Turk J Elec Engin, VOL.13, NO.1 2005, © TÜBİTAK

A Realization of SC-CNN-Based Circuit Using FTFN

Enis GÜNAY[1], **Esma UZUNHİSARCIKLI**[2], **Recai KILIÇ**[1], **Mustafa ALÇI**[1]
[1]*Erciyes University, Dep. of Electronic Engineering, 38039, Kayseri-TURKEY*
e-mail: egunay@erciyes.edu.tr, kilic@erciyes.edu.tr, malci@erciyes.edu.tr
[2]*Erciyes University, Kayseri Vocational College, Electronic Programme,*
38039, Kayseri-TURKEY
e-mail: uzunhise@erciyes.edu.tr

Abstract

In this paper, a realization of the State Controlled Cellular Neural Network (SC-CNN)-based circuit using Four Terminal Floating Nullor (FTFN) as active element is presented. In this realization, a new version of autonomous Chua's circuit has been considered using FTFN realization of SC-CNN-based circuit. The performance of the proposed SC-CNN-based circuit is demonstrated by PSpice simulations.

Key Words: *Cellular Neural Networks, FTFN, Chaos.*

1. Introduction

In recent times, many studies were reported about chaotic circuits and their applications. From this point of view, a variety of chaotic circuits have been used as chaos generator. Since it exhibits a rich variety of bifurcations and chaos, the most preferable circuit as the chaos generator is Chua's circuit [1].

On the other hand, since its definition by Chua & Yang [2], Cellular Neural Networks (CNNs) received a great deal of interest. Although many of these applications were proposed for numerous disciplines like artificial life and image processing [3], some have been adapted for chaos [4-7]. In one of these applications, Arena et al. realized unfolded Chua's circuit using the connection of three simple generalized CNN cells and called this network structure as State-Controlled CNN (SC-CNN) [4]. The proposed SC-CNN-based circuit is realized by using voltage-mode op amp (VOA) as an active element. Afterwards this SC-CNN based circuit has been used in the chaos-based secure communication systems as a chaos generator [5,6]. As an active element, VOAs have been used in a broad band of applications, e.g. filters, linear and non-linear amplifiers, analogue simulations etc. In the evolution of VLSI circuits, because of VOA's certain limitations such as slew-rate problem and fixed gain-bandwidth product, designers changed the processed signal from voltage to current [8].

On the other hand, current-mode circuits are receiving much attention for their potential advantages such as wider dynamic range, inherent wide bandwidth, simpler circuitry and lower power consumption than voltage-mode circuits [9,10]. Among the current-mode circuits, four terminal floating nullor (FTFN)-based current-mode circuits are more flexible, versatile and stable active element in the synthesis of active networks than VOAs and current conveyors [8-14]. Because of the potential advantages of current-mode signal processing techniques, in literature many methods have been investigated for transforming the well-developed voltage-mode circuit into their current-mode counterparts through the use of nullor model [9]. One of the implementations of the nullor model is an ideal voltage-mode op amp (VOA). It has been shown that, the nullor equivalent of VOA can be replaced with the nullor equivalent of FTFN without imposing any restrictions [13].

In this paper, by utilizing the transformation between VOA and FTFN, the circuit realization of SC-CNN-based circuit has been constituted with FTFN. The organization of the paper is as follows: In Section 2, the generation of Chua's circuit dynamics using SC-CNN is given. In Section 3, the circuit realization of the SC-CNN-based circuit using FTFN is described and simulation results are presented and finally a conclusion part is presented in Section 4.

2. SC-CNN-Based Circuit

As the most preferable chaos generator, diverse realizations of Chua's circuit have been used in several applications. One of the realizations of Chua's circuit has been derived by using a suitable connection of three simple generalized CNN cells. The proposed circuit has been called as the State Controlled-Cellular Neural Network (SC-CNN) [4]. While the dimensionless state equations of the Chua's circuit are defined as follows:

$$\begin{aligned} \dot{x} &= \alpha[y - h(x)] \\ \dot{y} &= x - y + z \\ \dot{z} &= -\beta y - \gamma z \end{aligned} \tag{1}$$

where

$$h(x) = m_1 x + 0.5 \cdot (m_0 - m_1) \times (|x+1| - |x-1|) \tag{2}$$

the proposed SC-CNN-based circuit is defined by the following nonlinear state equations [4]:

$$\begin{aligned} \dot{x}_1 &= -x_1 + a_1 y_1 + s_{11} x_1 + s_{12} x_2 \\ \dot{x}_2 &= -x_2 + s_{21} x_1 + s_{23} x_3 \\ \dot{x}_3 &= -x_3 + s_{32} x_2 + s_{33} x_3 \end{aligned} \tag{3}$$

