

## Effect of A/D conversion static errors on magnetic accommodation measurements

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**Abstract-** In this paper we analyze how static errors of Analog-to-Digital converters (ADCs) can influence the measurement of magnetic phenomena such as accommodation in soft hysteretic materials. The discussion is carried out through a series of simulation of ADC response curves and applied to simulated signals and data measured on a toroidal soft ferrite core. The final purpose of this work is to analyze the impact of INL on the measurement of the accommodation phenomenon of minor loops in soft magnetic materials.

### I. Introduction

Magnetic hysteresis is a subject of great interest to the scientific community since many years and phenomenological models require accurate measurements. Thus, experimental results are very important for developing and validating hysteresis models. Besides, a powerful measuring technique is practically not usable without the possibility of quantifying the associate measurement uncertainty. Therefore, our attention is oriented to the study of the magnetic accommodation (the drift of a minor loop when the magnetic field cycles between two extreme values) and to correct the measurements errors. Although various measurement techniques can be adopted for magnetic material characterization, in this paper the voltamperometric technique [1 - 4] is proposed because it is a non-invasive cost-saving method, easy to implement in an automatic test equipment. The ADCs are essential components in this measurement scheme; thus the problem of the metrological qualification of the data acquisition system is a fundamental issue for an accurate characterization of the investigated phenomenon. In this paper, we analyse the impact of the ADC static errors, especially integral non-linearity (INL) in the voltamperometric technique used to characterize hysteretic soft magnetic materials. Obtained results are discussed throughout the paper.

### II. Experimental setup

The voltamperometric method is a well-know technique used in the identification of symmetric hysteresis cycles. Its extension to asymmetric loops, proposed in [3], involves some difficulties, as for example the high pass filter behaviour of the transformer, the presence of artefacts that could lead to incorrect measurements, and so on. Anyway, a critical aspect of the suggested method is the very different signal dynamic during the measurement of both major and minor loops. As a consequence, different scales and resolutions would be required in the acquisition stage. In Fig. 1, we show the experimental setup used for the measurements. The source  $v_s$  is an arbitrary signal generator connected to the primary circuit via a power amplifier. The values of  $H$  and  $B$  can be derived via the well-known Ampère's and Faraday-Neumann's laws, through the measurement of the primary current  $i_1$  and the secondary voltage  $v_2$ .

In the scheme, ADC<sub>1</sub> measures the primary current  $i_1$ , thus  $H = N_1 i_1 / L$ , while ADC<sub>2</sub> measures the open circuit secondary voltage  $v_2$ , thus  $B$  via the relationship  $v_2 = N_2 S (dB/dt)$ . The terms  $N_1$  and  $N_2$  are the turn numbers of the primary and secondary coils,  $L$  is the mean path along which the magnetic field circulation is evaluated, and  $S$  is the core cross section.

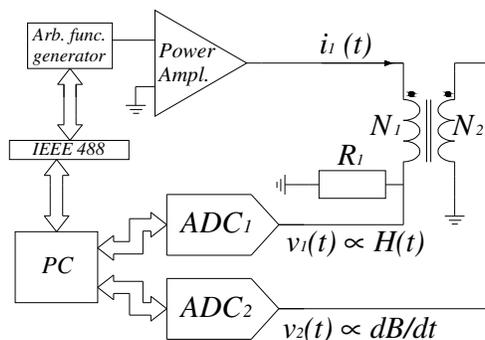


Figure 1. Experimental setup

### III. Results

By considering the real-world ADC, both the primary current and the secondary voltage measurements are affected by five different error components, produced by noise, gain, offset, nonlinearity and quantization [5]. In this first step the authors have observed the contribution of the nonlinearity error (INL) on the magnetic accommodation.

In Fig. 3, we report a typical behaviour of the primary current  $i_1$  and the secondary voltage  $v_2$  measured on a commercial soft ferrite core for exploring possible accommodation phenomena of cycling minor loops [4], [6].

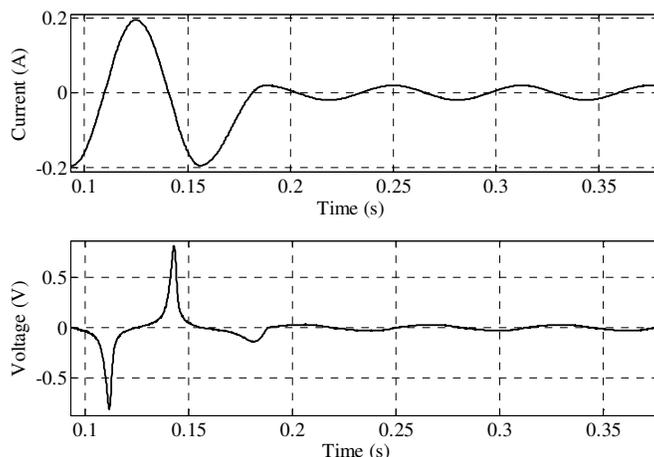


Figure 3. Upper plot: primary current  $i_1$  – Lower plot: secondary voltage  $v_2$ .

