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TWO-CHANNEL ADC SYSTEM FOR HYSTERESISGRAPH

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Abstract: *System for measurement of dynamic hysteresis loops is based on a pair of measuring ADC boards. Influence of different phase shift in both channels causes false phase information in the digitised signals. The character of the phase shift was identified as transport delay and its frequency dependence was measured. Software correction was implemented and tested. Study of the effective number of bits of resolution is also presented.*

Keywords: Phase shift, phase corrections, ENOB.

1 INTRODUCTION

A system for measurement of dynamic hysteresis loops up to 100 kHz has been described in previous publications [1, 2, 3]. More detailed study of errors caused by phase shifts and non-linearity is presented in this paper. Short description of the system is provided here for the sake of clarity (see Figure 1):

A pair of plug-in measuring boards (14-bit / 100 kSa/s by JanasCard Prague, using MAX121 successive approx. ADC) is interconnected (Clock signal, Conversion start signal) so that the measured voltages in both channels are sampled synchronously. Moreover, external clock signal for both measuring boards is brought from internal clock circuit of plug-in arbitrary waveform generator DATEL PC-420. In this way, sampling of measured signals is synchronous with excitation signal from the generator and thus equivalent-time (stroboscopic) sampling allows extending the effective sampling rate up to 10 MSa/s for repetitive signals (100 samples per period at 100 kHz signal frequency). Since the synchronous sequential sampling implemented in the system is derived from the same clock signal as generated excitation wave, eventual clock frequency deviations doesn't affect accuracy of reconstructed waveform and thus related errors (thoroughly discussed in [4]) are avoided.

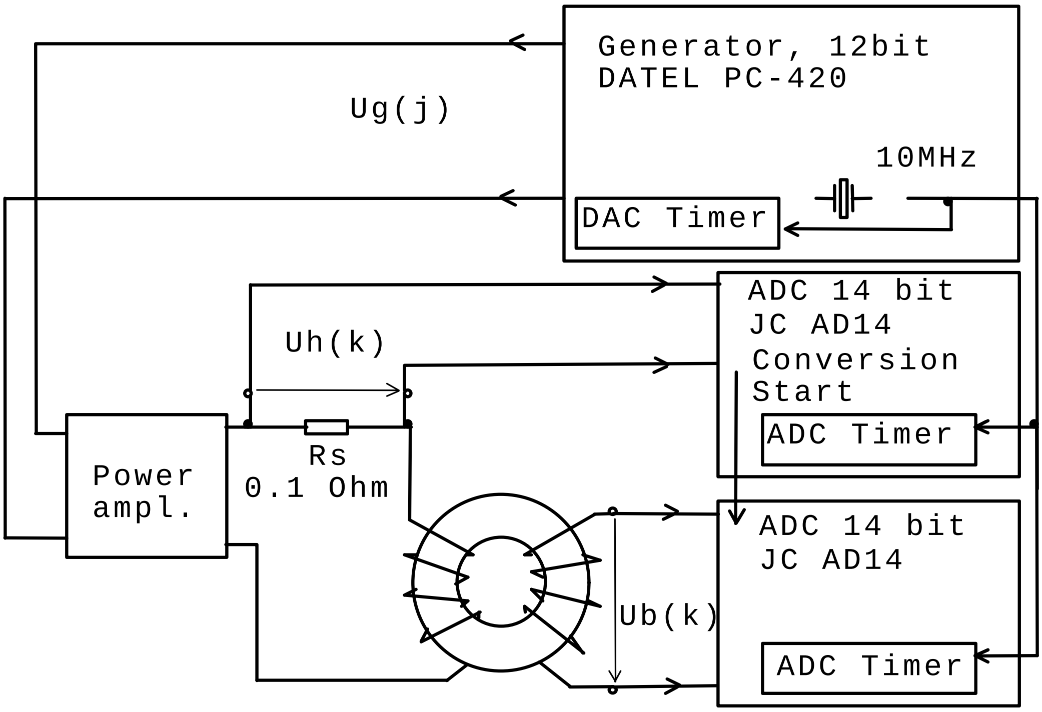

Figure 1. Digital hysteresisgraph layout. (Redrawn from [1].)

2 ERRORS INFLUENCING THE MEASUREMENT

Two main sources of inaccuracy were identified in the system. First of them is the phase shift between channels that has several sources. In this article we deal with different phase shift introduced by both measuring boards. It must be noted, however, that another (and more severe) source is the frequency dependence of Vishay VCS302 sensing resistor R_s 0.1 Ω (7 deg at 100 kHz).

