СЕКЦІЯ 4.
Методи та засоби перетворення форми інформації

Method of determining the unused combinations in the ADC of successive approximation with weight redundancy

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Метод визначення невикористаних комбінацій в АЦП послідовного наближення з ваговою надлишковістю

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***Abstract* — The analysis of transfer curve successive approximation ADC with weight redundancy is done. The method and algorithm of determining the unused combinations in the transfer curve of the successive approximation ADC with weight redundancy is present.**

***Анотація* — Проведено аналіз характеристики перетворення АЦП послідовного наближення з ваговою надлишковістю. Запропоновано метод та алгоритм визначення невикористаних комбінацій в характеристиці перетворення АЦП з ваговою надлишковістю.**

Keywords— Analog-to-digital conversation, weight redundancy, successive approximation ADC, transfer curve, unused combinations.

Ключові слова —Аналого-цифрове перетворення, вагова надлишковість, характеристика перетворення, невикористані комбінації.

I. INTRODUCTION

Successive approximation ADC are the most popular units of modern electronic circuits due to structure simplicity, high resolution (at the level of 16-18 bit), limited power consumption and relatively small conversion time (few microseconds). But at the result of environmental impact, first of all temperature changes, modification of some electrical parameters during time exploitation ADC linearity worsens and must be corrected[1]. There are many correction methods of ADC linearity error; the most popular ones use the self-calibration algorithms[2]. However, the choice of the optimal moment of time for calibration is the problem. Very frequent calibration reduces the time of the main operation, because during this period ADC cannot to perform conversion of input signal. On the other hand, long intervals between calibration cycles can lead to incorrect results of conversion. Using of information redundancy in successive approximation ADC gives the opportunity of automatically definition the needed moment of calibration time.

II. Analysis of Transfer Curve Successive Approximation ADC with Weight Redundancy

The main static characteristic of the ADC is the transfer curve (TC) - the relationship between the value of the analog signal at the input and the set of possible values of the output code. For ideal binary ADC (α=2) TC will be the ladder, where all steps are the same (Fig. 1). That gives unambiguous correspondence between input signal, as a rule voltage, and output code. On the other hand, for ADC with weight redundancy, for example α=1.6, TC will be another. The main difference – for some input signals will be more than one output codes. These parts of TC will be call the zones of ambiguous presentations.

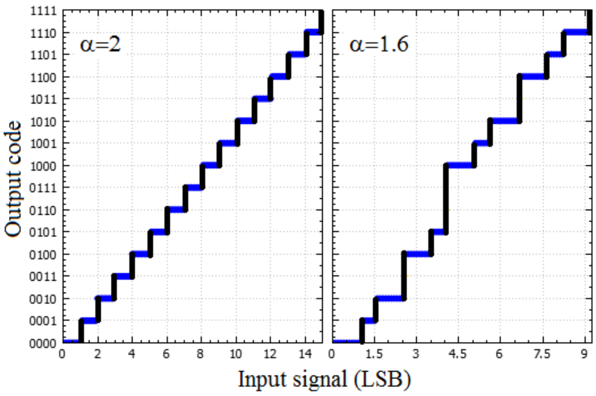

Fig.1 – The transfer curve for binary and redundant four-bit ADC

As a result, the output binary code of redundant ADC will have not all possible combinations. For example, TC for α=1.6 does not have combinations 0011, 0110, 0111 and 1011. These combinations will be call unused combinations (UC). The quantity and location of UC determines the base of counting system, resolution ADC and bit errors.

Location of any combination on TC is defined by equation:

$$A(K^s) = \sum_{i=0}^{n-1} a_i \cdot Q_i ,$$

where K – code combination, s – the number of code combination (decimal notation of binary combination). $Q_i = \alpha^i (1+\delta_i)$ – bit value with number i, where δ_i – correspondent bit deviation. $a_i \in \{0,1\}$ - bit values of K.

Because the base of counting system and resolution ADC are constant, transition from unused combination to used and vice versa is forced only by δ_i change.

In [3] was shown, that unused combinations form the groups with one and more successive codes. For example, on CP that shown on Fig.1 there are three zones of unused combinations. Central zone, it called (n-1)-level zone [3], has two successive combinations 0110 and 0111. Every from two zones (n-2)-level have one combination: 0011 and 1011.

III. Determining the Quantity of Unused Combinations Zones

The transfer curve for redundant six-bit ADC shown on fig.2. In order to analyze the process of transition combinations from unused to used and vice versa it is important to have an analytic method of finding unused combinations. It is known that, unused combinations form groups [4]. First of all it is necessary to find all zones unused combinations. In order to exist zone (n-k)-level must be true next inequation:

