ELectronics EXpress

Thermo data-weighted average dynamic element matching (DEM) encoder for current-steering DACs

Yuan Wang[a)], Baoguang Liu, Wei Su, Junlei Zhao, and Xing Zhang

Key Laboratory of Microelectronic Devices and Circuits (MoE), Institute of Microelectronics, Peking University, Beijing 100871, P.R. China

a) *wangyuan@pku.edu.cn*

Abstract: A novel dynamic element matching (DEM) method is presented, called Thermo Data Weighted Average (TDWA) for Nyquist-rate current-steering digital-to-analog converts (DACs). The proposed TDWA encoder technique chooses a sequence of unit current sources and increase or decrease units at different side. Thus this approach can not only reduce the switching number to minimum (as few as thermometer encoder), but also retain good ability to eliminate signal dependent distortions to achieve good linearity at high sampling frequencies.

Keywords: digital-to-analog converters (DACs), dynamic element matching (DEM), spurious free dynamic range (SFDR)

Classification: Integrated circuits

References

[1] D. Lee, Y. Lin and T. Kuo: IEEE Trans. Circuits Syst. II, Exp. Briefs **53** [11] (2006) 1264.

[2] S. Saeedi, S. Mehrmanesh, M. Atarodi and H. A. Aslanzadeh: Proc. Inter. Symp. Circuits Syst. (ISCAS) (2004) I-349-52.

[3] E. N. Aghdam, P. Benabes and J. Abbasszadeh: Euro Conf. Circuit Theory Design (ECCDT) (2009) 53.

[4] M. Shen, J. Tsai and P. Huang: IEEE Trans. Circuits Syst. II, Exp. Briefs **57** [5] (2010) 369.

1 Introduction

Due to its advantages of speed and linearity, current-steering digital-to-analog converters (DACs) have been popularly taken in high frequency applications, such as wireless communication and video signal processing [1]. However, the current source elements are inevitably susceptible to random process mismatches, which cause nonlinear distortion in the overall DACs. Dynamic element matching (DEM) technique converts signal-dependent distortions to signal-independent broadband noises by digital methods, which can effectively minimize these nonlinear distortions [2].

DOI: 10.1587/elex.10.20130459
Received June 14, 2013
Accepted July 04, 2013
Publicized July 11, 2013
Copyedited October 25, 2013

However, for the traditional DEM encoders, such as Data-Weighted Average (DWA), a complicated encoding is necessary, which means more switch transitions [3]. For the current-steering DAC operating at high speed, switch transitions will bring additional glitches energy to the output signal of the converters and degrade the DACs' dynamic characteristics, especial the spurious-free dynamic range (SFDR) [4].

In this paper, a novel DEM technique, called Thermo Data-Weighted Average (TDWA), is proposed. Compared to the traditional DWA encoder, the proposed encoder can not only reduce the switching number to a minimum value as few as thermometer decoding, but also retain a good ability to eliminate the signal dependent or mismatch dependent harmonics caused by element mismatches.

2 Proposed DEM techniques

Fig. 1 shows the principle three different digital encoders in a 3-bit DAC example, including thermometer, DWA, and proposed TDWA encoder. Fig. 1 (a) shows the element sequence using thermometer encoder. $\{U_1 \sim U_7\}$ stand for 7 unity weight current source elements. The initial input of five selects elements $\{U_1, U_2, U_3, U_4, U_5\}$. The second and third inputs select elements $\{U_1, U_2, U_3, U_4, U_5, U_6\}$ and $\{U_1, U_2\}$, in sequence. Apparently, every time when the input changes, the number of switch transitions (N_{ST}) is the least. However, the low (left) elements have a selected priority than the high (right) elements in the thermometer encoder.

