as Phasor Measurement Unit (PMU) ([9], [10]) or calibration of Low Power Instrument Transformers (LPIT) ([11]-[13]) with digital output (having as a reference an instrument transformer with analog output), where high phase accuracies, sometimes in the order of microradians, are required. In these situations, the absolute phase deviation of the single channel of the used digitizer may be comparable or higher than the required accuracy, introducing an unacceptable systematic error that highly influences the measurement result. An interesting technique for measurement of digitizer absolute phase error is proposed in [14], that involves the generation of a reference signal with known phase with respect to a time reference. In this paper, a technique for measuring the absolute phase errors of digitizer is presented. It is based on the preliminary characterization of the phase error of the used signal generator, through the use of a phase comparator ([6]-[7]). By means of a frequency counter, which measures the time delay between the sampling clock

of the Digitizer Under Test (DUT) and a Phase Reference Signal (PRS), and applying the Discrete Fourier Transform (DFT) of the DUT samples, the absolute phase error of the DUT is measured.

2. Measurement method

Let us suppose that the DUT is supplied with a sinusoidal signal s_g generated by an arbitrary waveform generator (AWG) and to have available a square waveform, i.e. the PRS, with the same frequency of the sinusoidal signal, as it is illustrated in Figure 1.

Assuming the rising edge of the PRS as the time reference (t = 0), the initial phase of the sine wave should be zero; however due to phase frequency response of the AWG and its internal time delay, the actual phase of the sine wave is φ_g. Thus, the DUT input can be written as:

$$s_g(t) = \sin(2\pi f_0 t + \varphi_g(f_0)) \tag{1}$$

where f_0 is the signal frequency and, for sake of simplicity, a unitary amplitude is considered. Suppose that the DUT sampling clock, with period T_s, is nominally aligned with the PRS, but, due to the delay of the clock paths, it is actually delayed of a quantity τ_c. Therefore, the samples at the output of the DUT can be expressed as:

$$s_{DUT}(kT_s) = \sin(2\pi f_0(kT_s + \tau_c) + \varphi_g(f_0) + \varphi_{DUT}(f_0)) \tag{2}$$

where $\varphi_{DUT}(f_0)$ is the phase deviation introduced by the DUT at frequency f_0 and the gain deviation has been neglected. The quantity $\varphi_g(f_0)$ can be measured with a phase comparator (COMP) ([1]) and the quantity τ_c can be measured with a frequency counter. The phase angle of the DUT samples $\angle F[s_{DUT}(kT_s)]|_{f_0}$, at frequency f_0, can be evaluated by performing the DFT; thus, the DUT phase error, at frequency f_0, can be evaluated as:

$$\varphi_{DUT}(f_0) = \angle F[s_{DUT}(kT_s)]|_{f_0} - 2\pi f_0 \tau_c - \varphi_g(f_0) \tag{3}$$

3. Measurement setup and results

To validate the proposed method a proper automated test bench has been realized. The system is based on a PXI chassis and the external universal frequency counter Agilent 53230A (350 MHz, 20 ps). The multifunction I/O module NI PXIe-6124 (+/- 10 V, 16 bit, maximum sampling rate of 4 MHz) has been used for DUT. The module NI PXI-5422 (+/- 12 V, programmable gain, 16 bit, maximum sampling rate of 200 MHz) has been used for AWG.
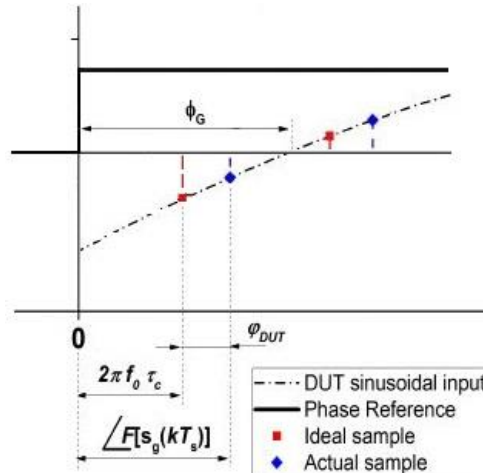

Figure 1. DUT sinusoidal input, Phase Reference Signal and ideal and actual samples acquired by DUT.