$$Q_{n-k} \leq \sum_{i=0}^{n-k-1} Q_i . \quad (2)$$

$$\alpha + \beta = \chi. \quad (1)$$

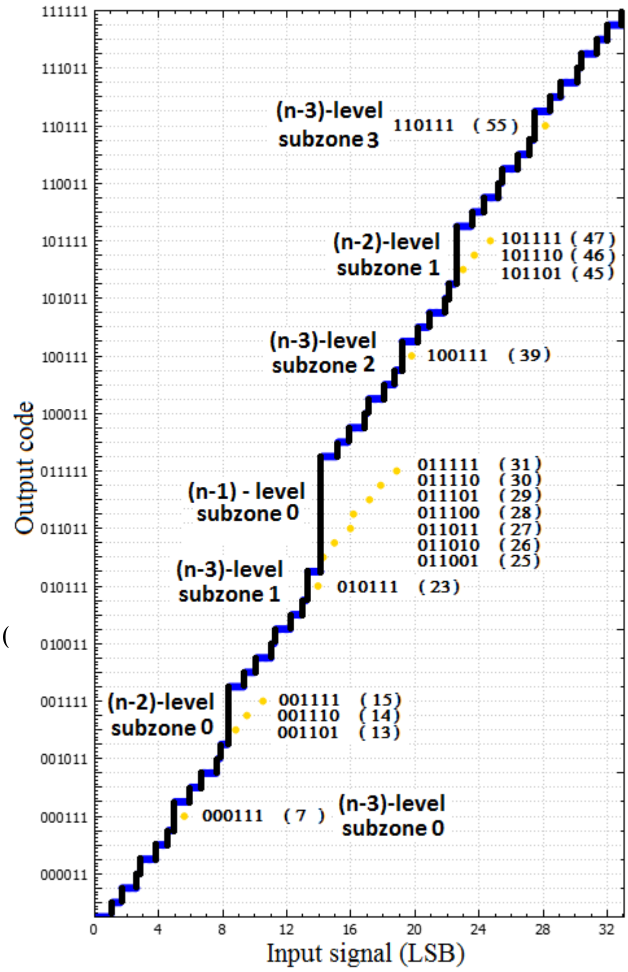

Fig.2 – The transfer curve for redundant six-bit ADC

Because the smallest level zone has only one unused combination and other zones have more than one ones, it is reasonably to find only the smallest level zone. For example, we have 10-bit ideal (without bit errors) redundant ADC with α=1.7, then inequation (2) will be true beginning from (n-k)=3. In fact, the number of the smallest level zone of ideal redundant ADC is defined only base of counting system. The relationship between the number of the smallest level zone and base of counting system shown in the table 1.

Table 1

The base of counting system	1,618	1,84	1,93	1,96
The smallest level zone number	2	3	4	5

The quantity of unused combinations zones depends on the number of level *i* and may be calculated by equation:

$$q_i = 2^{(n-1)-i}. \quad (3)$$

Any zone unused combinations, exclude (n-1) level zone, has some subzones. For example, the (n-2) level zone on the fig.1 has two subzones, first one contains combination 0011, and another contains 1011. The difference between combinations in first most significant bit (MSB). This bit identifies the subzone number: 0 – for 0011 and 1 – for 1011. Similarly, for six-bit redundant ADC on fig.2 there are three groups of unused combinations: (n-1), (n-2) and (n-3) level. (n-2)-level zone has two subzones; every of each has three unused combinations. (n-3)-level zone has fore subzones; every of each has one unused combination.

IV. Determining the unused combinations

The list of unused combinations of output code is the main information, which may be used for information about ADC bit deviations. It may be received by the observation of output codes after saw-like input voltage conversion. However, this method requires the additional generator of saw-like input voltage and additional time cycle for this operation. Other way is calculation of the unused combination positions. The calculation bases on the condition of appearing unused combination. Every (n-k)-level zone of unused combinations has border combination, which contains “1” in all smallest (n-k) bits. For TC on fig.2 they are: 011111 for (n-1) level, 001111, 101111 for two zones of (n-2) level and 000111, 01011, 100111, 110111 for fore zones of (n-3) level.

The border following combination (BFC) for any zone as a rule is used. For example, BFC for (n-2)-level subzone 1 is 11000 (48). In order to any output code combination *K* was unused and belong to subzone number j of zone level (n-k), the next inequation must be true:

$$A(BFC_{n-k}^{j})) \le A(K). \quad (4)$$

It is very important, that values of BFC do not depend neither base of counting system, no ADC resolution and may defined by the next rule:

- for (n-1)-level zone $BFC_{n-1}^{0} = 100...$ – the MSB=1, then follow all “0”;
- for (n-2)-level zone $BFC_{n-2}^{0} = 0100...$, $BFC_{n-2}^{1} = 1100...$ – the first MSB indicates the number of subzone, the next bit “1”, then follow all “0”;
- for (n-3)-level zone $BFC_{n-3}^{0} = 00100...$, $BFC_{n-3}^{1} = 01100...$, $BFC_{n-3}^{2} = 10100...$, $BFC_{n-3}^{3} = 11100...$ – two first MSB indicate the number of subzone, the next bit “1”, then follow all “0”;
- for (n-k)-level zone – k-1 first MSB indicate the number of subzone, the next bit “1”, then follow all “0”.

In this way, the algorithm of creation the list of unused combinations will be next:

1. Based on the base of the counting system value and resolution ADC with help of table 1 define the number of the smallest level zone.
2. For every subzone define the BFC.
3. Beginning from subzone number 0 of the smallest level zone through the (4) define the list of unused combinations in this zone.
4. Follow to the next level zone and define the list of unused combinations while go over to the (n-1)-level.

In order to minimize the quantity of calculations it is useful to consider some peculiarities of the location unused combination in different level zones and subzones:

- As a rule, the quantity of unused combinations in any subzone of zone level (n-k) more than in any subzone of zone level (n-k-1).
- The biggest unused combination in any subzone is constant and known.
- Unused combinations in any zone follow in sequence without gaps. It means that enough to define the smallest unused combination to know all members of the group.

Conclusion

The theses shows the opportunity of analytical identification the unused combinations in transfer curve of redundant ADC. The simple way of the calculation of the list of unused combinations allows defining the deviations of ADC bits during the main conversion without using external devises and procedures. The relationships between different zones of unused combination allow significantly reduce the time and computing resources for method realization.

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