The second source of inaccuracy is the limited number of effective bits of resolution of the measuring boards. Measurements with low-distortion sinewave generator showed that digitised signal spectra are distorted mainly by 3^{rd} harmonic component that is probably caused by A/D converter non-linearity. The number of effective bits of resolution (ENOB) was measured using a system developed at our department for evaluation of measuring boards.

2.1 Phase shifts

First important error introduced into the system is the phase shift between the channels. Experiments were conducted in order to determine the phase shift at various frequencies and to determine whether the frequency dependence is linear. The sinusoidal signal brought directly from the generator output was connected to both measuring boards and the two waveforms from individual channels were processed in order to determine their mutual phase shift. The tool used was Matlab by MathWorks, Inc. The best sinusoidal fit was performed on both waveforms using built-in FMINS function that uses multi-dimensional simplex search method. The penalty function defined for the search was sum of square differences between ideal sinewave (with variable parameters) and the current waveform to be fitted.

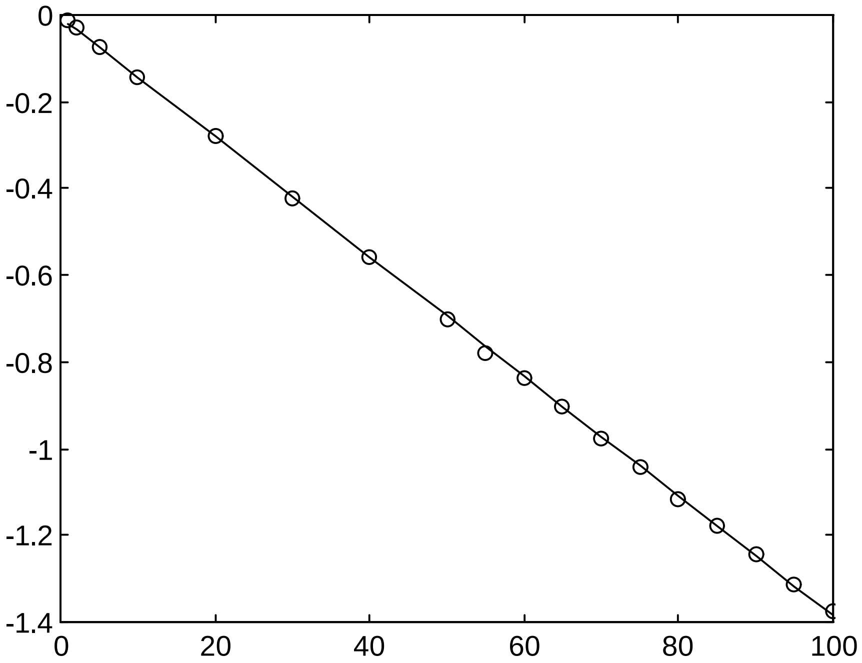

Figure 2. Phase shift between channels vs. frequency

Measured phase shift φ in frequency range f = 1 kHz up to 100 kHz is presented in Fig. 2. The graph suggests that the dependence is linear with good accuracy. Maximum linearity error is 1.035 % (relative to the max. phase shift –1.377 deg at 100 kHz). Linear regression (the full line in the graph) presents dependence (1):

$$j = -0.0051 - 0.0138 \cdot f \quad \text{[deg; kHz]} \tag{1}$$

As the residuals of linear fit appear strongly random (Fig. 3), conclusion can be made that the frequency dependence of the phase shift is well represented by linear approximation of the 1st order.

