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G.G. BORTNYK, M.V. VASYLKIVSKIY, M.L. MINOV
Vinnitsa National Technical University, Ukraine

FAST-ACTING ANALOG-TO-DIGITAL CONVERTER WITH WIDE DYNAMIC RANGE

Abstract – The method of fast-acting analog-digital transformation of signals is in-process offered with improving dynamic parameters, in which unlike existing the second digital processing of results of transformation of separate integral microcircuits of analog-to-digital converter is used, that results in expansion of dynamic range.
Key words: analog-to-digital converter, dynamic range, effective number of bits.

Г.Г. БОРТНИК, М.В. ВАСИЛЬКІВСЬКИЙ, М.Л. МІНОВ
Вінницький національний технічний університет, Україна

ШВИДКОДІЙНИЙ АНАЛОГО-ЦИФРОВИЙ ПЕРЕТВОРЮВАЧ З ШИРОКИМ ДИНАМІЧНИМ ДІАПАЗОНОМ

У роботі запропоновано метод швидкодійного аналого-цифрового перетворення сигналів з покращеними динамічними параметрами, у якому на відміну від існуючих використовується вторинне цифрове оброблення результатів перетворення окремих інтегральних мікросхем (ІМС) аналого-цифрових перетворювачів (АЦП), що призводить до розширення динамічного діапазону.

Метод побудови швидкодійних АЦП відрізняється від існуючих тим, що покращення динамічного діапазону здійснюється не просто шляхом послідовного структурного нарощення малорозрядних АЦП, а за рахунок вторинного цифрового оброблення результатів перетворення окремих ІМС АЦП.

Згідно запропонованого методу розроблено структурну схему швидкодійного АЦП та здійснено аналіз динамічного діапазону для даного перетворювача. Результати аналізу підтвердили покращення динамічних параметрів АЦП, а саме динамічний діапазон розширився порівняно з класичною структурою на 7÷14 дБ залежно від кількості ВІС АЦП, класу оброблюваних сигналів та співвідношення між власними шумами перетворювача та шумами квантування. Окрім того, виявилось, що даний метод побудови є нечутливим до неідентичності зразків ІМС АЦП за параметрами апертурної невизначеності. Встановлено, що при розходженнях у коефіцієнтах апертурного дрижання на рівні 10÷50% динамічний діапазон змінюється незначно у межах 0,4÷1,2 дБ.
Ключові слова: аналого-цифровий перетворювач, динамічний діапазон, ефективне число розрядів.

Entry

Improvement of quality descriptions of measuring facilities, that function on the base of methodology of digital signal processing depends on dynamic properties of analog-to-digital converter (ADC), that are basis of highway of analog-digital transformation of signals of the informatively-measuring systems (IMS). Most difficult is creation of ADC with the improved dynamic parameters that directly influence on efficiency of functioning of IMS in the wide stripe of frequencies.

Certain results are got in works [1,2], what are sent to development of fast-acting ADC with a wide dynamic range as integral microcircuits. The analysis of indexes of modern standards of ADC showed that a cost of 12-bit ADC of high fast-acting is in 10÷20 times exceeds the cost of 10-bit ADC of analogical fast-acting ADC [3]. It is explained by sharp complication of circuit technology and technology of making of analog knots of 12-bit ADC. Therefore an actual task is creation of wide-range ADC on the base of integral microcircuits (IMC) of fast-acting transformers.

The aim of work is expansion of dynamic range of fast-acting ADC due to secondary digital processing of results of transformation of separate integral microcircuits of transformers. For the achievement of the set aim it is necessary to untie such tasks:

- to define the dynamic range of fast-acting ADC;
- to work out the method of expansion of dynamic range of fast-acting ADC;
- to analyse the dynamic range of worked out ADC.

Estimation of dynamic range of fast-acting ADC

One of basic dynamic parameters of ADC there is a dynamic range. By a basic factor that influences there is power of noises of quantum on a dynamic range. As known [1], for an even scale power of noises of quantum equals $P_q = \frac{q^2}{12}$. From the brought expression over evidently, that power of noises of quantum does not depend on the level of entrance signal, but determined only by the step of quantum. If an entrance twoarctic signal has amplitude U_m, then the number of necessary levels of quantum of ADC equals $N = \frac{2U_m}{q}$.

By the parameter of signal that shows in how many times his amplitude exceeds a root-mean-square U_{rms}, there is a factor of spades $k_{pf} = \frac{U_m}{U_{rms}}$. Other record of expression looks like for noise of quantum:

$$P_q = \frac{1}{3} \cdot \frac{k_{pf}^2 \cdot U_{rms}^2}{N^2}. \quad (1)$$

From here the dynamic range conditioned by a quantum equals :

$$\frac{P_{in}}{P_q} = \frac{3N^2}{k_{pf}^2} \cdot \frac{U_{in}^2}{U_{rms}^2}. \quad (2)$$

More comfortable to estimate a dynamic range in decibels:

$$D = 10\lg\left(\frac{P_{in}}{P_q}\right) = 20\lg\left(\frac{N}{k_{pf}}\right) + 10\lg 3 + 20\lg\left(\frac{U_{in}}{U_{rms}}\right). \quad (3)$$