The flux density  $B$  vs. the magnetic field  $H$  relevant to Fig. 3 are shown in Fig. 4. In the enlarged right side plots the minor loops show a recognizable accommodation. Indeed, the magnetization of the extreme points exhibit a drift when the field is cycled between two fixed values.

In order to analyse the possible impact of INL on the reconstruction of the accommodation, a series of ad-hoc simulations was developed. The measured primary current was substituted by the driving input  $i_s$  of the arbitrary function generator, while the measured  $v_2$  was approximated by a fifth-order polynomial (branches of major loop and connecting section branch) followed by sinusoidal waveforms (minor cycles)  $v_s$ , as shown in Fig. 5. Simulated signals of Fig. 5 are defined so that the reconstructed major and minor loops do not present any accommodation. This is the starting condition for analysing the effect of the INL. Fig. 6 shows the  $B$ - $H$  path relevant to the simulated signals. It is apparent from the right side plots that minor cycles do not accommodate.

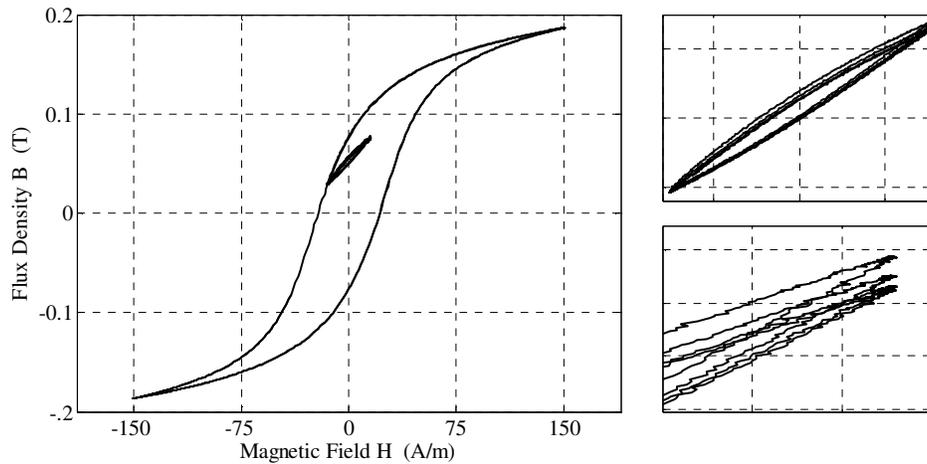


Figure 4. Left plot: major loop with minor asymmetric cycles – Right side plots: minor cycles and accommodation.

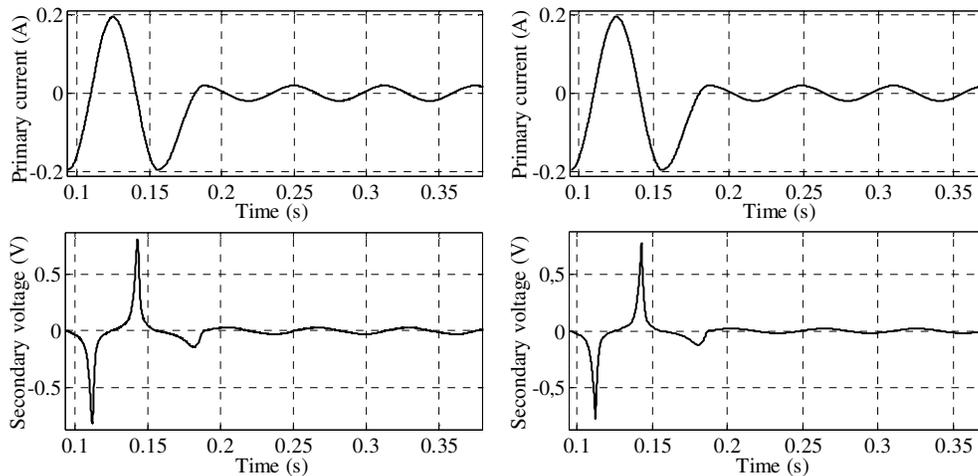


Figure 5. Upper left plot: measured primary current  $i_1$  – Upper right plot: simulated primary current  $i_1$   
 Bottom left plot: measured secondary voltage  $v_2$  – Bottom right plot: simulated secondary voltage  $v_2$ .

