

THE PROBLEM OF THE STANDARD CHARACTERIZATION OF ADC AND DIGITIZING WAVEFORM RECORDERS

M. Savino

Laboratory of Electrical and Electronic Measurements
Department of Electric's and Electronics (DEE) – Polytechnic of Bari
Via E. Orabona 4, 70125 Bari

Abstract. The problem of the metrological qualification of data acquisition systems and of waveform recorder is a fundamental issue for both users and manufacturers of digital instruments.

The need for an improved industrial standard leading to unification and standardization in this field is a very pressing requirement. Users have to receive technical specifications written in standard format and manufacturers to obtain them following standard test procedure.

The Main goal of this paper is to underline the need of unifying the modeling, identification and optimization of ADC-based systems, by minimizing the number of the experimental procedures to be employed.

Keywords: Digital Waveform Recorders, Analog-to-Digital Converters, Data Acquisition Systems, Metrological Qualification

1 INTRODUCTION

The considerable progress achieved in the fields of both electronic technology and digital signal processing is modifying the basic architecture of the measurement devices and the idea itself of measuring. It is more and more inadequate to consider an instrument as a device devoted to the measurement of a single quantity, whereas it is convenient to conceive an instrument as a data-processing system which acquires the physical variables and yields information necessary to determine the desired figures. Computer and signal processing techniques are the dominating technologies, leading to a drastic reduction of costs and increasing flexibility. It is indeed very common, nowadays, to build very complex automated measurement systems by interfacing comparatively cheap digital instruments, analog-to-digital conversion boards, and personal computers.

A primary problem in modern measurement technology is the *uncertainty qualification*, including testing, calibration and diagnosis. It must be highlighted that even the most powerful and sophisticated measurement system is *not* a measuring instrument if it is impossible to quantify the associated measurement uncertainty.

This is a multi-faceted problem with many aspects that deserve a specific discussion. Think, for example, about how to define error and uncertainty dealing with multi-dimensional signals, signals with time-varying parameters, etc. Or ask what does it mean to measure the reactive power in nonsinusoidal conditions, or to measure the "instantaneous frequency". Besides this kind of "high-level" problems there is, however, a lower level of problems arising from the following simple question:

"How does the analog-to-digital converter (ADC) modify a generic signal that one puts into a computer to measure it?"

Low-level problems are here, as in many other fields, by no means simpler. It can be convenient to examine them starting from the most practical and common viewpoint. Consider the familiar user manuals of digital instruments or the data-sheet of integrated ADC's employed for measurements. As a matter of fact, reading and interpreting the accuracy specifications of commercial devices yields a lot of difficulties, so that it is a real trouble to compare the performance of different instruments.

Indeed, the figures presented as "accuracy specifications" have changeable names, changeable meaning and always leave many questions unanswered. Besides, there is no indication how these parameters have been derived.

Many works and documents dealing with these arguments exist, but many limitations still must be overcome. For example, the scientific literature abounds of test methods that analyze particular effects or error phenomena in digital recorders, ranging from out-phase harmonics to narrow-band noise, etc.,

and it is not uncommon to run into puzzling questions and even contradictions when trying to arrange them together.

Even the most authoritative technical document about this field, the well-known IEEE Standard 1057/94 [1] and the subsequent Standard 1241 [2] give a wealth of useful definitions, test methods and mathematical analyses, but do not answer fully and satisfactorily the fundamental question stated above in inverted commas. In other words, it is needed, and cannot be found in the literature, a single set of equations, a *behavioral model*, that takes into account *all* error phenomena that could be encountered when transferring an analog *arbitrary* signal into the digital world of our microprocessor-based instruments. And, of course, there is not a single identification procedure for such a model, allowing one to derive all relevant parameters with a simple and clear-cut sequence of experiments.

These considerations explain the necessity of working for new regulating documents, i.e., standards, for *model identification of waveform recorders*. It is noteworthy to underline that this need of unification and standardization is desirable for both users and manufacturers, as a deeper understanding, more reliable measurements and a more meaningful representation of the metrological characteristics of digitizing systems are fundamental goals for the development of modern measurement technology. From this point of view, not only instrument manufacturers but also, and above all, universities and researchers play a fundamental role, and in their hands lies a big part of the next evolution in measurement technology.

2 A POSSIBLE STRUCTURE FOR A COMPLETE BEHAVIORAL ERROR MODEL

It has been said that modeling is the main issue to understand, to evaluate and to minimize errors in ADC's and ADC-based instruments. A suitable behavioral model of digitizer should be able to describe the largest possible number of practical devices, and should allow one to easily identify its parameters. In particular, to give a suitable mathematical description of the transformations introduced by an actual digitizer, both systematic and random errors must be considered, and both errors relevant to the time axis (sampling) and to the amplitude axis (quantization).

