

Measurement of Absolute Phase Error of Digitizers

G. Crotti¹, A. Delle Femine², D. Gallo², D. Giordano¹, C. Landi², M. Luiso²

¹Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy {g.crotti, d.giordano}@inrim.it

²Dept. of Industrial and Information Engineering, University of Campania Luigi Vanvitelli, Aversa (CE), Italy {antonio.dellefemine, danielle.gallo, carmine.landi, mario.luiso}@unicampania.it

Abstract—Some engineering applications, such as Phasor Measurement Unit and calibration of instrument transformers with digital output, require the knowledge of phase error of digitizers, to reach high phase measurement accuracy. This paper proposes a method for the measurement of digitizer absolute phase errors. The technique is based on the characterization of generator phase response and on the measurement of the time delay between the digitizer sampling clock and a phase reference signal. Taking into account the phase deviation introduced by generation system and the clock delay it is possible to accurately evaluate the digitizer absolute phase error.

Index Terms—Phase Measurement, Data Acquisition System, Calibration, Power System Measurements, DFT, PMU, LPIT.

I. INTRODUCTION

Phase measurements are common in many engineering fields, from telecommunications to power systems. Most modern instrumentation makes use of 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. This phase deviation is considered negligible in many applications, while in others one could be interested only in the phase delay of two channels of the same digitizers. 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 ([1]–[3]). However, there are special applications, such as Phasor Measurement Unit (PMU) or calibration of Low Power Instrument Transformers (LPIT) with digital output (having as a reference an instrument transformer with analog output), where, since high phase accuracy is required, the absolute phase deviation of the single channel of the used digitizer may highly influence the measurement result. An interesting technique for measurement of digitizer absolute phase error is proposed in [4], 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 [1], [2]. 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.

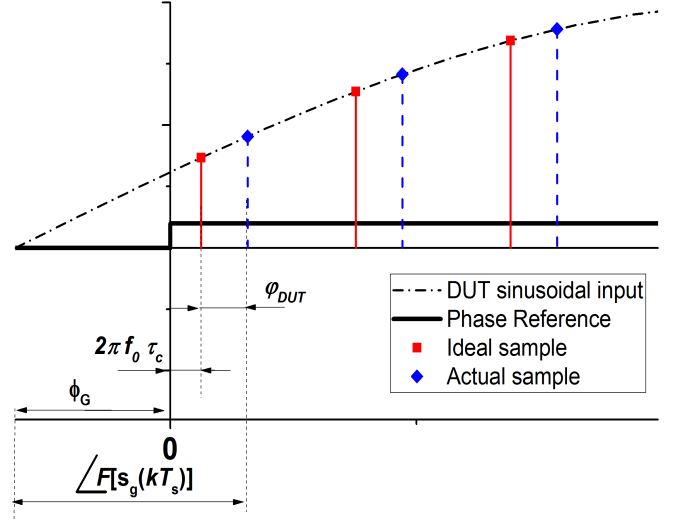


Fig. 1. DUT sinusoidal input, DUT clock and Phase Reference Signal.

II. MEASUREMENT METHOD

We assume to supply the DUT with a sinusoidal signal 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 Fig. 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 signal (s_g) can be written as:

$$s_g(t) = \sin(2\pi f_0 t + \phi_g(f_0)), \quad (1)$$

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 by a quantity τ_c . Therefore the samples acquired by the DUT can be expressed as:

$$s_g(kT_s) = \sin(2\pi f_0(kT_s + \tau_c) + \phi_g(f_0) + \varphi_{DUT}(f_0)), \quad (2)$$

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 $\phi_g(f_0)$ 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 $\angle F[s_g(kT_s)]|_{f_0}$, at frequency f_0 , can be evaluated by performing the DFT; thus, the DUT phase error, at frequency f_0 , can be evaluated as:

$$\varphi_{DUT}(f_0) = \angle F[s_g(kT_s)]|_{f_0} - 2\pi f_0 \tau_c - \phi_g(f_0). \quad (3)$$

III. MEASUREMENT SETUP AND FIRST 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). Two identical multifunction I/O modules NI PXIe-6124 (+/-10 V, 16 bit, maximum sampling rate of 4 MHz) have been used one for AWG and one for 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 4 MHz (i.e. the maximum allowed module sampling rate), while the sampling clock of the DUT, which is externally provided, is variable, in order to test the DUT phase error dependence also on the sampling frequency. The PRS is generated by the NI PXI-6683H, too.