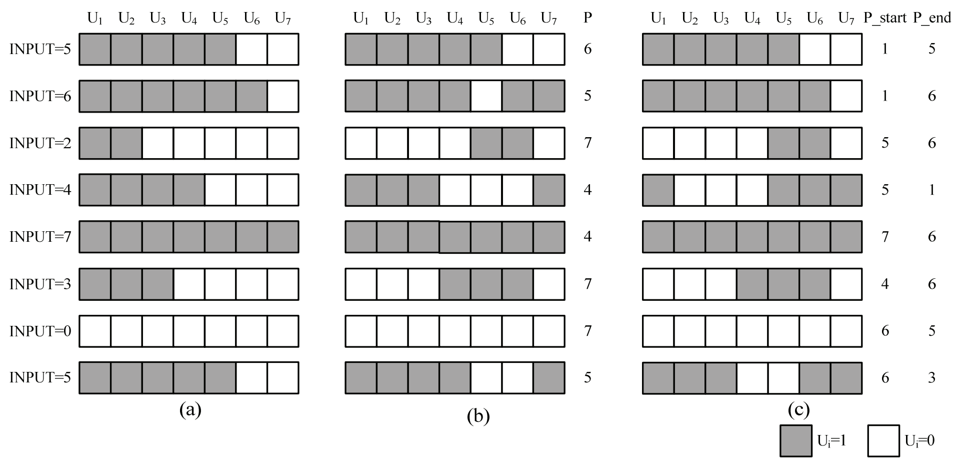

Fig. 1. The principle of thermometer (a), traditional DWA (b), and proposed TDWA (c) encoders

Fig. 1 (b) shows the DWA encoder [3]. When the input code changes, the status of selected elements is simply memorized by a pointer P described at end of selected unary elements. This is done by sequentially selecting elements from an array, beginning with the next available unused element. The DWA encoder averages the selected priority of overall seven elements. But the switch transitions increases dramatically. For example, when the input is changed from 2 to 4, N_{ST} is equal to 6 compared to 2 of thermometer encoder. It is predictable that the DWA encoder has a poor static linearity caused by more switch transitions, which is specified as integral nonlinearity (INL) and differential nonlinearity (DNL).

DOI: 10.1587/elex.10.20130459
Received June 14, 2013
Accepted July 04, 2013
Publicized July 11, 2013
Copyedited October 25, 2013

Fig. 1 (c) shows the principle of the proposed TDWA encoder. Based on the DWA coding, the TDWA encoder cycles through sequentially selecting the elements according to the input codes. Two extra pointers are used, named P_start and P_end, to mark the edge of the selecting sequence. For example, when the initial input code is 5, P_start is set with 1 and P_end is 5. It means the encoder chooses the elements from U_1 to U_5. When the second input code is 6, P_start is still 1 and P_end is set with 6. It means the encoder chooses the elements from U_1 to U_6. When the third input code is 2, P_start is set with 5 and P_end is still 6. It chooses the elements from U_5 to U_6. Subsequently, when the i_{th} input code is larger than the $(i-1)_{th}$ input code, the encoder adds elements to the P_end. And when the i_{th} input code is smaller than the $(i-1)_{th}$ input code, the encoder reduces elements from the P_start. Apparently, the TDWA encoder only increases or only decreases the number of the selected elements when input code changes as well as the thermometer encoder, which will induce the least switch transitions.

3 Implementation of TDWA encoder

Fig. 2 shows the implementation of the proposed encoder on the operation of an N-bit converter. For the N-bit TDWA coding converter, its output code U[j] has (2^N-1)-bit and stand for 2^N levels. For each P_start, it will be 2^N-1 kinds of possible positions for P_end. Apparently, these two pointers cannot satisfy all 2^N kinds of possibilities. Hence, the proposed encoder should regard the input code "0" as a special one. If the input code is "0", P-start will be set to (P_end+1) and all the output U $[1]\sim U[2^N-1]$ will be "0". When the input code is not "0" or "7", the encoder will compare the i_{th} input code X[i] with the previous one X[i−1]. If X[i] is larger, P_start will remain unchanged and P_end will be set to (P_start+X[i]−1), and if X[i] is smaller, P_end will remain unchanged and P_start will be set to (P_end−X[i]+1). Certainly, if the pointer overflows, it is necessary for a cycle operation. After getting new P_start and P_end, the encoder will set the output bits

