

SOME ASPECT OF STANDARDISATION OF PERFORMANCE CHARACTERISTICS FOR MODULAR DATA ACQUISITION SYSTEMS

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Abstract - To estimate the measurement uncertainty using a modular DAQ system, factors influencing the quality of A/D modules have to be determined. While integral and differential non-linearity describes the static quality of an ADC, the effective number of bits or SINAD are typical integral parameters characterising the dynamic quality of an A/D module. The paper analyses how individual disturbing factors and imperfections of the A/D module influence the quality of digitalisation, and how they could be specified for a future standardisation. It is shown that (in the case of a time-variable input signal) the factors mentioned above induce disturbing undesirable components in the digital output and so they influence the value of SINAD of the investigated A/D module.

Keywords - DAQ system, A/D module, standardisation, quality.

1. INTRODUCTION

Measurements in industrial laboratories have to satisfy quality standards, based on calibration and definition of measurement uncertainty. However, it is not always possible to fulfil these quality requirements when the measuring instrument is realised using a „flexible“ approach based on PCs or other modular DAQ systems tailored for the application with A/D modules and with a specially developed software.

There are some risks if standardisation in this area will not be done :

- difficulties in the correct use of commercially available products,
- ambiguity in measurement results and in the definition of measurement uncertainty,
- calibration criteria related to separate applications without generally applicable rules.

In relation to the problems mentioned above, following sub-tasks were solved at CTU Prague:

- Methods for estimation of operational conditions in the system case and of disturbance immunity of A/D modules were designed and verified, and the actual results concerning PC plug-in boards were published in [3]. Extensions to notebooks and PC Cards were realised last year, published in a separate paper [4].

- Methods for measurement of the effective number of bits described in [1] and [2] were modified and implemented for testing of A/D modules ([5], [6]). A new view on other particular problems concerning standardisation will be mentioned in this paper.

2. SELECTED PARAMETERS DESCRIBING THE QUALITY OF A/D MODULES

Concerning future standardisation of modular DAQ systems, there are several parameters of A/D plug-in modules that could be appropriate for a description of their dynamic quality. Further analysis takes into account primarily A/D modules with successive approximation ADCs that are widespread in industrial applications. However, the basic conclusions are essentially valid also for A/D modules with other types of ADC, but some relations can be more complicated.

While static parameters concerning the errors of an A/D module can easily be described by *DNL* and *INL* (and naturally also with zero and gain errors), the effective number of bits (*ENOB*) or *SINAD* are typical integral parameters characterising the dynamic quality of them. However, they are influenced by several main factors (see fig. 1):

- static values of *DNL* and *INL*,
- A/D modules disturbance immunity,
- internal noise of A/D module and crosstalk between channels,
- settling time of a pre-amplifier,
- jitter of a S/H circuit that causes the frequency dependence of *ENOB* (or *SINAD*)
- frequency dependence of a pre-amplifier non-linearity.

While the first factor is well known, and the second one has been investigated in last years, the last four factors should more precisely be specified in order to estimate the actual *ENOB* (or *SINAD*) for an A/D channel of a modular DAQ system. If the parameters describing the factors mentioned above will be specified and mentioned in data sheets of A/D modules, the measurement uncertainty for an application can be estimated in most cases.

The expression „whole noise“ mentioned bellow will include all undesirable components (real noise, higher harmonic and spurious components etc.) of the digital output signal (both the „whole noise“, and its individual components will be expressed in LSB).

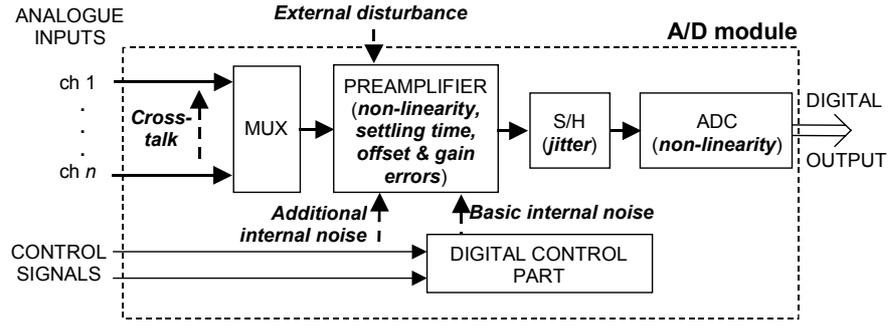


Fig. 1 - The parameters influencing the quality of A/D module

2.1. Essential parameters for digitising low frequency signal

In the case of low frequency input signals (frequency of an input signal is much lower than sampling frequency), the influence of the first four factors mentioned above is provable. Let us deal with an internal noise of an A/D channel at first. It influences the $ENOB$ (or $SINAD$) mainly for 16-bits modules and/or high gains used, and it proves significantly especially by low disturbance in a system case. This noise should be measured at nearly ideal EMC conditions. An external DC power supply with a negligible AC component should be used, and the tested A/D module should be placed in a shielding case (outside the PC case or notebook). An existing experience shows that there are three components of internal noise - the basic internal noise, the additional internal noise arising by applying auxiliary digital signals (e.g. external clock), and due to crosstalk between channels using multichannel measurement.