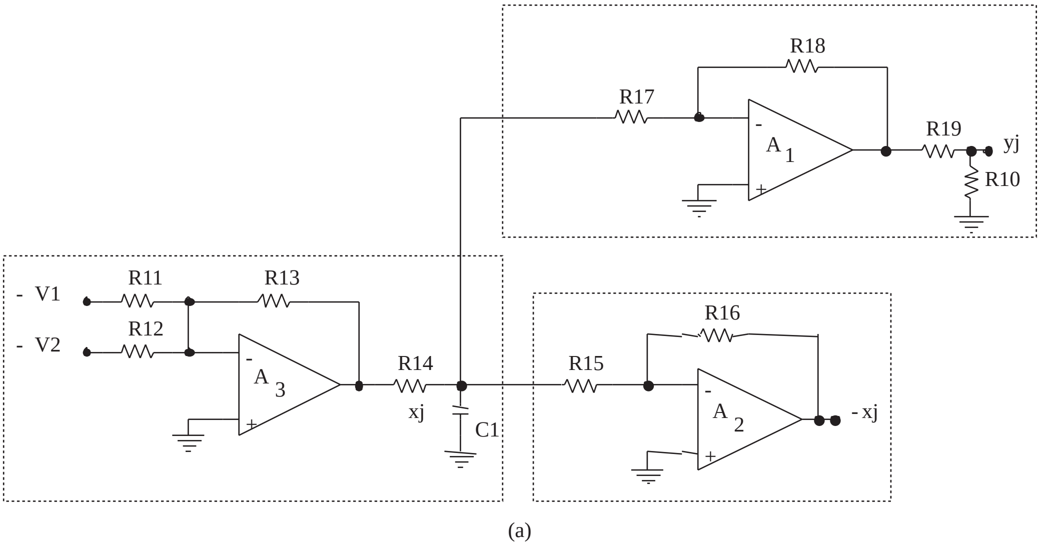
To obtain SC-CNN version of Chua's circuit, the "a" and "s" parameters determined as $a_1 = \alpha(m_1 - m_0); s_{33} = 1 - \gamma; s_{21} = s_{23} = 1 s_{11} = 1 - \alpha \cdot m_1$; $s_{12} = \alpha$; and $s_{32} = -\beta$ [4]. It is demonstrated that the state equations of Chua's circuit defined in Eq. (1) could be obtained with SC-CNN state equations. The generalized cell circuit can be seen in Figure 1(a). To obtain the output non-linearity, R_{17} and R_{18} designed such that the A_1 output saturates when $|\mathrm{x}_1| > 1$, and also designed R_{19} and R_{10} to scale the output voltage $-\mathrm{y}_1$ in the range [-1,1] [4].

$$R_{18}/R_{17} = V_{satC_1}/V_{satx_1} \tag{4a}$$

$$R_{17}/R_{18} = R_{10}/\left(R_{19} + R_{10}\right) \tag{4b}$$

A_2 is an inverting amplifier and it has a unity gain, so $R_{15} = R_{16}$. From A_3, the SC-CNN cell state equation can be written as follows:

$$C_j x_j' = -\frac{x_j}{R_4} + \frac{R_3}{R_1 R_4} V_1 + \frac{R_3}{R_2 R_4} V_2 \tag{5}$$



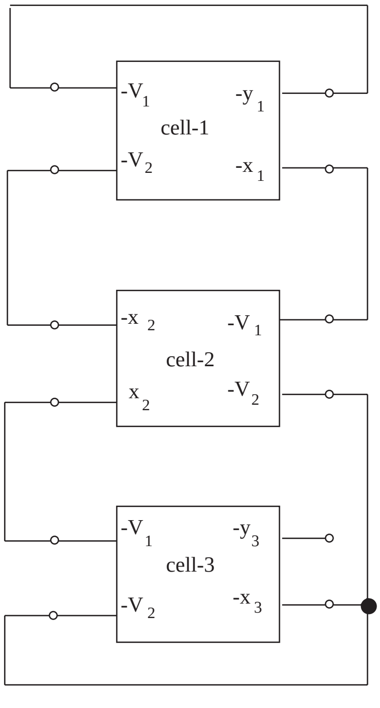


Figure 1. (a) The generalized cell circuit, (b) The cell connection scheme.