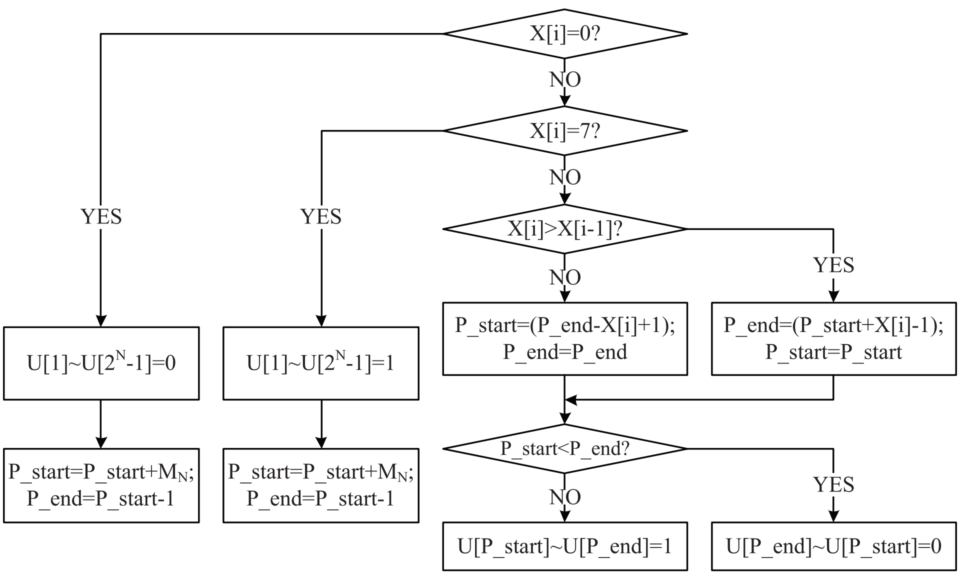

Fig. 2. Simplified implementation diagram of proposed TDWA encoder

DOI: 10.1587/elex.10.20130459
Received June 14, 2013
Accepted July 04, 2013
Publicized July 11, 2013
Copyedited October 25, 2013

between U[P_start] to U[P_end] (close interval) by 1 and the rest by 0 when P_start is smaller than P_end. If P_start is larger, the encoder set the output bits between U[P_end] to U[P_start] (open interval) by 0 and the rest by 1. Moreover, when the input code is “0” or “7”, the next element selection is regarded as a new beginning. To increase the randomness of the selected elements, P_start is added by a given number (M_N) and P_end is equal to P_start minus one. For the N-bit TDWA encoder, M_N is defined as 2. For example, in Fig. 1, when the input code is changed from “4” to “7”, P_start is set to 7 (equal to 5 plus 2) and P_end is set to 6.

4 Simulation results

To simulate the element mismatch error in more cases, the current source elements have been set with the max mismatch about 10% and a random quadratic error distribution. It is fulfilled to simulate 100 times with different random error distribution of elements to get the average SFDR, INL and DNL.

Fig. 3 (a)–(c) shows the distribution of SFDR value of three encoders. Because the element mismatch distribution is randomized for each simulation, the SFDR value may not keep a fixed value. Hence, the Y axis in Fig. 3 is the number of runs which corresponds to the SFDR value in the X axis. Apparently, the two DEM encoders have a higher mean SFDR value above 50 dB compared with the thermometer encoder. It is because that the thermometer encoder cannot convert nonlinear distortion into noise without DEM techniques. Moreover, in Fig. 3 (d), when the ratio of f_{in} to f_s is increasing, the DWA encoder has a jumping switch-transistor

