DESIGN AND REALIZATION OF DYNAMIC ELEMENT MATCHING METHOD FOR 4-BIT DA CONVERTER

Ondřej Valehrach
Bachelor Degree Programme (3), FEEC BUT
E-mail: o.valehrach@centrum.cz

Supervised by: Lukáš Fujcik
E-mail: fujcik@feec.vutbr.cz

ABSTRACT

Multi-bit ΣΔ structures are widely used because of theirs good stability. Unfortunately, these structures are very sensitive to linearity of the internal digital-to-analog converter (DAC). In fact, D/A converter's elements cannot have the same properties due to the fabrication process, and thus they generate mismatch error in analog values corresponding to input digital codes. The difference, called integral nonlinearity, is represented as harmonic distortion at the output of internal DAC and undesirably affects the whole ΣΔ structure. The one of dynamic element matching method (DEM), called data weighted averaging (DWA), is presented in this paper.

1. INTRODUCTION

As was said above multi-bit ΣΔ structures are very sensitive to nonlinearities of the internal DAC, which are caused by differences between DAC's unit elements. These differences have been named mismatch error and they are caused by the fabrication process of integrated circuits. Mismatch error between elements introduces harmonic distortion at the output of DAC and in many applications the quantization error of the sigma-delta modulator and the conversion error of the internal DAC may share the same band of frequencies but are separate from the input signal. One way how to design a perfect DAC is to make the power of DAC's conversion error low in bandwidth occupied by processed signal and concentrate its power at frequencies, where it could be filtered out. This linearization technique for DACs is called mismatch-shaping and is the basis for the DEM method like DWA [1].

2. DIGITAL-TO-ANALOG CONVERSION WITH MISMATCH-SHAPING

Objective of mismatch-shaping is to remove conversion error signal with suitable signal processing. On the basis of the system presented in [1], analysis shows that the mismatch error of unit elements in z-domain is given by

$$E_{DEM} \quad z \quad = \Gamma \qquad\qquad z \tag{1}$$

$\Gamma(z)$ is z-transform of $\gamma[n]$ and have only mathematical meaning. This error can be spectrally shaped by suitable choice of transfer function $H(z)$, e.g. making $H(z)$ equal to $1 - z^{-1}$ we obtain the first order mismatch-shaping, because the error signal is 1st-order high-pass filtered. Higher order mismatch-shaping is also available and generally achieves better results.

3. DATA-WEIGHTED AVERAGING

DWA has prevailed as the most practical DEM technique to linearize the internal DAC of a multi-bit ΣΔ modulator. Principle of DWA method is shown in Fig. 1. The way how the unit elements are selected is given by equation

$$c\ n\ = \qquad - \ + \qquad \text{ɔd}\, N \tag{2}$$

Signal $y[n]$ is an input signal, signal $c[n]$ is an internal signal, and both are used for generation of output code to control DAC unit elements. Scheme (Fig. 1) represents a 4-bit DAC with 15 unit elements. If the input signal $y[n]$ at time n is equal to 3 and signal $c[n]$ has value of 6, three unit elements with index 3 to 5 will be activated. Next value of $c[n]$ at sample $n + 1$ is estimated from new value of input code $y[n + 1]$ and the last value of signal $c[n]$ according to (2). It is equal to 12 and six unit elements with index from 6 to 11 will be activated.

Conversion error signal of internal DAC is given by

$$e_{DWA} = \sum_{i=}^{c\ "} \qquad \sum_{=} \quad , \tag{3}$$

where h_i is mismatch error of i-th unit element. By substituting first sum in (3) by function $IM(c[n])$, the expression for e_{DWA} in z-domain can be rewritten as [2]

$$E_{DWA}\ z\ = \qquad - \qquad = - \qquad , \tag{4}$$

so data-weighted averaging is the 1st-order mismatch-shaping dynamic element matching method.