The digitizer used for the phase comparator is, instead, the module NI PXI 4462 (+/- 10 V, 24 bit, maximum sampling rate of 204.8 kHz). Excluding the comparator, which operates asynchronously, all the instruments of the test bench use clocks generated by the NI PXI-6683H synchronization board, so they are all synchronous. In particular, the sampling frequency of the AWG is 5 MHz, while the sampling clock of the DUT is 1 MHz. The PRS is generated by the NI PXI-6683H, too. A digital storage oscilloscope (Tektronix TDS 2014B) is used to control the correct operation of the setup. The block diagram of the measurement setup is shown in Fig. 2, where C_{DUT} is the DUT sampling clock and C_{AWG} is the sampling clock of the AWG.

The sine wave is connected to both the DUT and the COMP. The COMP measures the phase difference between the sine wave and the PRS. The frequency counter receives a 10 MHz clock as external timebase and measures the time delay between PRS and DUT sampling clock.

All the clock and signal paths are symmetric in order to avoid different propagation delays. Since the two input channels of COMP and of the counter could have inter-channel time (or phase) delay, in order to compensate for these systematic errors, two measurements are performed, interchanging the signals between the two channels, both for COMP and counter ([1]).

Measurement software is developed in LabVIEW. For each test point, amplitude and frequency of the test signal of the DUT can be chosen and 30 repeated measurements of $\angle F[s_{DUT}(kT_s)]|_{f_0}$, τ_c and $\varphi_g(f_0)$ are performed.

An automated test, sweeping frequency of the test signal from 50 Hz to 20 kHz, has been performed. Two amplitudes, 5 V and 10 V, and a constant DUT sampling frequency of 1 MHz have been chosen.

Fig. 3 shows the DUT phase frequency responses, at 5 V and 10 V, where, for each point, mean value and standard deviation is plotted.

It is worth noting that the DUT does not use antialiasing filter. Therefore, as expected, its phase error is linearly dependent on the input signal frequency and it is due to an almost constant time delay introduced by the digitizer in its bandwidth.
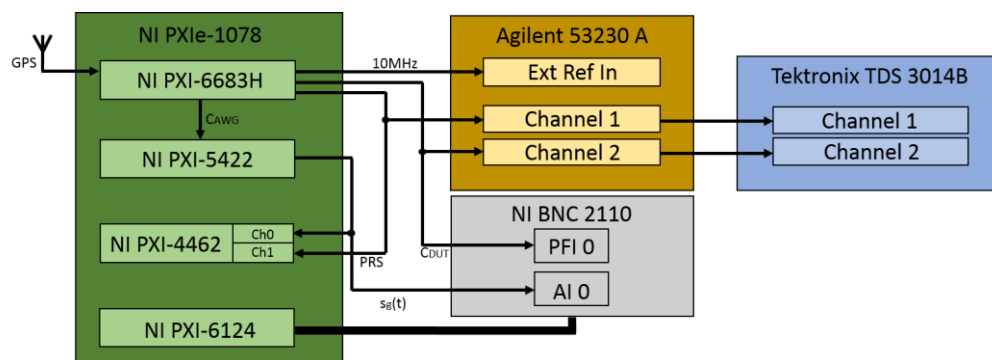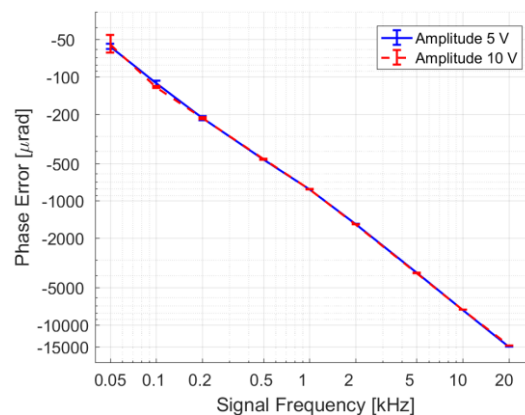

Fig. 2. Measurement setup.

Figure 3. DUT phase frequency response.

4. Conclusion

In this paper a new technique for the measurement of digitizers' absolute phase error is presented. A commercial digitizer has been characterized changing input signal characteristics, i.e. amplitude and frequency. However, the technique is general and can be applied to evaluate the absolute phase error of every digitizer.

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