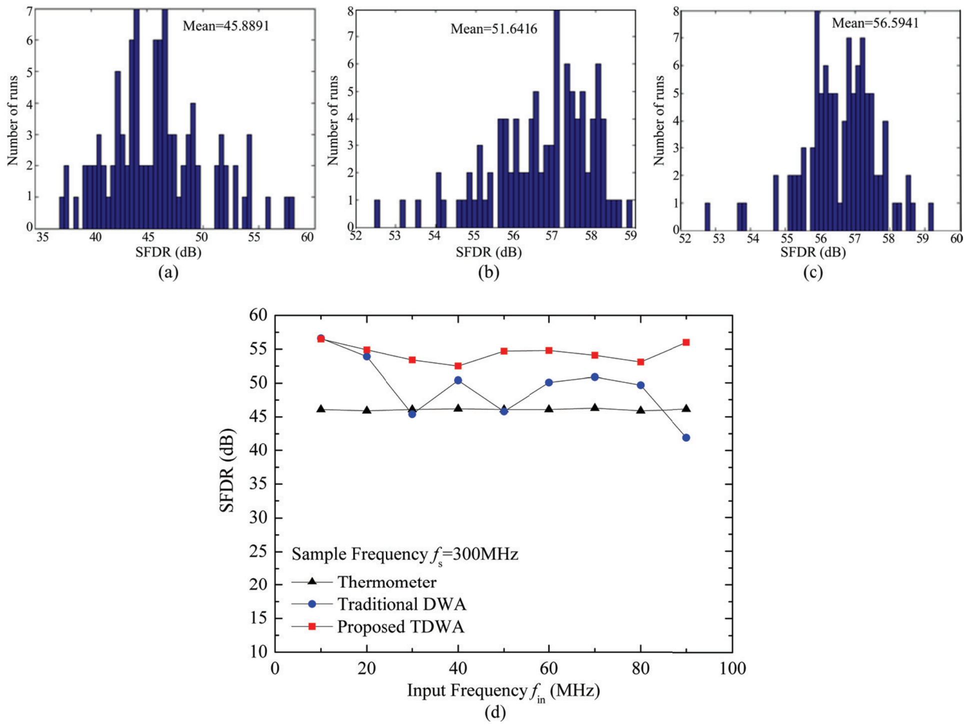

Fig. 3. The SFDR distributions of (a) thermometer, (b) DWA, and (c) proposed TDWA encoder; (d) Measured mean SFDR versus input frequency for three encoders

DOI: 10.1587/elex.10.20130459
Received June 14, 2013
Accepted July 04, 2013
Publicized July 11, 2013
Copyedited October 25, 2013

number and glitch energy, which degrades its SFDR value. Oppositely, because the proposed TDWA techniques swap the selecting element randomly and minimize the number of switched current sources, the SFDR value of the novel encoder can keep a high level and be unrelated to the input frequency. Even though f_{in} is up to 90 MHz (@ f_s=300 MHz), the mean SFDR value of the proposed TDWA encoder can achieve 56 dB.

Fig. 4 shows the distribution of INL and DNL value due to the randomized mismatch for three encoders. Simulation results show that the TDWA encoder has low mean INL and DNL values same as thermometer encoder, which has a significant decline of about 32.2% for the mean INL value and 78.3% for the mean DNL value compared with traditional DWA encoder.

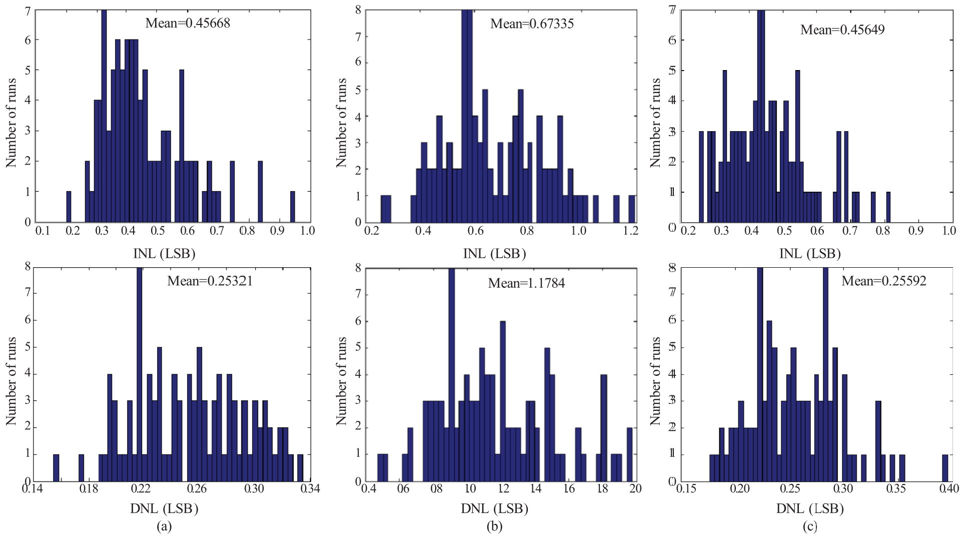

Fig. 4. Average INL and DNL of (a) thermometer, (b) DWA, and (c) TDWA encoder

5 Conclusions

A novel DEM coding technique called TDWA for the Nyquist-rate current-steering DAC has been presented in this work. The technique has two pointers to mark the elements sequence and has the lowest switch transitions as possible. Simulating results show that the novel DEM encoder has both static and dynamic performances compared with the existing works.

Acknowledgments

This work is supported by the Special Funds for Major State Basic Research Projects (Grant No.2010CB934200)

DOI: 10.1587/elex.10.20130459
Received June 14, 2013
Accepted July 04, 2013
Publicized July 11, 2013
Copyedited October 25, 2013