To realize Chua's circuit, the three cells connection determined as, $v_1 = y_1$ and $v_2 = x_2$ for the first cell, $v_1 = x_1$ and $v_2 = x_3$ for the second cell, $v_1 = -x_2$, $v_2 = x_3$ for the third cell and this cell connection scheme is given in Figure 1(b) [4]. To perform a double-scroll chaotic attractor as in original Chua's circuit with the parameter values $\beta = 14.286$, $\alpha = 9$, $\gamma = 0$, $m_0 = -1/7$ and $m_1 = 2/7$, the parameter values of SC-CNN based circuit chosen as $R_{11} = 13.2$ kΩ, $R_{12} = 5.7$ kΩ, $R_{13} = 20$ kΩ, $R_{14} = 390$ Ω, $R_{15} = 100$ kΩ, $R_{16} = 100$ kΩ, $R_{17} = 74.8$ kΩ, $R_{18} = 970$ kΩ, $R_{19} = 27$ kΩ, $R_{10} = 2.22$ kΩ, $C_{11} = 51$nF for the first cell, $R_{21} = R_{22} = R_{23} = R_{25} = R_{26} = 100$ kΩ, $R_{24} = 1$ kΩ, $C_{21} = 51$nF for the second cell, $R_{32} = R_{33} = R_{35} = R_{36} = 100$ kΩ, $R_{34} = 1$ kΩ, $R_{31} = 7.8$ kΩ, $C_{31} = 51$nF for the third cell [4]. From the cell connection scheme in Figure 1(b), it can be easily seen that there is no need to constitute an output non-linearity for the second and third cells. Then the usage of the resistors R_{27}, R_{28}, R_{29}, R_{20} and R_{37}, R_{38}, R_{39} and R_{30} are unnecessary. While the dc characteristic of SC-CNN-based circuit is demonstrated in Figure 2, the chaotic dynamics observed in x_1, x_2 and x_3 cells, and the double scrolls between x_1-x_2, x_3-x_2, and x_1-x_3 cells of the SC-CNN-based circuit are shown in Figure 3 and Figure 4, respectively.

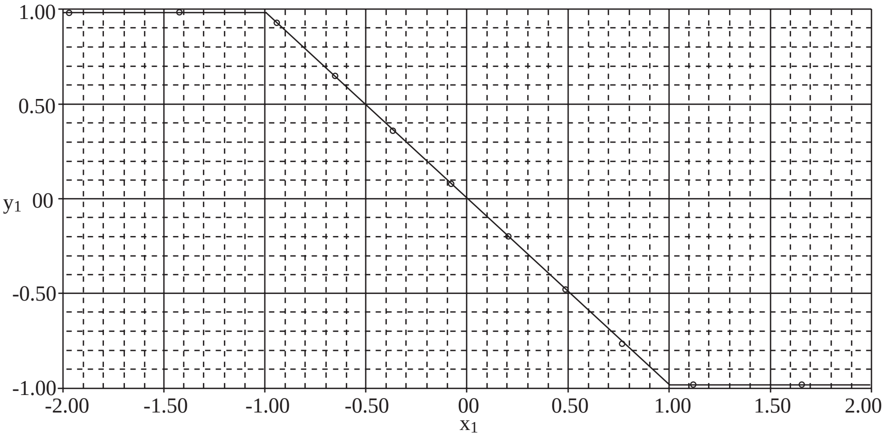
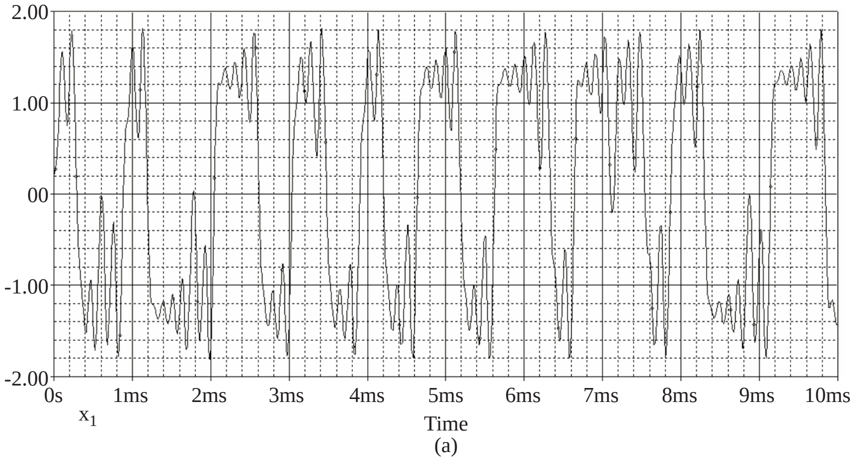


Figure 2. The dc characteristic of SC-CNN-based circuit.