At analog-digital transformation of signal from one source $U_{in} = U_{rms}$ and in such case will get:

$$D = 20\lg\left(\frac{N}{k_{pf}}\right) + 10\lg 3. \quad (4)$$

For n-bit of ADC will get $N = 2^n$. Putting this value in (4), find analytical expression for an evaluation D, conditioned a quantum:

$$D = 6{,}02n - 20\lg k_{pf} + 4{,}8, \text{[dB]}. \quad (5)$$

Thus, a dynamic range depends not only on the number of bits of ADC but also from description of the converted signal. This expression takes into account only noises of quantum of ideal ADC and ignores existence of surplus noises and harmonic distortions due to non-linearity of description of transformation of ADC.

Method of improvement of dynamic range of ADC

For the decline of level of lateral accordions it is possible to give on the entrance of ADC except an entrance signal yet and additional noise. Amplitude of additional noise constituent must not exceed the step of quantum of ADC q. If for this case to execute deduction from the spectral constituent of sinewave signal of noise frequency constituent, then it is possible to get the value of loss of bit of ADC:

$$n_{BL} = \log_2 \frac{P_q + P_d}{P_q}, \quad (6)$$

where P_d – is power of the artificially brought in low-level noise.

Analysing this expression, it is possible to assert that such method of improvement of dynamic parameters of ADC is effective only for a case, when $P_q >> P_d$, id est for littlebit transformers. An offer method of construction of such ADC is based on such positions. An entrance signal and ideally quantized noise of ADC are sizes correlated and can be summarized coherently. Own noises of ADC – uncorrelated and summarized as a mean quadratic value.

For simplification of analysis it is needed to take advantage of another dynamic parameter of ADC, that characterizes his bit in the dynamic mode, is an effective number of digits [4]:

$$n_{ef} = n_{sc} - \log_2 \frac{P_q + P_c}{P_q}, \quad (7)$$

where n_{sc} – is a bit of one ADC in the static mode; P_c – is power of own noises of ADC.

Using previous statements about cooperation of own noises of transformer, noises of quantum and entrance signal, it is possible to create ADC, the row of base of the same type transformers initial signals of that is summarized enters in the complement of that. The effective bit of ADC, built on such principle, equals

$$n_{ef} = n_{sc} - \log_2 \frac{L \cdot P_q + \sqrt{L} \cdot P_c}{L \cdot P_q} = n_{sc} - \log_2\left(1 + \frac{P_c}{\sqrt{L} \cdot P_q}\right), \quad (8)$$

where L – is a number of base standards of ADC.

From it is here possible to find a dynamic range synthesized by such method of ADC:

$$D_L = 6{,}02n + 4{,}8 - 6{,}02\log_2\left[1 + \frac{P_c}{\sqrt{L} \cdot P_q}\right] - 20\lg k_{pf}. \quad (9)$$

On the base of the got expression it is possible to build dependences of dynamic range of ADC on the number L of base IMC transformers for different correlations P_c / P_q. On fig. 1 such graphic arts over are brought for a case, when a sinewave signal comes on the entrance of ADC. As known, factor of spades of sinewave signal $k_{pf} = \sqrt{2}$.

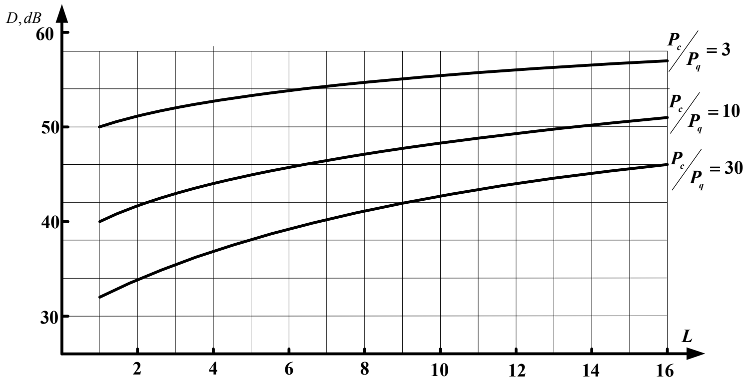

Fig. 1. Dependence of dynamic range on a number IMC of ADC for a sinewave entrance signal