The basic level of the internal noise ($NOISE_{IN}$) can easily be determined from the output signal by the short-circuited input using a 50Ω resistor, and for no signals at the other analogue and digital inputs. It should be specified for all input ranges, because it is not generally proportional to the set gain. Their value radically limits the real resolution, and for the available effective number of bits it must be always valid

$$ENOB_{ID} < \frac{1}{6.02} 20 \log \frac{2^n / (2\sqrt{2})}{NOISE_{IN}} \quad (1)$$

for n -bits ADC and $NOISE_{IN}$ expressed in LSB.

However, the basic level of the internal noise can be measured also including the influence of a non-linearity of the tested A/D channel (both ADC and preamplifier) applying the FFT method and the low frequency testing signal. The RMS value of all higher harmonic components, spurious components and noise ($NOISE_{IN+NLAD}$) describes the influence of all parasitic components by the conditions mentioned above. (Using these methods, the components $NOISE_{IN}$ and $NOISE_{NLAD}$ can easily be separated, because the

RMS value of the higher harmonic components corresponds to $NOISE_{NLAD}$ and the spurious components and the noise corresponds to $NOISE_{IN}$.) It corresponds to the $SINAD$ definition by the near ideal EMC conditions mentioned before using no external digital signals and the one-channel input mode.

The noise that adds to the basic internal noise of an A/D module, if the external digital signal is applied ($NOISE_{EDS}$), can be determined from an output noise by connecting this external digital signal ($NOISE_{IN+EDS}$). Also in this case it can easily be executed for the short-circuited input using a 50Ω resistor according the formula

$$ENOB_{ID} < \frac{1}{6.02} 20 \log \frac{2^n / (2\sqrt{2})}{NOISE_{IN}} \quad (2)$$

It should be specified for all external digital signals i ($i = 1, 2, \dots$) applicable in A/D module (external clock, signals by using digital inputs or outputs, etc.) and for the frequency of this/these signal(s), for which is this noise maximal. Then

$$NOISE_{EDS,i} = \sqrt{\sum_i NOISE_{EDS,i}^2} \quad (3)$$

The last source of noise is the external disturbance (external form the A/D module point of view), which includes both an internal disturbance in the system case (according the previous experience only the disturbing magnetic field is significant [4], [7]) and an external disturbing field. This noise ($NOISE_{EMC}$) corresponds to the level of the disturbance in the area of A/D module and the disturbance immunity factor of it (see [3]). As far as the disturbance immunity factor of an A/D module for the basic input range $\pm 5 \text{ V}$ ($DIF_{\pm 5V}$) will be specified in a data sheet, the value of $NOISE_{EMC}$ can preliminary be estimated. The typical value of an internal disturbing field in the certain type of computer (see [3], [4]), and a presumptive external field can be applied (for n -bits ADC and $NOISE_{EMC}$ expressed in LSB) using the formula

$$NOISE_{EMC} = \sqrt{NOISE_{EMC,INT}^2 + NOISE_{EMC,EXT}^2} = \frac{2^n}{2\sqrt{2}} \frac{G}{DIF_{\pm 5V}} \sqrt{(f_D H_D)_{INT}^2 + (f_D H_D)_{EXT}^2} \quad (4)$$

where f_D is the frequency and H_D is the intensity of the disturbing magnetic field (both external and internal), and the set gain $G = 10/U_R$ for this purpose (U_R is the input range of a tested module e.g. for the declared input range ± 0.5 V is $U_R = 1$ V).

As far as the disturbance immunity factor is not specified and/or the value of $f_D H_D$ of the disturbing field is unknown, the value of $NOISE_{EMC}$ can be determined in the actual case using the similar way as for $NOISE_{EDS}$. The A/D module should be placed in the computer using the same configuration as by a practical application, and also the external disturbing field should have the same parameters. Then the value of $NOISE_{EMC}$ can be determined from the output noise ($NOISE_{IN+EMC}$) by the short-circuited input using a 50 Ω resistor according to the formula

$$NOISE_{EMC} = \sqrt{NOISE_{IN+EMC}^2 - NOISE_{IN}^2} \quad (5)$$

Using multichannel measurement, the additional noise can arise by a crosstalk (the definition see [1] chap. 3.1). The value of this noise ($NOISE_{CT}$) corresponds to the value of a disturbing signal, which is induced from all other channels (using full range signal) to the used channel. The value of the crosstalk should be specified in a data sheet (as far as it is published there). In this case (the value of the crosstalk CT in dB), the maximum value of $NOISE_{CT,j}$ (in LSB) in the channel j with set input range U_j and n -bit ADC can be determined using formula

$$NOISE_{CT,j} = \sqrt{\sum_{ch=1} NOISE_{CT(i)}^2} = \sqrt{\sum_{ch=1} \left(10^{\frac{CT}{20}} U_i \frac{2^n}{U_j} \right)^2} \quad (6)$$

where CT is the value of the crosstalk in dB,
 U_i is the set range of the other used channels $i \neq j$,
 ch is the number of the used channels.