(a)

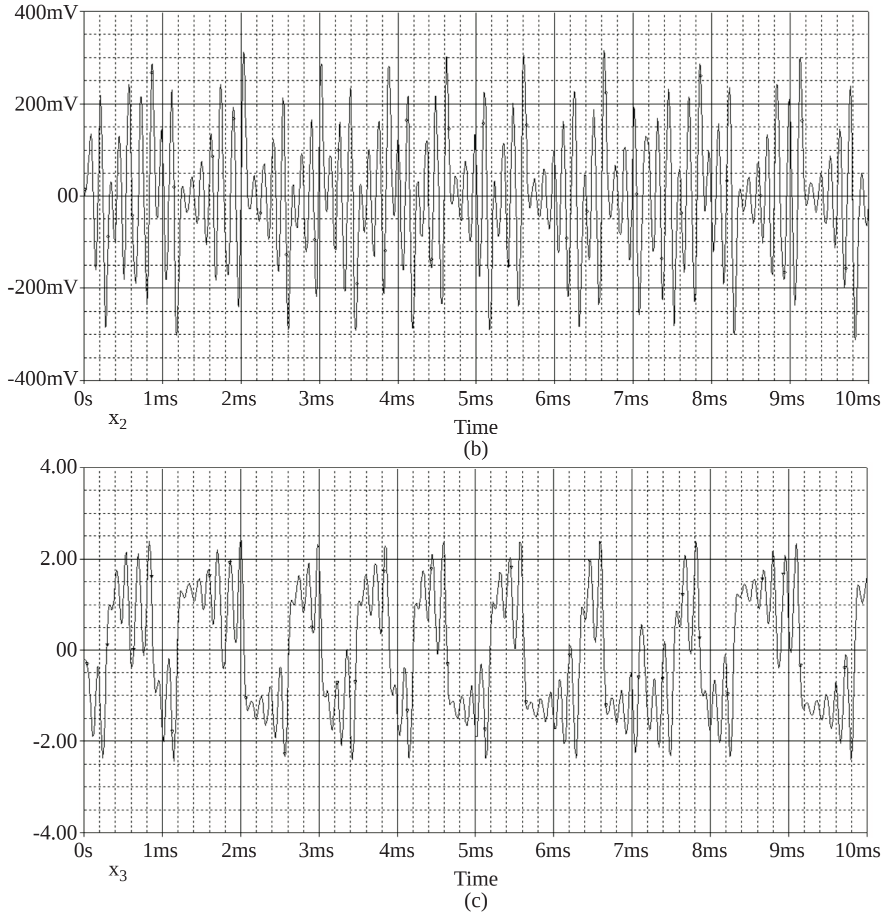


Figure 3. The chaotic dynamics of SC-CNN-based circuit, (a) x_1 dynamic, (b) x_2 dynamic, (c) x_3 dynamic.

3. FTFN Realization of SC-CNN Based Circuit

As theoretical active elements nullator with zero voltage and current, which is a one port two terminal element, and norator with arbitrary voltage and current, which is a one port two terminal, have been used in the synthesis of active networks. The union of nullator and norrator is called "nullor" and its symbol is given in Figure 5(a). It can be seen from Figure 5(a) that nullor has a nullator input and a norator output. One of the implementations of the nullor model is an ideal voltage-mode op amp (VOA).

One can consider that VOA can be realized by using norator's arbitrary output voltage and arbitrary output current characteristics, and also nullator's zero input voltage and zero input current flowing characteristics. So the nullor equivalent of the voltage-mode op amp can be seen in Figure 5(b).