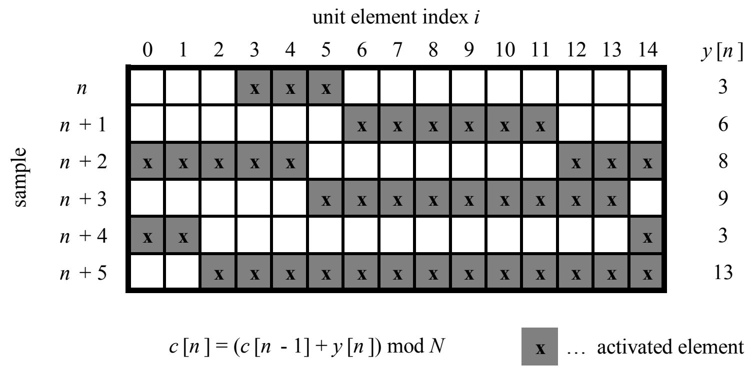
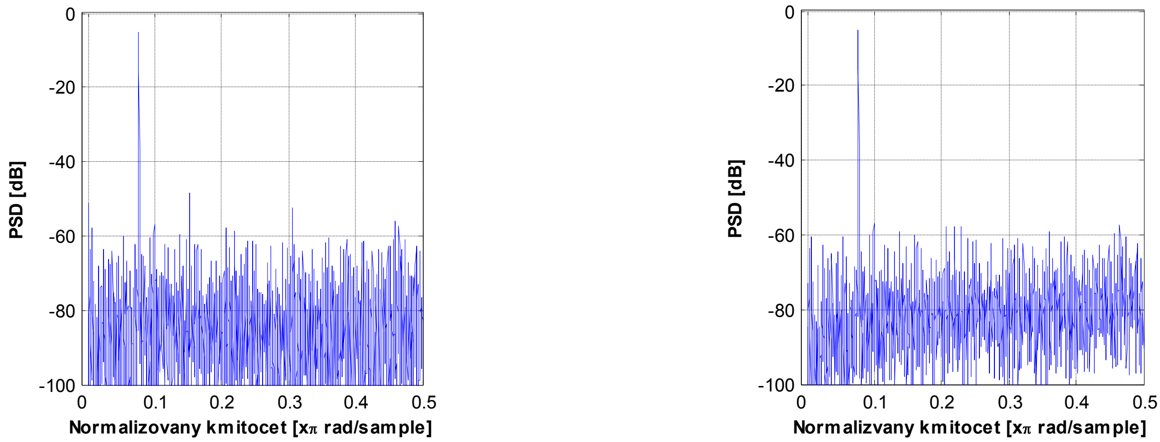


Fig. 1: Element selection algorithm of DWA.

4. SIMULATION

Simulation is performed using SIMULINK for the 4-, 5-, 6- and 8-bit DAC. The DAC input signal is sinusoid with normalized frequency 313π/2048 *rad/sample*, mismatch errors of unit elements are chosen as independent Gaussian random variables with a standard deviation of 5 % of the 1-bit DACs nominal step size.

Fig. 2 shows the power spectral density (PSD) of the output of 6-bit DAC. As can be seen in Fig. 2b the tones of harmonic distortion are attenuated in comparison with the PSD of the output DAC without using DWA in Fig. 2a.



(a) *(b)*

Fig. 2: PSD of 6-bit DAC (a) without using DWA (b) using DWA.

5. CONCLUSION

The data-weighted averaging as the linearization method for imperfect DAC is presented. On the basis of analyzing DWA method the simulation is performed for 4-, 5-, 6- and 8-bit DAC. PSD of 6-bit DAC is shown in Fig. 2 and numerical results of *SNR* and *ENOB* are shown in Tab. 1.

	bits	4	5	6	8
SNR [*dB*]	ideal	25,6	31,7	37,7	49,8
	nonideal	25,3	31,3	35,5	43,5
	DWA	25,3	31,5	37,5	49,6
ENOB [*bit*]	ideal	3,96	4,97	5,97	7,98
	nonideal	3,91	4,91	5,60	6,93
	DWA	3,91	4,94	5,94	7,95

Tab. 1: Simulation results of SNR and ENOB.

REFERENCES

[1] L. Hernández: A Model of Mismatch-Shaping D/A Conversion for Linearized DAC Architectures, *IEEE Trans. Circuits and Systems I: Fundamental theory and applications*, vol. 45, no. 10, October 1998.

[2] Kuan-Dar Chen a Tai-Haur Kuo: An Improved Technique for Reducing Baseband Tones in Sigma–Delta Modulators Employing Data Weighted Averaging Algorithm Without Adding Dither, *IEEE Trans. Circuits and Systems II: Analog and digital signal procesing*, vol. 46, no. 1, January 1999.