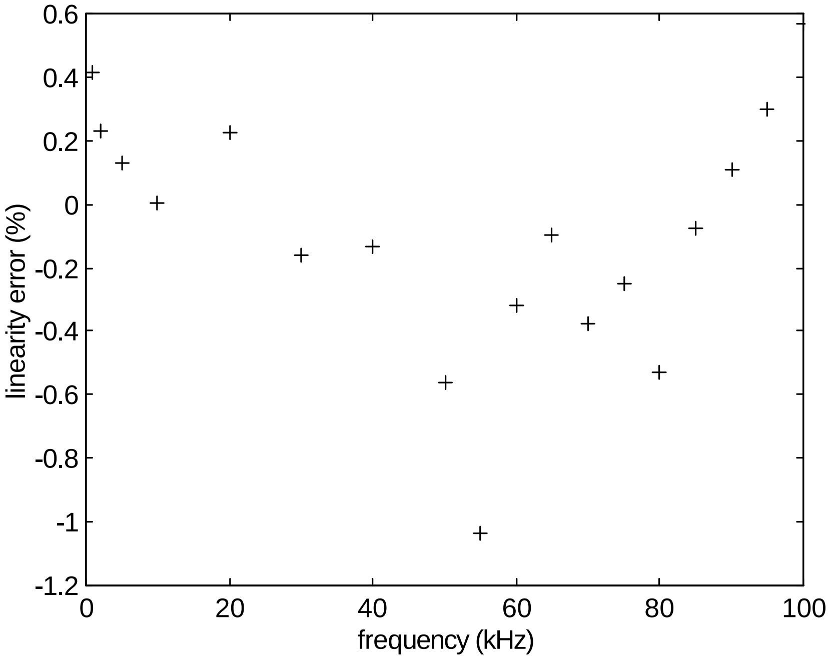

Figure 3. Linear regression linearity error (in % relative to maximum phase shift, i.e. -1.38 deg) shows no clear pattern.

In order to examine a differential phase jitter a batch of 100 measurements was performed. The result of measurement at frequency 100 kHz is presented in Fig. 4. The mean value of the phase error was -1.3576 deg, standard deviation was 0.0126 deg.

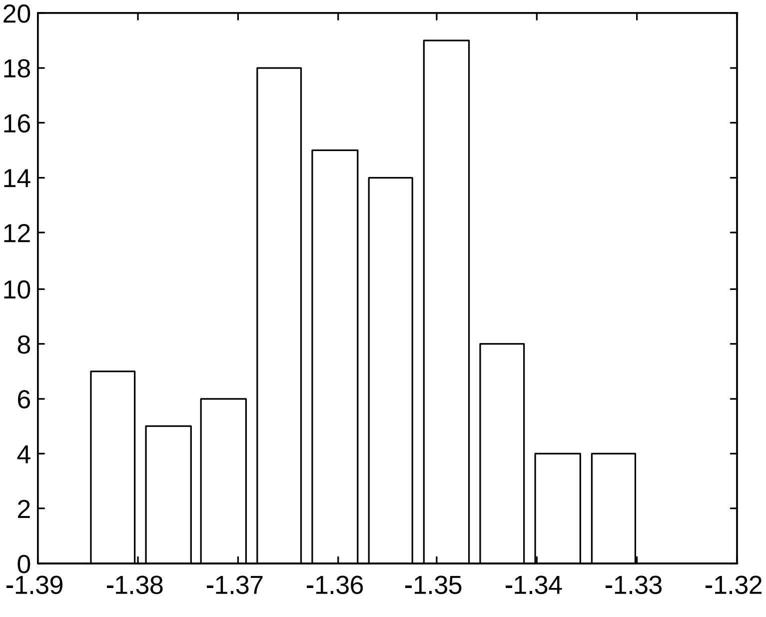

Figure 4. Histogram of measured phase shift between channels (100 measurements)

2.2 Phase shift correction

The linearity of the phase shift frequency dependence suggests that it can be attributed to transport delay and therefore easily corrected in software. In the opposite case, FFT decomposition of the signal, application of phase shift to individual spectral components and reconstruction of corrected signal would be necessary.

In our case, simple rearranging (shifting) of the recorded samples in time should compensate the erroneous phase shift. Because we have only 100 samples available at the signal frequency 100 kHz and one step between successive samples corresponds to 360 deg / 100 = 3.6 deg, this does not allow to rearrange samples with required accuracy. Therefore, interpolation is performed and the correct value of voltage in given time is calculated from the values of neighboring samples and the phase shift estimated for the given signal frequency. Experiments suggest that simple linear interpolation gives acceptable results, although higher-order interpolation would be more accurate.

2.3 Resolution of the A/D converters

As the non-linearity of ADCs causes distortion of digitised signal, the presence of higher harmonic components in spectrum was examined using pure sinewave generator. The effective number of bits of resolution and its dependence on signal frequency was also examined. Stanford Research Systems DS 360 ultra-low distortion generator (THD -100 dB up to 20 kHz, -85 dB up to 200 kHz) was used to evaluate the performance of the ADCs.