If the crosstalk is not specified in a data sheet, the values of $NOISE_{CT}$ can be determined using similar way as in the case of the noise arising by connecting an external digital signal (see above).

In case of multichannel measurement, the error arising due to channel switching by maximum voltage differences between these channels should be also taken into account [9]. It is caused by the settling time of the used amplifier. This amplitude error of individual samples can approve oneself as

a further undesirable component in the digital output signal. However, to estimate the RMS value of this component ($NOISE_{ChSw}$) is very difficult, because it is strongly dependent on the relation between input waveforms connected to the neighbouring channels. Therefore it has to be estimated individually (if the relevant data are published by producer or were measured accordingly [9]).

The all undesirable components of the output signal (whole noise), which significantly influence the measurement uncertainty by applying an A/D module in virtual instruments, can be estimated for a low frequency input signal (the frequency of an input signal is much lower than the sampling frequency) using the formula

$$NOISE_{LF} = \sqrt{\sum NOISE_F^2} \quad (7)$$

where $NOISE_F$ are the undesirable components of output digital signal ($NOISE_{IN+NLAD}$, $NOISE_{EDS}$, $NOISE_{CT}$, $NOISE_{ChSw}$, and $NOISE_{EMC}$ - see above) corresponding to the individual factors that are necessarily taken into account in the actual case.

Then the actual value of $SINAD$ of an A/D channel in a modular DAQ system can be estimated using the formula:

$$SINAD_{LF} \leq 20 \log \frac{2^n / (2\sqrt{2})}{NOISE_{LF}} \quad (\text{dB}) \quad (8)$$

for a n -bits ADC and $NOISE_{LF}$ expressed in LSB.

2.2. Further essential parameters for digitising of signals with higher frequency

There are additional factors influencing measurement uncertainty in the case of an input signal, the frequency of which is not much lower than the sampling frequency. The first of them is of course the analogue bandwidth of an A/D channel. The others are jitter of S/H circuit and the frequency dependence of non-linearity of a pre-amplifier. They cause a decrease of the $ENOB$ (or $SINAD$) with the frequency increasing.

The analogue bandwidth of an A/D channel is defined by a decrease of gain by 3 dB. The A/D bandwidth of an A/D channel ($f_{A/D,max}$) can be defined by decreasing $SINAD$ of 3 dB caused due to increasing the frequency of input signal - see [8]. (The $SINAD$ decreasing of 3 dB corresponds to a decreasing the effective number of bits $\Delta n_{eff,f} \cong 0.5$).

If the parameters mentioned above and the EMC conditions will be known, the actual value of the all undesirable components of an A/D channel output (whole noise) do not exceed the value

$$NOISE \leq \sqrt{NOISE_{LF}^2 + 0.5^2} \quad (9)$$

and $SINAD$ in the same case

$$SINAD \leq 20 \log \frac{2^n / (2\sqrt{2})}{NOISE} = SINAD_{LF} - 3 \quad (\text{dB}) \quad (10)$$

for n -bits ADC and $NOISE$ expressed in LSB ($NOISE_{LF}$ - see (7)).

Using the input signal with a frequency above $f_{A/D, \max}$, the frequency dependence of $NOISE_{IN+NLAD}$ should be specified to be possible to estimate the measurement uncertainty in this wider frequency range. Concerning an analogue bandwidth of an amplifier, it has to be also taken into consideration.

3. CONCLUSION

The parameters mentioned above present the minimum of data, which should be specified for A/D modules used in virtual instruments to allow a rough estimation of their measurement uncertainty at least in simple cases. The transformation of the majority of A/D module imperfections (instead of gain and offset errors) to undesirable components of the digital output signal (real noise, higher harmonic and spurious components etc.) makes it possible to estimate the „whole noise“ particular for an individual application. It can be applied in the number of simple cases as a „type A“ uncertainty by a whole measurement uncertainty estimation.

For example, for a virtual instrument designed for a one channel measurement of the RMS value (in generally, of any integral parameter), the measurement uncertainty can easily be estimated for low frequency signals based on knowledge of INL , $NOISE_{IN}$, (or $NOISE_{IN+NLAD}$), $NOISE_{EMC}$, and gain and offset errors (as far as the DSP error needs not be taken into account). In the case of more channel measurement (or power measurement) also the crosstalk and the error arising due to channel switching by maximum voltage differences between used channels should be taken into account. If some digital input of an A/D module is used (e.g. the clock input for synchronisation), the undesirable component $NOISE_{EDS}$ should be taken into account.

In the case of more complex virtual instruments (e.g. spectrum analyser), the $SINAD$ defined according (8) or (10) can be used for a rough estimation of the resolution. The inclusion of particular undesirable components is dependent on the actual realisation of a virtual instrument. A correct uncertainty estimation demands a more complex model of errors both of the A/D module and the virtual instrument (including software part).

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