With this consideration in mind, a generic digital recorder can be modeled [3] as depicted in Figure 1. The digitizer is thought as an ideal analog scope preceded by horizontal (timebase) and vertical (amplitude) analog errors, and followed by ideal sampling and ideal quantization. The essence of the model is obviously in the analog error blocks, that include nonlinearity and noise (i.e. systematic and random errors), affecting both the horizontal and the vertical axis.

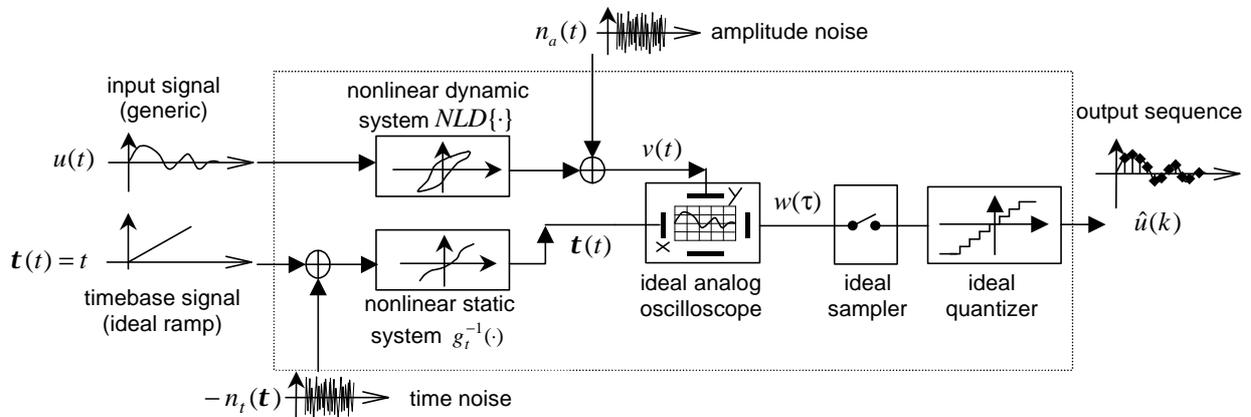


Figure 1 – A model structure for digital waveform recorder, showing the errors affecting the amplitude axis and the time axis.

Without going too deep into details, some general comments about the model are needed. First of all, this scheme separates “extrinsic” and “intrinsic” errors, i.e., errors due to the non-ideality of the real-world device and errors inherent to the A/D conversion itself. The ideal sampler and the ideal quantizer blocks, that transform $w(t)$ into $\hat{u}(k)$, are responsible for intrinsic errors. Their parameters are perfectly known from the *nominal* characteristics of the physical device and their effects are computable by using well-known concepts and formulae of sampling and quantization theories.

The remainder of the structure, i.e., that transforming $u(t)$ into $w(t)$, is the true theoretical and practical problem, but its understanding is a little simpler than that of the black box that transforms $u(t)$ into $\hat{u}(k)$. This part of the model is indeed purely analog and can be mathematically treated by using familiar continuous-time and continuous-amplitude tools

refined methods, based on more complete error models (see, for example, the very convincing test for timebase errors illustrated in [6]). Certainly a single and clear-cut identification procedure, that takes into account all the error phenomena in a waveform recorder, cannot be found anywhere.

With this considerations in mind, a complete behavioural error model must embody two noise generator, $n_a(t)$ and $n_t(t)$ and two non-linear systems, static $NLS(\cdot)$ and dynamic $NLD(\cdot)$.

To avoid the inherent complication due to the use of Volterra kernels [7] it is possible to decompose $NLD(\cdot)$ in three simpler block as in Figure 2, so that a simplification and comprehension of system is yielded.

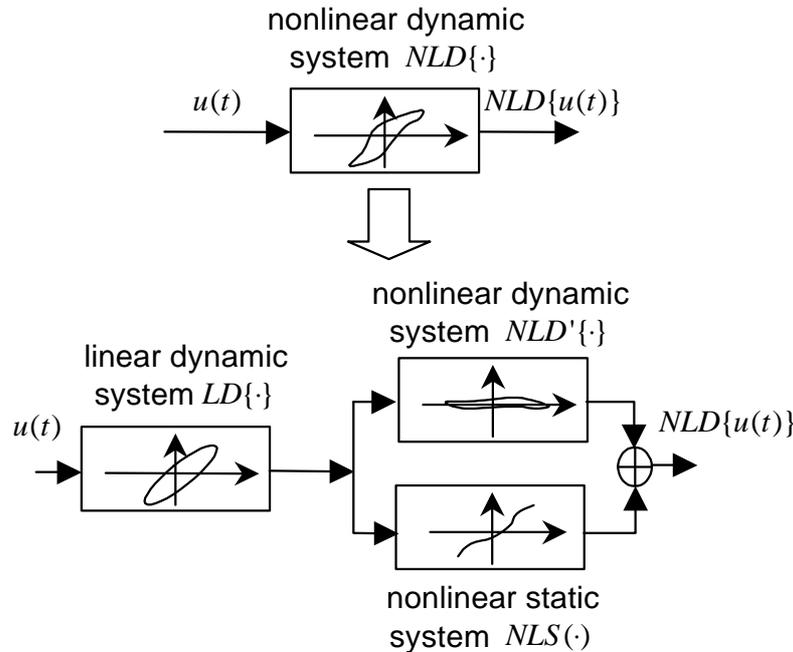


Figure 2 – Decomposition of the linear dynamic block $NLD\{\cdot\}$.