Fig. 7 shows three hypothesized INLs for a 12-bit ADC. In particular, the solid line describes an INL with a maximum absolute value of 0.23 LSB, while the dashed and the dotted lines represent two different INLs with a maximum absolute value of 0.64 LSB.

Figs. 8-10 report the reconstructed B-H cycles when the three INLs affect the simulated signals. In all the cases a drift of minor loops can be observed, with more separate cycles when a higher INL affects the data (Figs. 9-10). It must be noted that in all the cases the accommodation must be considered a purely apparent phenomenon generated by the INL, since the original "true" signals are exempt from the phenomenon.

These results already show how the investigated magnetic phenomenon can be seriously affected by the ADC INL, and how difficult can be a correct accommodation estimation if the INL is not known. In order to further analyse the impact of the INL on the accommodation phenomenon, the INL defined by the solid line in Fig. 7 has been applied to the original measured data, presenting actual accommodation.

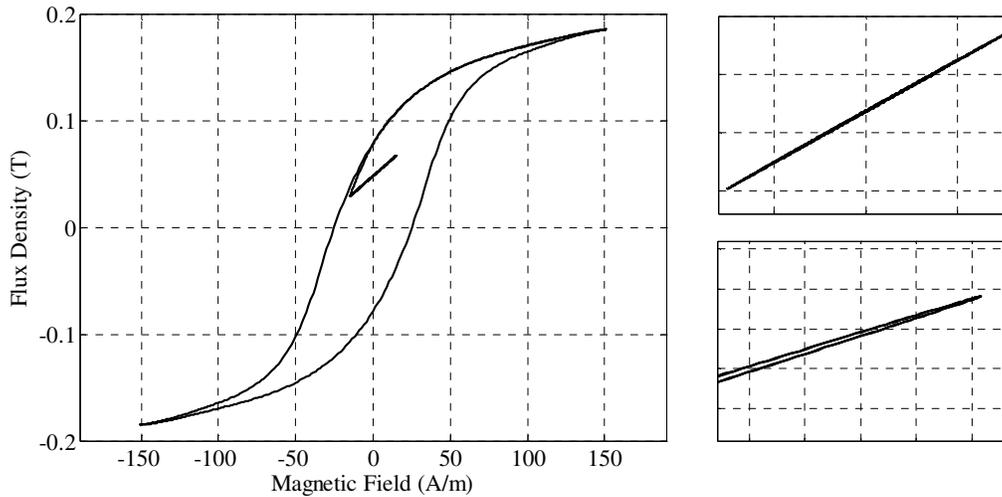


Figure 6. Major loop with minor asymmetric loops obtained by simulated signals  
 Enlarged boxes: not accommodating minor cycles.

It must be noticed that this means to sum a simulated arbitrary INL to a real INL already affecting the data. On the other hand, this does not prevent to observe possible effects of the INL on the accommodation phenomenon. The results of this simulation involving actual measurements and a simulated INL are shown in Fig. 11. The centre bottom subplot has been obtained without application of the simulated INL and serves as a "benchmark". The bottom left and bottom right subplots have been obtained by applying, respectively, the simulated (dashed line of Fig. 7) INL with its original sign (negative INL at the extreme codes) and with inverted sign (positive INL at the extreme codes). The simulated INL has opposite effects in the two cases, i.e. it leads to a reduction of the accommodation phenomenon in the first case, and to an increase of the phenomenon in the second case. The reason for the INL affecting the observed accommodation is not obvious at a first glance, but may be understood intuitively when the data processing after the data acquisition is considered. The accommodation is a natural phenomenon associated to a relaxation trend in the magnetization of the minor cycles, but the distortion introduced by the INL alters the average voltage  $v_2$  during the minor cycles, and therefore affects the magnetization drift. However, the analysis of the effect of the INL in testing hysteretic magnetic materials sheds some light on the accommodation phenomenon, and certainly deserves deeper study.