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 and the sampling frequency of the DUT can be chosen and 30 repeated measurements of $\angle F[s_g(kT_s)]|_{f_0}$, τ_c and $\phi_g(f_0)$ are performed.

Two automated tests sweeping frequency of the test signal or DUT sampling frequency have been done. In all the tests, the sine wave amplitude is of 5 V. In the first test, the signal frequency varies in the range 50 Hz to 20 kHz with a constant sampling frequency of 1 MHz. In the second test, a constant signal frequency of 50 Hz is used, while the DUT sampling frequency is in the range 1 kHz to 1 MHz.

Fig. 2 shows the DUT phase frequency response (first test), where, for each point, mean and standard deviation are plotted. It is worth noting that the DUT does not use anti aliasing 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 digitizer in its bandwidth.

In Fig. 3 the DUT phase error, at 50 Hz, as function of sampling frequency is reported. It shows that increasing the sampling frequency the phase error becomes lower; however, it becomes almost constant, about $-65 \mu\text{rad}$, over 10 kHz.

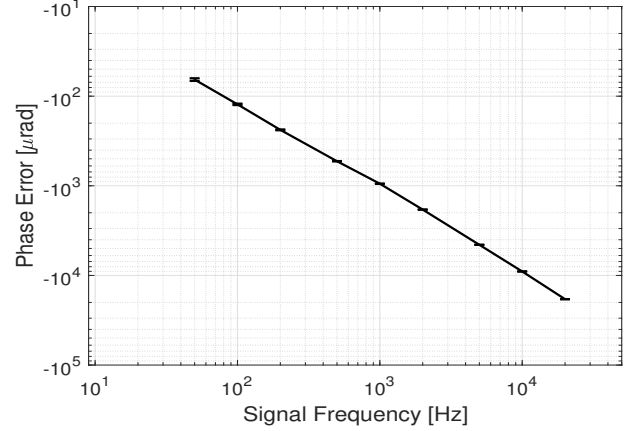


Fig. 2. DUT phase frequency response.

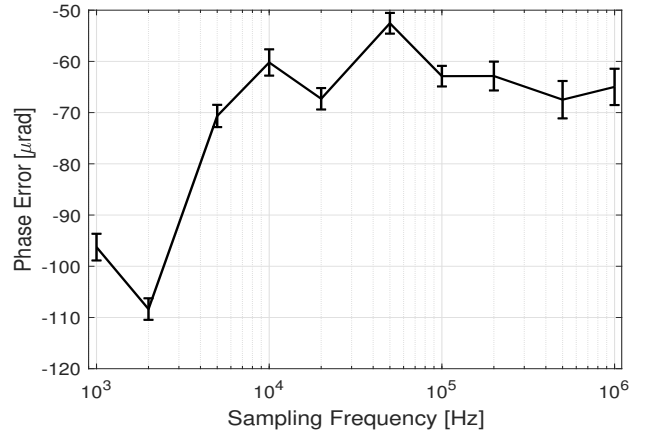


Fig. 3. DUT phase error at 50 Hz vs sampling frequency.

IV. CONCLUSION

This paper presents a technique for measurement of absolute phase errors of digitizers. The key role is played by the phase reference signal: it act as a reference for arbitrary waveform generator characterization but, being a square wave, it also allows for the measurement of DUT sampling clock delay. It is worth highlighting that this method does not lose generality when using higher voltage levels or current signals. There is just the necessity of voltage or current amplifiers and transducers which are characterized through independent methods and instrumentation [1], [2]. The evaluation of the uncertainty budget of the proposed method is in progress.

REFERENCES

- [1] B. Trinchera, D. Serazio, and U. Pogliano. Asynchronous phase comparator for characterization of devices for pmus calibrator. *IEEE Transactions on Instrumentation and Measurement*, 66(6):1139–1145, June 2017.
- [2] G. Crotti, D. Gallo, D. Giordano, C. Landi, and M. Luiso. Industrial comparator for smart grid sensor calibration. *IEEE Sensors Journal*, 17(23):7784–7793, Dec 2017.
- [3] E. Mohns, J. Meisner, G. Roeissle, and M. Seckelmann. A wideband current transformer bridge. *IEEE Transactions on Instrumentation and Measurement*, 63(10):2322–2329, Oct 2014.
- [4] M. Acanski, G. Rietveld, and D. Hoogenboom. Accurate phase calibration of pmus and pmu calibrators. In *2016 Conference on Precision Electromagnetic Measurements (CPEM 2016)*, pages 1–2, July 2016.