On the other hand, in literature the FTFN is defined as the ideal nullor [12], and its generalized nullor equivalent scheme and circuit symbol are given in Figure 6(a) and Figure 6(b), respectively. The port relations of FTFN is characterized by the following equations:

$$\begin{aligned} &Vx = Vy \\ &Ix = Iy = 0 \\ &Iz = Iw \end{aligned} \tag{6}$$

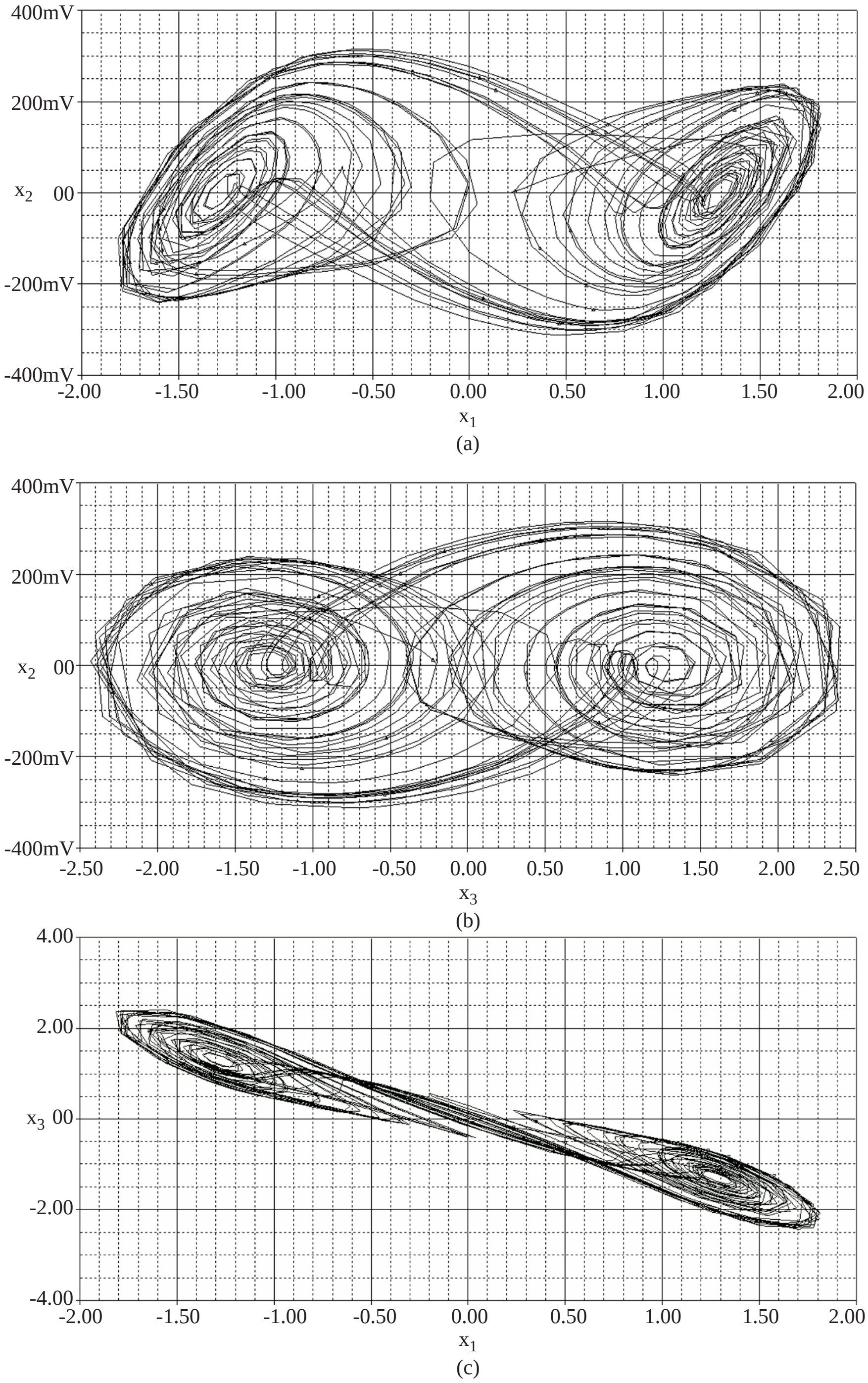
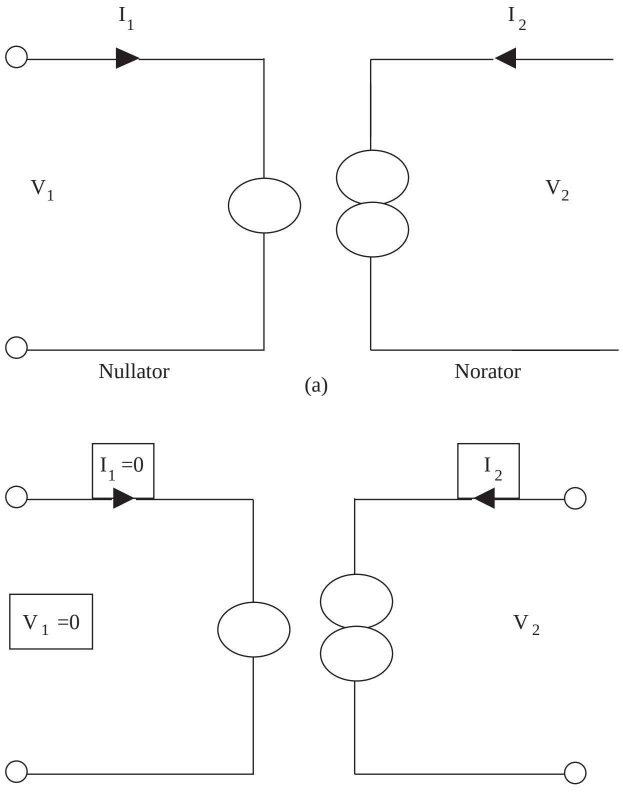