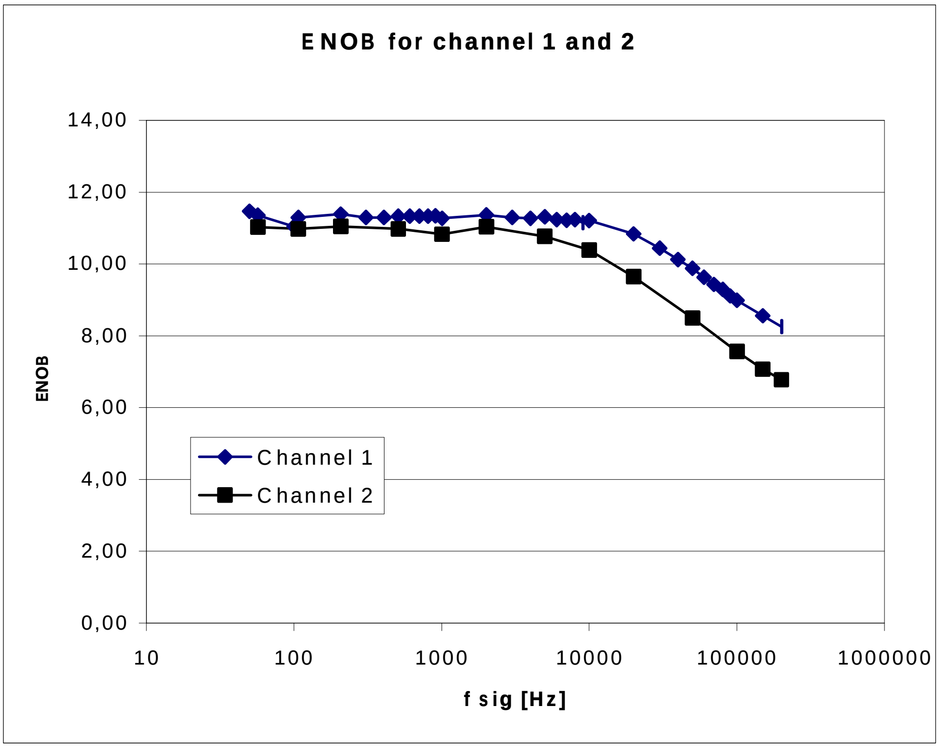

Figure 5. ENOB for both measuring boards (from [5])

While the nominal resolution of A/D converters used in measuring boards is 14 bit (MAX121), the effective resolution is significantly reduced by internal noise of the boards and the manufacturer specifies ENOB 12 bits. While measured DC resolution roughly corresponds to the specification, it decreases for frequencies above 10 kHz and for 100 kHz it is approximately 8 bits (master board), and 7 bits (slave board) respectively.

Figure 5 summarises results of measurements with our system for measuring boards evaluation [6]. (The method evaluates spectrum of digitised signal from high-purity sinewave source.)

Measurements with on-board programmable gain amplifier (PGA) set to 1x, 2x, 4x and 8x gains (always with input signal covering full-scale of the ADC) indicated no differences. Therefore we can conclude that the ENOB is influenced mainly by Analogue to Digital Converter (jitter, non-linearity) and not by the PGA.

Digitised waveforms from master measuring board (channel 1) were processed in Matlab (signal frequency 100 Hz and 100 kHz). As the measuring system always records exactly one (or an integer multiple of) period of signal, no windowing is applied to the waveform before FFT (coherent sampling [7]).

In the case of 100 kHz signal, equivalent-time (stroboscopic) sampling is used (real sampling rate is approximately 99 kSa/s). While 100 Hz signal has higher harmonic components -80 dB below the fundamental, 100 kHz signal has significantly worse parameters: the level of some higher harmonic components reaches -50 dB.

Spectra of digitised signals from measuring board are presented in Fig. 6-7.