Omitting useless details, it's noteworthy that a unique decomposition requires some constraints and particularly the minimum condition, which simplify the initial complicate block.

Particularly, the proper method for identifying the non linear static block $NLS(\cdot)$ is the "histogram" or "code density" test [8], which is conceptually simple and produce an accurate valuation of distortion. Unfortunately, this procedure is very slow, particularly for ADC with high resolution, requiring hundreds of samples and doesn't produce any information relevant to other kinds of errors.

On the contrary, the frequency domain analysis, which uses the fast Fourier transform (FFT), carries out both the noise and the harmonic distortion identification with a limited number of samples (~ 4000) even for 12-16 bits ADC and is always very fast. Unfortunately, it doesn't identify completely the nonlinear static block but yields an indirect information, that is the harmonic distortion generated by the nonlinearity. To overcome this restriction, the Chebyshev polynomials of the first order can be used [9]. This theory of non-linear system applied to ADC tests carry out an accurate identification of nonlinear static blocks and can be suggested as a fast test to verify and correct the static linear error in waveform recorders.

Besides, the dynamic linear transfer function, the dynamic nonlinearity and the timebase $g_t(t)$ arise simultaneously with high frequency signals and their separation renders the estimate difficult. As regards $g_t(t)$ it is known that its measurement is disturbed by the presence of $inl_d\{x(t)\}$, which arise simultaneously with high frequency signals.

Differently from suggestions of IEEE method, that presumes an error model in which timebase errors are predominant, it seems that a recently proposed procedure, in [6]., can be able to measure the timebase distortion with σ_t and σ_a , in the presence of arbitrary amplitude distortion

Finally, after $g_t(t)$ and $NLS(\cdot)$ estimation it is possible to search for the linear system $LD(\cdot)$ and then determine the residual dynamic nonlinearity $NLD'(\cdot)$.

4 CONCLUSIONS

In this paper some basic ideas about the description and characterization of digitizing waveform recorder have been put forward and some new testing methodologies have been indicated.

Mainly, the need of unification and standardization in this field has been highlighted. Even if many test methods for evaluating the errors in an actual digitizer have been proposed, a procedure that identify the behavioral model of the digitizer does not exist.

This is a real problem as the users require that the technical specifications are written in standard format and the manufacturers must obtain them following standard test procedures.

A good standard, therefore, should contain a set of procedures for identification, testing and correction of the model.

With this aim, a practical contribution, which organizes the typical errors of digitizer in a unified complete behavioral model, has been presented. Its takes into account both the systematic and random errors separately in the time and amplitude domains.

Following this idea, the paper, more than giving solutions, is intended to show up a set of the problems, which I hope will gain the attention of the researchers in this field so that the development of suitable test methods is stimulated.

REFERENCES

- [1] IEEE Standard 1057 for Digitizing Waveform Recorders, Dec. 1994.
- [2] IEEE Standard 1241 for Terminology and Test Methods for Analog-to-Digital Converters, Draft, May 1999.
- [3] G. Andria, F. Attivissimo, G. Cavone, N. Giaquinto, M. Savino, A. Trotta, Ideas for a standard on model identification of digital waveform recorders, *Proceedings of 4th International Workshop on ADC Modelling and Testing*, (Bordeaux, 9-10 September 1999) France, 1999, p.218-221.
- [4] J. Schoukens, A critical note on histogram testing of data acquisition channel, *IEEE Trans. Instr. Meas.*, **44** (3) (1995) 860-863.
- [5] F. H. Irons, D. M. Hummels, S. P. Kennedy, Improved compensation for analog-to-digital converters, *IEEE Trans. Instr. Meas.*, **38** (3) (1991) 958-961.
- [6] G. Vandersteen, Y. Rolain, J. Schoukens, System identification for data acquisition characterization, *Proceedings of the IEEE-IMTC/98 Conference* (St. Paul, 16-18 May 1998) Usa, 1998, p. 1211-1216.
- [7] J. S. Bendat, *Nonlinear system analysis and identification from random data*, Wiley, New York, 1990.
- [8] C. Morandi, L. Niccolai, An improved code density test for the dynamic characterization of flash A/D converters, *IEEE Trans. Instr. Meas.*, **43** (2) (1994) 384-388.
- [9] F. Adamo, F. Attivissimo, N. Giaquinto, Measurement of ADC integral nonlinearity via DFT, *in these Proceedings*.

AUTHOR: Prof. Mario SAVINO

Electrical and Electronic Department, Polytechnic of Bari

Via Orabona, 5, 70125 Bari - Italy, Phone Int ++39 080 5963662, Fax ++39 080 5963410,

E-mail: savino@poliba.it