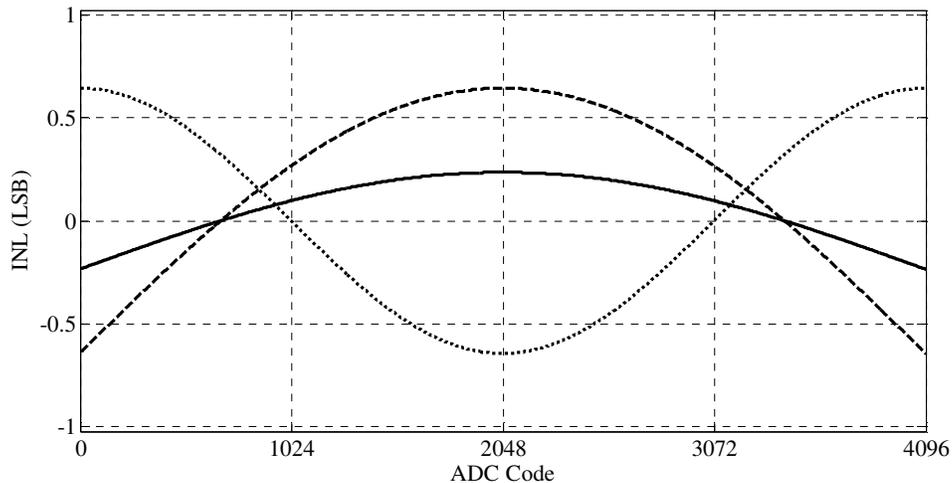


Figure 7. Simulated INL for a 12 bit ADC converter (solid line: results in Fig. 8 - dashed line: results in Fig. 9 - dotted line: results in Fig. 10).

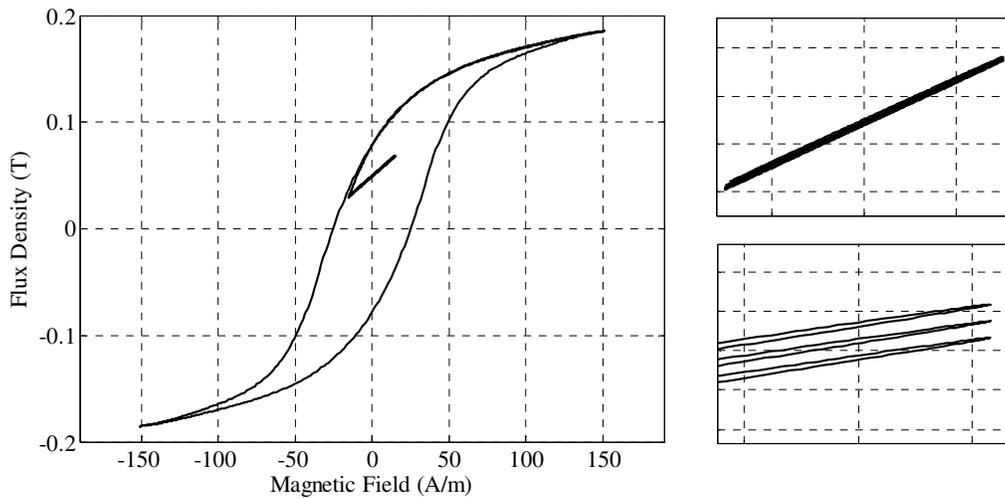


Figure 8. Impact of INL on accommodation measurement for a 12bit ADC converter ( $INL = +0,23$  LSB).

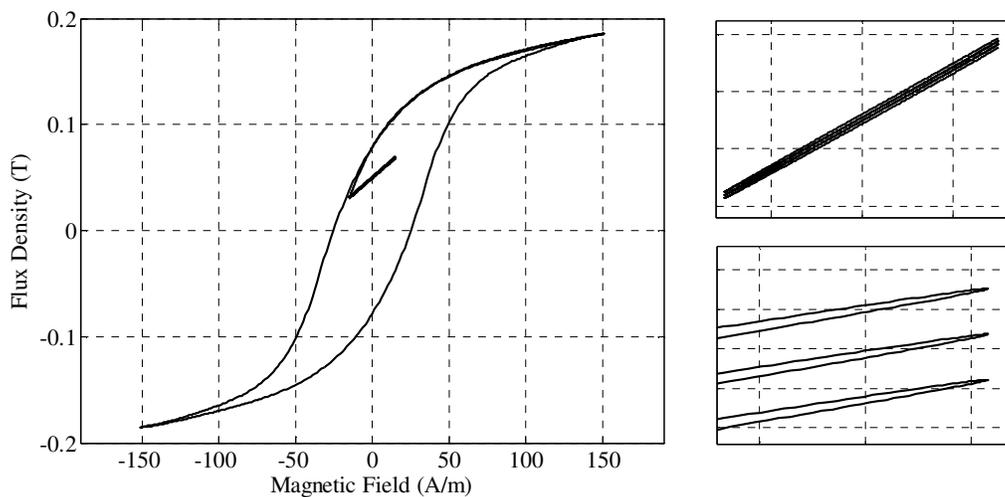


Figure 9. Impact of INL on accommodation measurement for a 12bit ADC converter ( $INL = +0,64$  LSB).