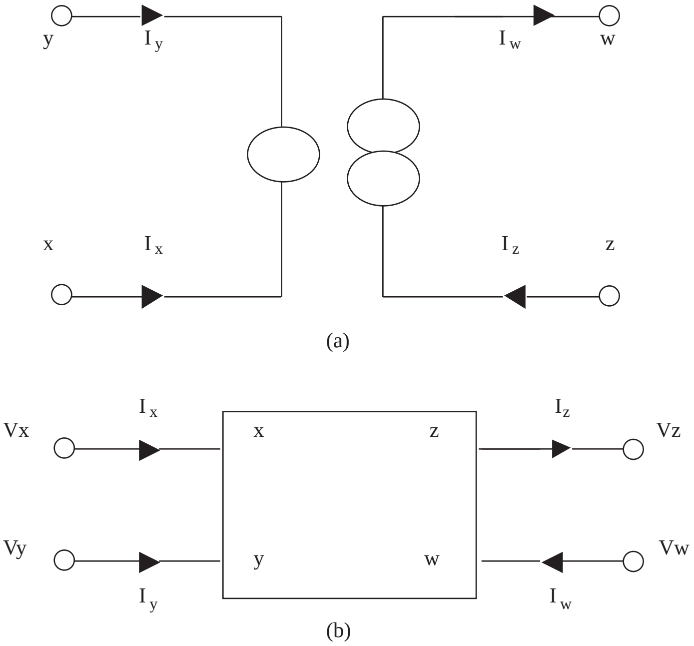
Figure 4. The double scrolls observed in (a) x_1-x_2 plane, (b) x_3-x_2 plane, (c) x_1-x_3 plane.



(a)

(b)

Figure 5. (a) The symbol for “nullor”, (b) The nullor equivalent of an ideal VOA.



(a)

(b)

Figure 6. (a) The nullor equivalent of FTFN, (b) The circuit scheme of FTFN.

