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# DAC consistent terminology: static parameter definitions

E. Balestrieri *, S. Rapuano

*Faculty of Engineering, University of Sannio, Piazza Roma, 82100 Benevento, Italy*

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**Abstract**

In this paper, the existing DAC static parameter definitions are evaluated highlighting their differences and similarities. Great attention has been paid to the most commonly used specifications. As a result of this analysis a unique set of DAC specifications is proposed considering that each parameter has to be unambiguously defined and practically measurable.


*Keywords:* DAC; Resolution; Full scale range; Gain; Offset; LSB; DNL; INL

## 1. Introduction

The considerable development that has characterized DACs in these last years, even though has given a wider and deeper choice to the user, on the other hand, has produced burdensome problems due to the lack of standard terminology and tests. In fact, even though DACs perform the same function, in practice different converters may behave quite differently. Therefore, a number of specifications determining the DAC static and dynamic performance is essential. But, DACs made by different manufacturers are often not comparable, due to the different ways of specifying and testing parameters, making the user fail in selecting the best suited device for his needs.

Standards can help users to avoid misinterpretation of the real device performance and the dependence on a single manufacturer allowing a broader choice among cheaper products. Users can also have increased confidence in the quality and reliability of manufacturers who use standards. DAC metrology standardization leads benefits also to manufacturers in terms of compatible products and services, reduction in development costs, easy conformity assessment, mass production, economy of scale as well as facilitation of satisfying user requirements and the access to new markets.

Aware of this the Waveform Measurement and Analysis Technical Committee (TC-10) of the IEEE Instrumentation and Measurement Society is currently work on a new project aimed to produce a standard defining terminology and test methods for DACs [1].

One of the most relevant aspects concerning the definition of this new norm is related to the choice of a consistent terminology since different DAC terms and acronyms often represent the same

* Corresponding author. Tel.: +39 0824305817; fax: +39 0824305840.
*E-mail addresses:* balestrieri@unisannio.it (E. Balestrieri), rapuano@unisannio.it (S. Rapuano).

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concept as well as different definitions are often used for parameters having the same name.

In this paper, several DAC static performance parameter definitions coming from existing standards, scientific literature and manufacturers' documentation are collected, compared and discussed to propose a unique and unambiguous set of parameter definitions in order to give a contribution and ideas for discussion concerning the new DAC standard.

During the research work, great attention has been paid to the most commonly used specifications focusing on the following parameters: resolution, full scale range, Least Significant Bit (LSB), offset and gain, Integral NonLinearity (INL), Differential NonLinearity (DNL). This paper is a part of a research project oriented to provide a comprehensive overview on DAC topics [2]. The DAC static specifications should be chosen considering that each parameter has to be unambiguously defined and practically measurable. The measurableness is an essential requirement in prototype characterization, production testing and for the device evaluation. For this reason each definition should be joined with its measurement unit taking as reference the International System of Units (SI).

The final set of DAC specifications is proposed taking into account the most used definitions coming from the collected references. For each parameter the existing definitions have been entirely adopted, modified or completely rewritten in order to satisfy the above reported requirements. Since some DAC specifications (where possible), could be derived from the ADC ones with the appropriate changes, the IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters (IEEE Std. 1241) [3] has been used as guideline. In the following the paper has been divided into five sections, each of them analyzes a single parameter and proposes a possible new definition.

## 2. Resolution

The DAC resolution can be expressed in different forms. The IEC 60748-4 [4] distinguishes among the *numerical*, the *analog* and the *relative resolution* clarifying that "the terms for these different forms may all be shortened to "resolution" if no ambiguity is likely to occur (for example, when the dimension of the term is also given)". The numerical resolution is defined as "the number of digits in the chosen numbering system necessary to express the total number of steps" of the transfer characteristic, where a step "represents both a digital input code and the corresponding discrete analogue output value". The *analog resolution* is defined as the nominal value of the difference in step value between two adjacent steps, (step height) often used as a reference unit named LSB. Finally the *relative resolution* is "the ratio between the analog resolution and the full scale range (practical or nominal)".

In scientific literature, the shortened term resolution is used in the numerical or in the analog sense [5]. The most commonly used definition of resolution provided by manufacturers' datasheets is the *numerical resolution* expressed in bits [6–9].

The IEEE Std. 1241 [3] does not define the term resolution, but, uses the LSB definition to indicate the *analog resolution* reported in [4].

The *numerical* and the *analog resolution* are the definitions that most often appear in the references. The first is determined by architecture, is dimensionless and not measurable. The second is measurable and is expressed either in volt or ampere. Considering that the *analog resolution* can be defined through the LSB definition and that the specification set, purpose of this paper, must include univocal definition of each parameter, the numerical sense of resolution is recommended for adoption.

However, the IEC 60748-4 [4] *numerical resolution* definition requires to know what is a step. A better definition could be the following:

"The number of bits used to produce each analog output level. The higher is the number of bits, the smaller is the analog (voltage or current) output step that could be generated. An $N$-bit resolution implies producing $2^N$*distinct analog levels*".

The above definition does not require the knowledge of other DAC parameters and simply highlights the differences between DACs with different resolutions.

## 3. Full scale range

The Full Scale Range (FSR) is the difference between the maximum and minimum analog output values that the DAC is specified to provide. For an $N$ bit DAC, these values are usually given as the ones matching with code 0 and $2^N$.

The code $2^N$ is used only to define the ideal DAC transfer function not existing in the practical usage. So the maximum analog output of the converter quite never reaches such output level defined as analog Full Scale (FS). In particular, the maximum