#### IV. Conclusions

In this paper a series of simulation were carried out, in which different INL errors were applied to both simulated and measured signals relevant to tests on a toroidal soft ferrite core. Results showed that the actual behaviour of the ADC can significantly affect the observed accommodation phenomenon in asymmetric minor loops. In particular, for a given maximum INL the shape plays an important role, leading to an apparent reduction or increase of the phenomenon. Future work includes a more in-depth analysis of the links among accommodation, acquisition errors, and data processing, and the possible development of ad-hoc compensation techniques.

#### References

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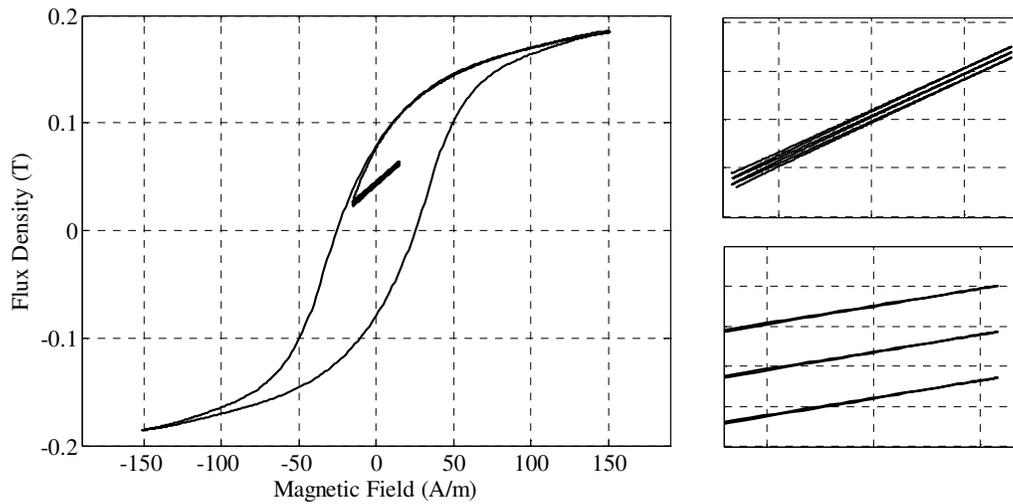


Figure 10. Impact of INL on accommodation measurement for a 12bit ADC converter ( $INL = +0,64$  LSB).

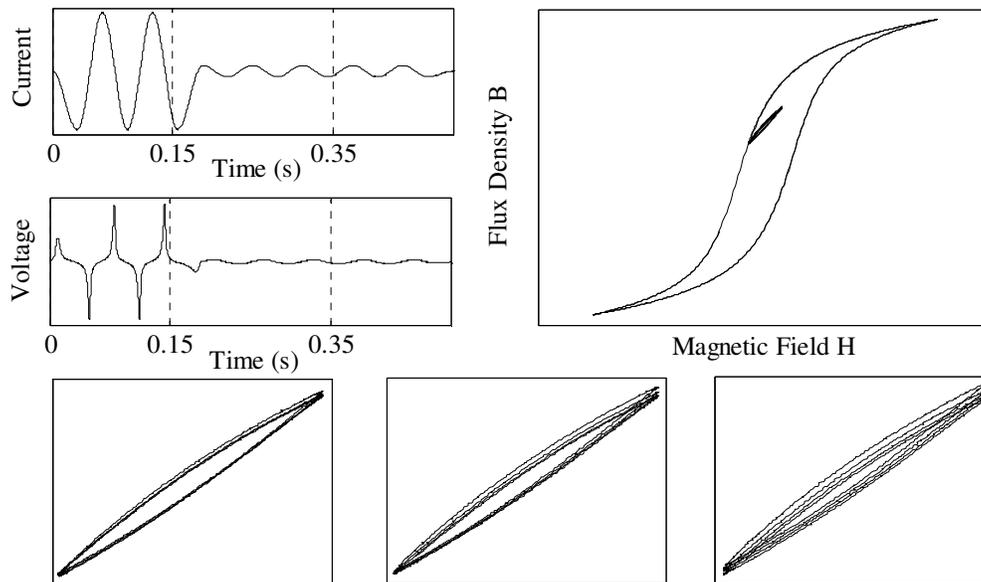


Figure 11. Upper left plot: primary current  $i_1$  – Center left plot: secondary voltage  $v_2$  – Upper right plot: major loop with minor asymmetric loops – Bottom plots: asymmetric minor cycles and accommodation (center plot: benchmark; left plot: INL negative values of extreme codes; right plot: INL positive values of extreme codes).

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