A System for the Characterization
of High Resolution DACs and ADCs

Umberto Pogliano

Istituto Nazionale di Ricerca Metrologica (I.N.Ri.M.) Strada delle Cacce 91,10135 Torino, Italy
phone +39 011 3919.433, Fax +39 011 346384, pogliano@ien.it

Abstract-This paper describes the system under construction at I.N.Ri.M. for the characterization of high resolution DACs and ADCs. The main measurement instrument used as a reference is a high precision sampling multimeter, which is properly configured for the measurement of both dc and ac voltages supplied by the DAC under test. A proper voltage pattern is supplied to the ADC under test by means of a multichannel output board put inside a computer, combined by suitable supplementary electronic circuits. The constructed signal is then measured by the multimeter and analyzed by the computer.

I. Introduction

Analog to digital converters (ADCs) and digital to analog converters (DACs) are widely used in modern instrumentation. The digital signal processing is employed by the manufacturers of measuring instruments because modern microprocessors can easily and inexpensively perform the operations required. Furthermore, this approach based on software can produce instruments that are, in principle, re-configurable.
To take fully advantage of all such features, while maintaining the possibility of the complete calibration of the instruments, systems and methods for calibrating such converters both as components and boards employed in these instruments have to be developed.
The National Institute for Metrological Research (I.N.Ri.M.), which is the primary laboratory for electrical metrology in Italy, has been repetitively asked to supply the traceability for such instruments and a calibration service for DACs and ADCs.
As a primary laboratory we are now evaluating the feasibility of a system for the characterization of high accuracy converters. The target is a system sufficiently accurate to calibrate devices or boards with resolution in the range of 16-18 bits.
For this purpose the generation of signals both in dc and ac with very high accuracy is needed, while the sample rate for the acquisition of the digital signals seem not to be the major problem.
Further features, required to the system, are the quick measurement of the voltage value at the level of a few parts in 10^6 and, for the large amount of data required for the determination of the parameters, the full automation of all operations.

II. Hardware of the system

The design aim at implementing the essential elements for the measurement of both the static and dynamic characteristics of DACs and ADCs. To be fully transportable, in order to operate for the calibration of device or computer boards directly in the field of the application like other systems of this type [1], the system is based on a few instruments. The two main elements are a flexible generator for supplying the ac and dc voltages to the ADC under test and a precision multimeter acting as the metrological reference, which is dedicated to the measurement of both the voltage produced by a DAC under test or by flexible generator.
The scheme of the generator of the system, which can supply the reference signals is represented in Fig. 1. It is realized by means of a multichannel analog output board and a bidirectional input/output digital programmable board both put within a computer. The multichannel analog output board can supply eight outputs channels. However, at the moment the system utilizes only two of them and the input/output digital signals. All analog outputs have a resolution of 16 bits and sampling rate of 1 Msample/s.
A high precision sampling voltmeter is then used as a metrological reference and some of analog circuits are employed in the measurement configurations for the static and dynamic characteristics. These circuits, which consist in two adders that combine with different weight two or more inputs, an integrator and filters, can be arranged in a particular configuration for the specific measurement to be

performed.
In both the dc and ac cases the adder is built as an instrumentation amplifier connected in a multiple input configuration. The difference between the ac and the dc case is the amplifier optimized in dc for the offset and bias and in ac for the bandwidth and the noise.

A. Static characterization of DACs

The calibration of DACs is the simpler task for the system described. The suitable sequence of digital signals is given to the digital input of the DAC under test and its output is read by the voltmeter. After the measurement the computer, which has stored all the digital data supplied to the DAC and all the voltages measured by the voltmeter, evaluates the parameter characterizing the DAC.

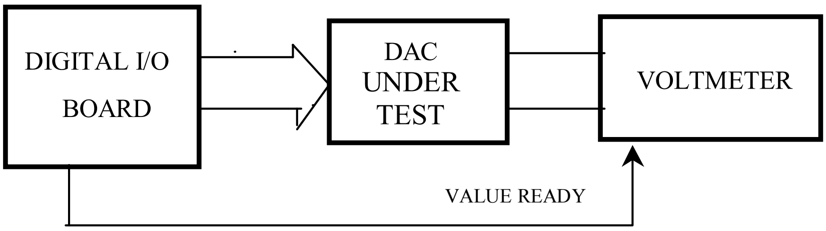

Fig. 1 Configuration of the system for the static characterization of an DAC

B. Static characterisazion of ADCs

In order to increase over 16 bits the resolution of the voltage supplied to the ADC under test, a combination of two outputs of the board and a linear adder has been employed. The weights of the two inputs of the adder are in a ratio that can be selected between 1/1000 or 1/100. A further input is employed to interpolate linearly measured values for the determination of the static characteristics.

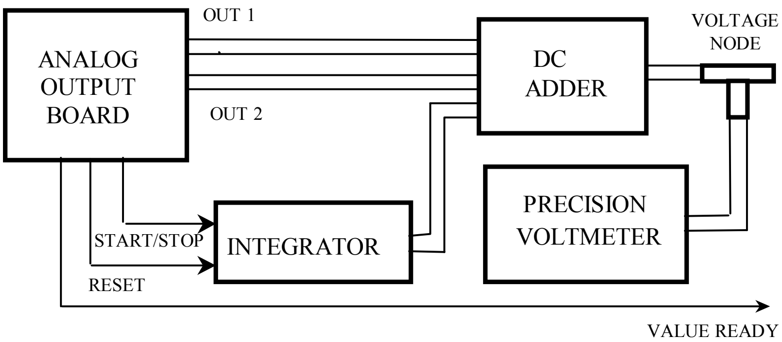

Fig. 2 Generator of the system for the static characterization of high accuracy ADCs.