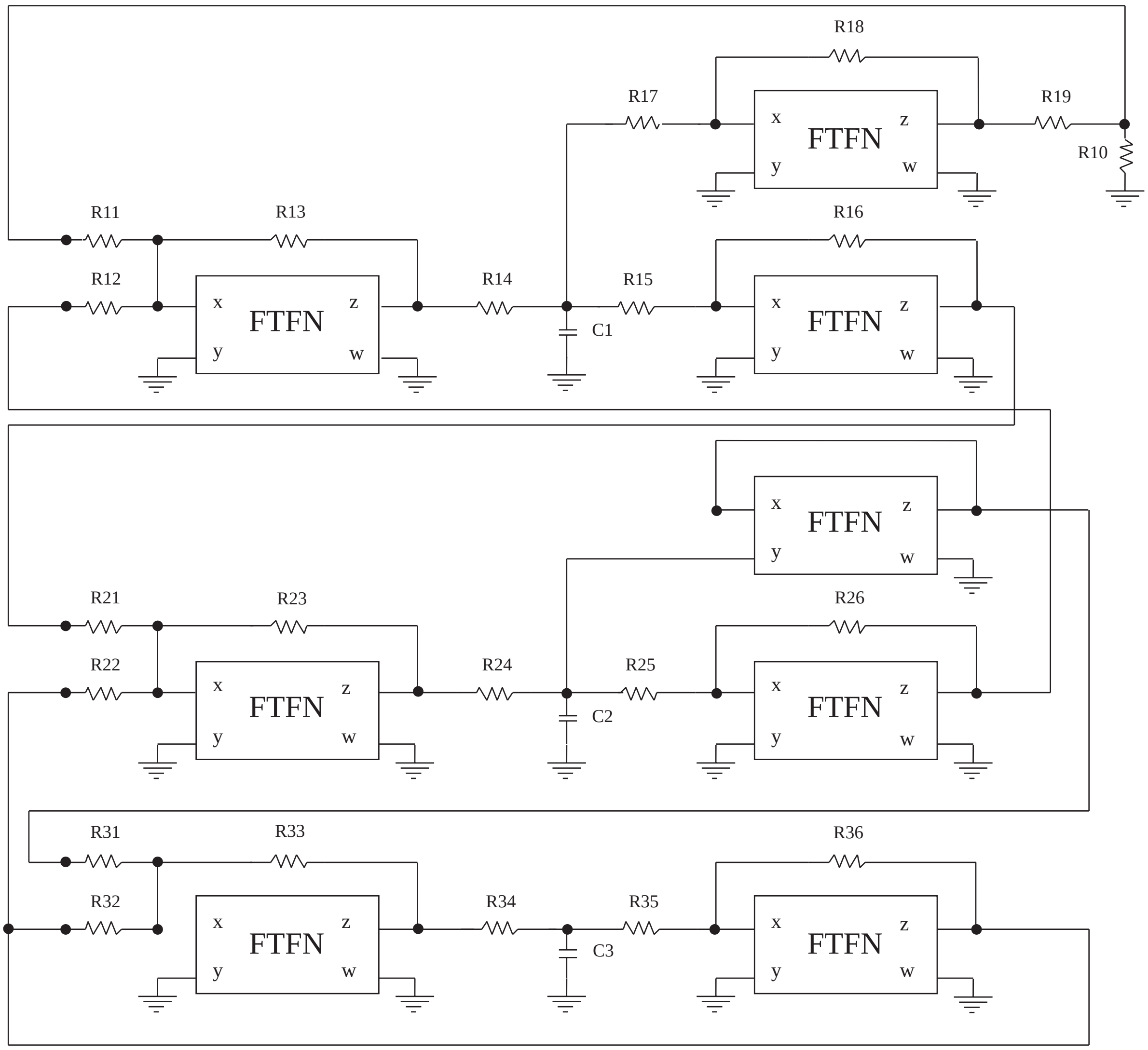


Figure 7. The proposed FTFN realization of SC-CNN-based circuit.

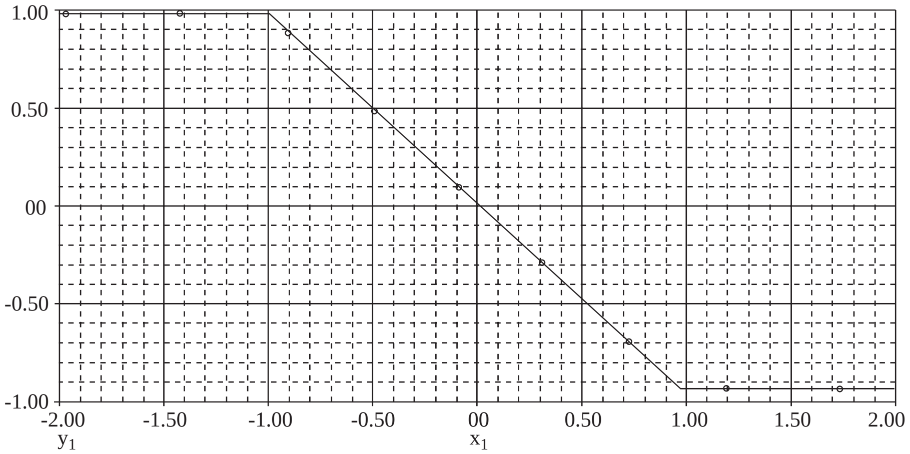


Figure 8. The dc characteristic of the proposed circuit.