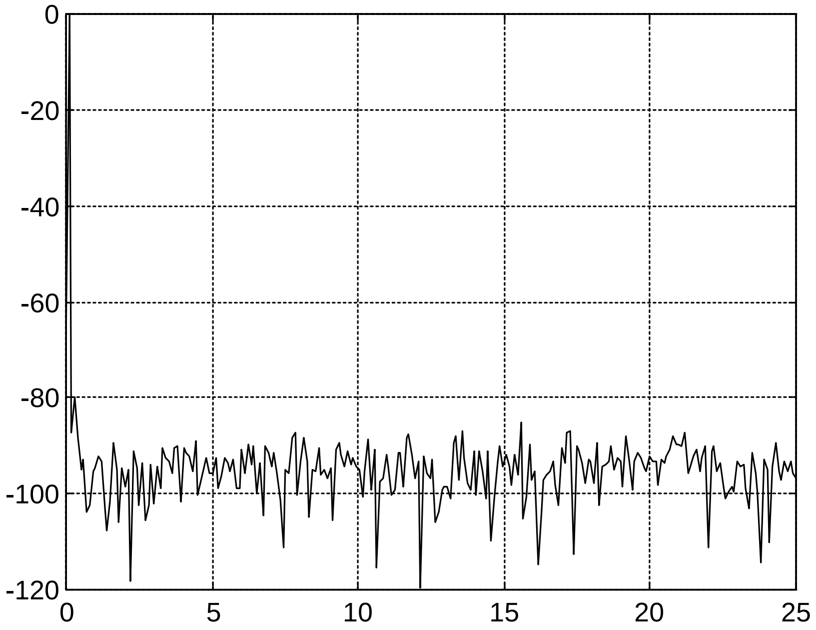

Figure 6. Spectrum of digitized signal (100 Hz), effective sampling rate is 50 kSa/s. (Master board.)

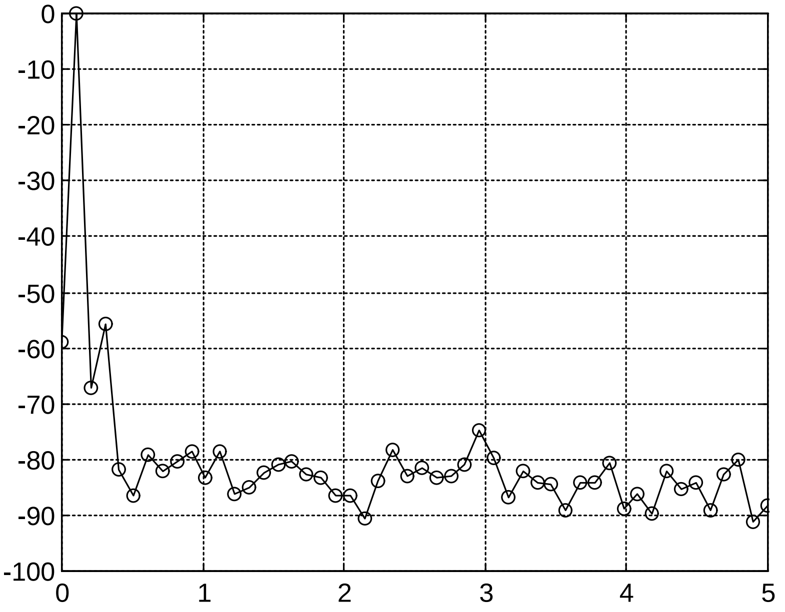

Figure 7. Spectrum of digitized signal (100 kHz), effective sampling rate 10 MHz, real sampling rate is 99 kSa/s. (Master board.)

3 CONCLUSION

Conducted experiments show that the measurement system has phase error with linear frequency dependence. Software correction of this dependence was implemented and tested.

Performance of the A/D Converters was examined in the working frequency range (100 kHz). The effective number of bits of resolution seems to be limited by ADC non-linearity.

Further research will concentrate on the analysis of the noise parameters.

REFERENCES

[1] A. Platil, P. Ripka, P. Kašpar, J. Roztoèil, Digital Hysteresisgraph Based on Plug-in Boards for PC (in Czech), *ASR 97 Seminary in Ostrava*. VSB Ostrava, The Czech Republic, 1997, pp. 40

[2] A. Platil, P. Ripka, J. Roztoèil, P. Kašpar, Dynamic Hysteresis Loops Measurement System, *NI Week 98,* National Instruments, Austin, TX, USA.

[3] A. Platil, J. Roztoèil, P. Kašpar, P. Ripka, AC Digital Hysteresisgraph*. Magnetic Measurements – Magnetické Merania 98*, Vrátna, Slovakia.

[4] P. Carbone, D. Petri, Accurate Equivalent-Time Sampling*. 4th Intl. Workshop on ADC Modelling and Testing*, 1999 Bordeaux, France. pp. 119-122.

[5] A. Platil, P. Ripka, J. Roztoèil, P. Kašpar, Factors limiting the accuracy of sampling hysteresisgraph, *Baltic Electronics Conference 2000*, submitted paper.

[6] V. Haasz, H. Schumny, Methods for Dynamic Quality Tests of AD-converters and Microcontrollers with Integrated AD-converters. *Symposium IMEKO TC-4*, Naples 1998, pp. 419-423.

[7] IEEE Std. 1241 Draft: Standard for Terminology and Test Methods for Analog-to-Digital Converters. February 1998.

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