For the determination of the static characteristics several strategies can be utilized, which operate at different level of accuracy, but also at different speed.
The maximum accuracy can be reached by the following procedure:

- setting of the value of the first output of the board,
- reading of the voltage by the voltmeter,
- on the basis of the measured value, setting the value on the second output of the board,
- verification that the exact voltage, within a given uncertainty, is reached.

When the exact dc value is obtained the VALUE READY signal is set and the voltage can be read by the ADC under test.
A quicker method can be obtained by the same circuit by setting the two outputs using a predetermined tables of the corrections for the first output, while the exactness of the second is assumed for its limited weight. This method is less accurate, because does not take into account the possible drift of the board.

A compromise between the two methods is obtained by making the measurement in different sequences:

- a specific value is set on the first output with the second one at a minimum value;
- the voltage at the output of the adder is read;
- the second output of the analog board changes gradually and the output of the adder is sent to the ADC under test.

When the second output reaches the predetermined value the voltage at the output of the adder is read again and all sequence can be identified by interpolation and a new sequence can start. An equivalent procedure can use the integrator to produce the interpolation between the two measured values.

C. Dynamic characterisazion of ADCs

By means of this system the dynamic characterization of the ADC can be obtained using different methods such as 3 parameter sine fit, 4 parameters sine fit [2], istogram [3] or DFT [4]. In all these methods it is necessary to supply a very low distortion sinewave.

Passive filters built with very linear component can be used for this purpose, but they have the disadvantage that need a manual tuning that can be troublesome for automatic measurements. In this system the sinusoidal signals are obtained from a staircase waveform signals produced by the first and the second output of analog board in the computer. The combination of the two outputs (the second one with a weight of 1/1000) is filtered by a passive low pass filter to reduce the high order harmonic components in ac signals and is measured by the multimeter. Instead, for frequencies up to a few kiloherz the sampling multimeter can reconstruct by means of suitable algorithm the harmonic contents of the distortion, as for example that described in [2]. This harmonic components can be then reduced by appropriately programming the signal at the second output.

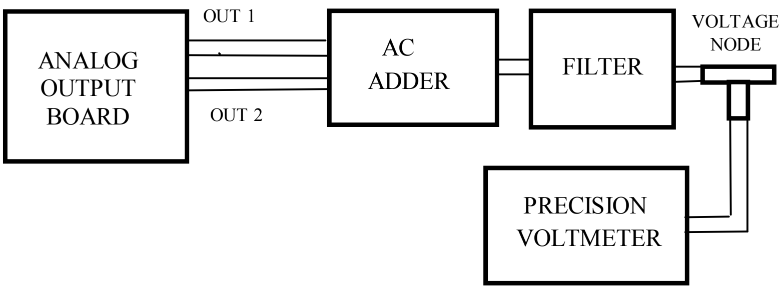

Fig. 3 Generator of the system for the dynamic characterization of high accuracy ADCs.

III. Test of the generator for the static characterization

Some tests have been performed by measuring the output with high accuracy by the multimeter in some fixed values have shown the stability of the outputs. For example with the output of 10 V the short and medium term stability at the level less than 3 parts in 10^6. Such stability allows to produce voltages that are defined almost one order of magnitude better than the resolution of the board. The dc adder has been tested and does not introduce significant noise nor instability to the input and allows to reach any programmed voltage in the range between -10 V to +10 V with an accuracy of 30 μV in two steps. Sequences of high accuracy voltages are then possible for the determination of the static characteristics.

The distortion of a voltage produced by the first output of the circuit followed by a passive LC 100 kHz low pass filter depends moderately on the frequency from 50 Hz up to 1 kHz, where has been measured to be less than 0.003%. The algorithm for the evaluation of the harmonic components shows a repeatability in the measurement of each harmonic component better than 1 parts in 10^6. Preliminary experiments have shown the possibility to reduce by compensation, the distortion less than 0.0005%, which is a sensitivity limit for the instrument used for the distortion measurements. Other more efficient algorithms for controlling and reducing the distortion are now under development.

IV. Conclusions

A system for the high precision characterization of DACs and ADC is now under construction at I.N.Ri.M. Such system is based on a high resolution and high sampling rate board and a precision digital multimeter and other analog circuits.
Tests on the stability of the source and precision of the associated voltmeter have shown the possibility of performing a high precision static characterization of DACs and ADC.
The same system, in a slightly different configuration, can also generate a very low distortion signal for the precision dynamic characterization of high resolution ADCs.

Acknowledgment

The author would like to tank Mr. G. Savino and Mr. D. Antonello for their contribution in the development of programs in Labview to perform preliminary tests on the system.

References

[1] A. Carullo, M. Parvis, and A. Vallan, "A Traveling Standard for the Calibration of Data Acquisition Boards", *IEEE Trans. on Instrum. and Measur.*, vol. IM-53, no. 2, pp. 557-560, 2004.
[2] IEEE Std 1241-2000 IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters, 2000.
[3] J. Doernberghae, S. Lee and and A. Hodges, "Full-Speed Testing of A/D Converters", *IEEE Journal Of Solid-State Circuits*, vol. SC-19, no. 6, 1984.
[4] F. J. Harris, "On the use of windows for harmonic analysis with the discrete Fourier transform", *Proc. IEEE*, vol. 66, 1978.
[5] U. Pogliano, "Precision Measurement of AC Voltage below 20 Hz at IEN", *IEEE Trans. on Instrum. and Measur.*, vol. IM-46, no. 2, pp. 396-372, 1997.