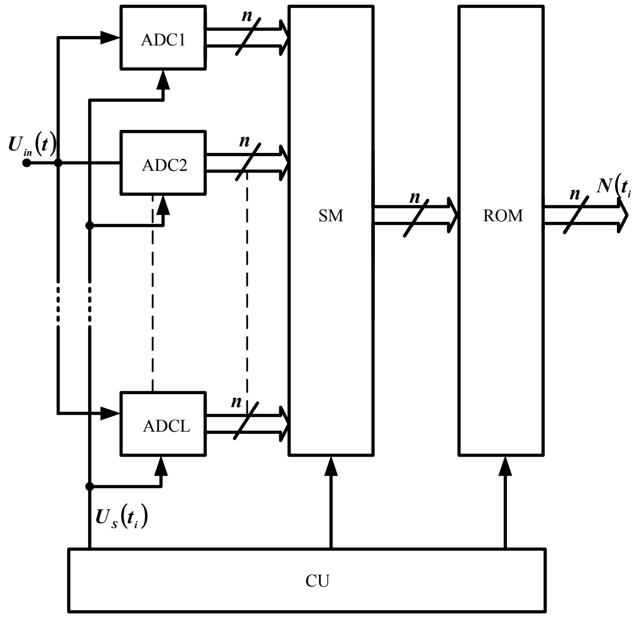

Fig. 2. Structure of fast-acting ADC is with a wide dynamic range

From fig. 1 evidently, that by an increase IMC of ADC a dynamic range gets better for a case, when $P_c/P_q = 3$ this parameter grows from 50 dB for single ADC of to 57 dB for 16 IMC of ADC. And for a case, when own noises of ADC exceed noises of quantum in 30 times, id est $P_c/P_q = 30$, there is the yet best dynamics of increase of dynamic range, namely: from 32 dB to 46,3 dB.

Structure of fast-acting ADC, the built on the base of an offer method is brought around to fig. 2. Output n-bit tire IMC it is connected ADC to the input busses of summator (SM). An exit SM is connected with the address bus of ROM that performs the duty of setting of norms of value of output code of ADC $N(t_i)$.

Number of address entrances ROM equals $m = n +]\log_2 L[$. CU is intended for synchronization of functioning of all constituents of ADC.

Analysis of dynamic range of worked out ADC

Will execute research of influence of aperture errors separate IMC of ADC on the dynamic range of transducing synthesized in obedience to an offer method. If to consider that for n-bit of ADC an aperture error must not exceed the step of quantum, then between frequency of discretisation f_S, correlation takes place aperture time τ_a and relative aperture error:

$$\frac{1}{2^n} = 4\pi \cdot f_S \cdot \tau_a . \tag{10}$$

Then aperture instability of separate IMC of ADC, on that it is built fast-acting ADC, it is possible to take into account, using such expression:

$$L_{k\tau} = L \cdot \left[1 - \frac{4\pi \cdot \Delta\tau_{am}}{T_S}\right], \tag{11}$$

where $\Delta\tau_{am}$ – is a maximal value of the aperture trembling of ADC.

With taking (11) into account, expression for the evaluation of effective bit of fast-acting ADC, that it is built on IMC of ADC with the unidentical values of aperture time, will purchase such kind:

$$n_{ef_{L\tau}} = n_{sc} - \log_2\left[1 + \frac{P_c}{\sqrt{L_\tau} \cdot P_q}\right]. \tag{12}$$

From here the dynamic range of fast-acting ADC equals:

$$D_{L\tau} = 6{,}02n + 4{,}8 - 6{,}02\log_2\left(1 + \frac{P_c}{\sqrt{L_\tau} \cdot P_q}\right) - 20\lg k_{pf} . \tag{13}$$

Will analyse, as a dynamic range of fast-acting ADC depends on the number of unidentical IMC of ADC for the different values of aperture instability (fig. 3).

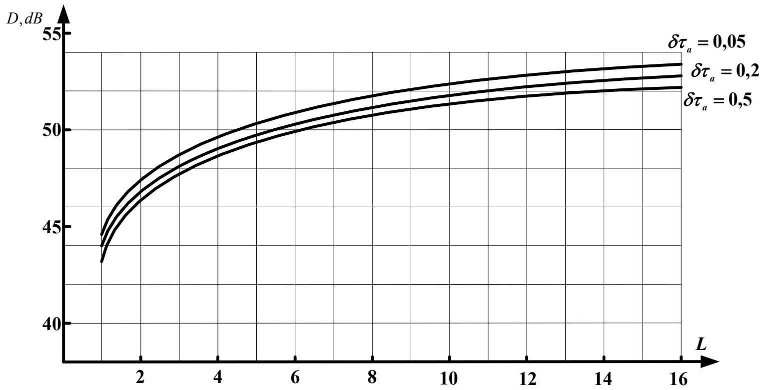

Fig. 3. Dependence of dynamic range of fast-acting ADC on the number of unidentical IMC of ADC

Analysing the above-mentioned graphic arts, it is possible to assert that unidentity of aperture time of separate IMC of ADC insignificantly influence on the dynamic range of fast-acting ADC. Even for a case when divergences of aperture delays arrive at a 50 % difference in the change of dynamic range does not exceed 1,2 dB. This method of improvement of dynamic parameters of ADC is not sensitive to instability of aperture errors of separate IMC of converters.

Conclusions

It offers to create the effective structures of fast-acting ADC with the use of procedures of summarization and further being of middle results of transformation on a base IMC of ADC.

The results of analysis of worked out ADC showed that a dynamic range had broadened comparatively with a classic structure on 7÷14 dB depending on an amount IMC of ADC and betweenness by own noises of transformer and noises of quantum. This method of construction is insensitive to the unidentity of standards IMC of ADC on the parameters of aperture noise. It is set that at divergences in the coefficients of the aperture trembling at the level of 10÷50% a dynamic range changes insignificantly within the limits of 0,4÷1,2 dB.

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