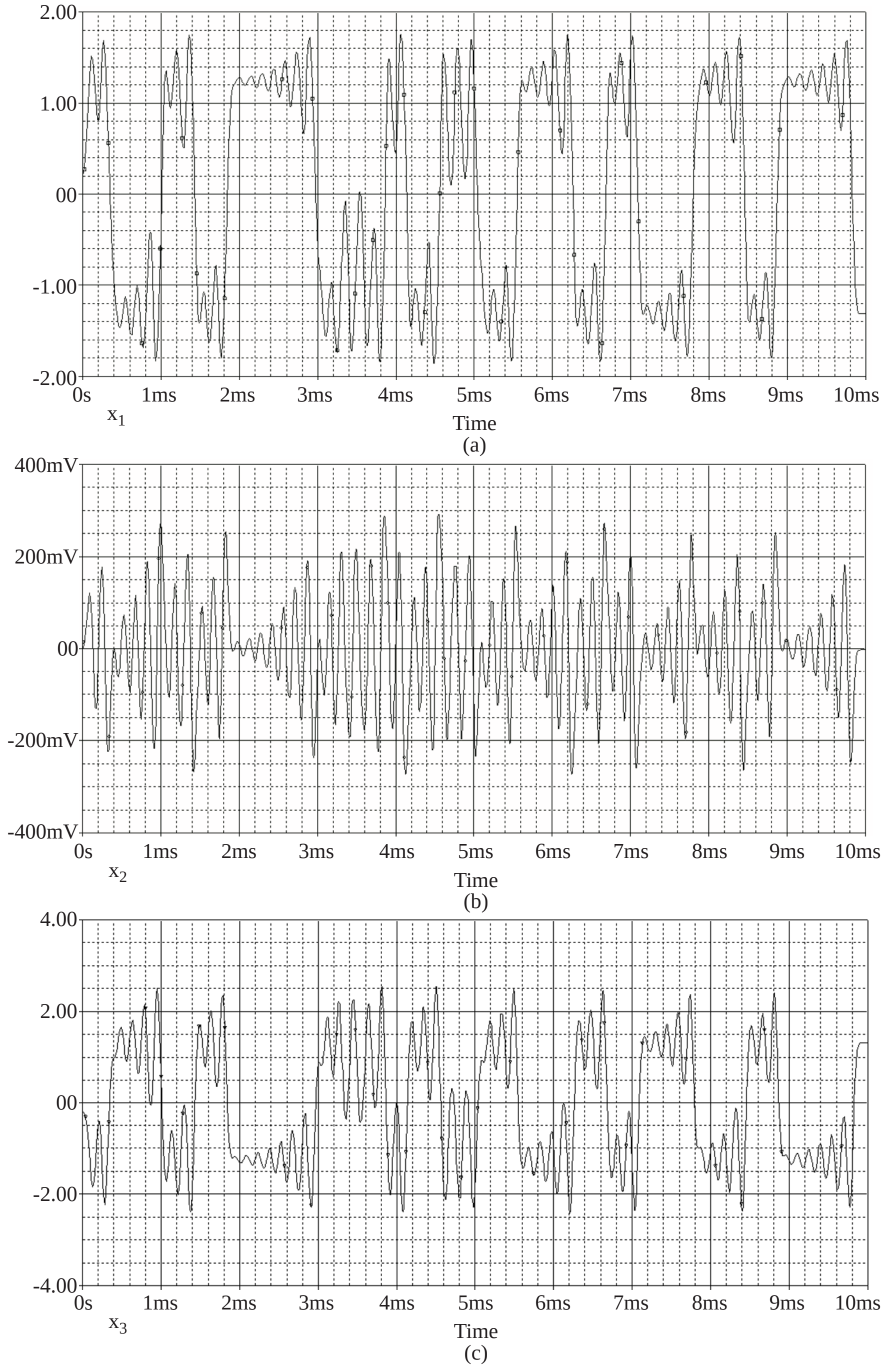


Figure 9. The chaotic behaviors of proposed FTFN realization of SC-CNN-based circuit; (a) x_1 dynamic, (b) x_2 dynamic, (c) x_3 dynamic.

Without imposing any restrictions the nullor equivalent of FTFN used instead of the nullor equivalent of VOA. In this transformation, by determining x port as the inverting input terminal, y port as the non-inverting input terminal, z port as the output terminal of a VOA, and also w port is grounded, FTFN can behave as VOA.

In this paper, by utilizing this transformation between VAO and FTFN building blocks, without any change in the other circuit elements and circuit connections, we used FTFN blocks instead of VOAs in Figure 1(a). We obeyed the design considerations in Eqn. 4(a) and Eqn. 4(b).

While there are no changes in circuit elements and circuit connections for A_2 and for A_3, to form the saturation of A_1 output when $|x_1| > 1$, and to scale the output voltage $-y_1$ in the range [-1,1], the parameter values of R_{17} and R_{19} are redesigned, as 149.6K and 12.32K, respectively. The proposed FTFN realization of SC-CNN-based circuit is given in Figure 7 and dc characteristic of the proposed circuit is given in Figure 8.

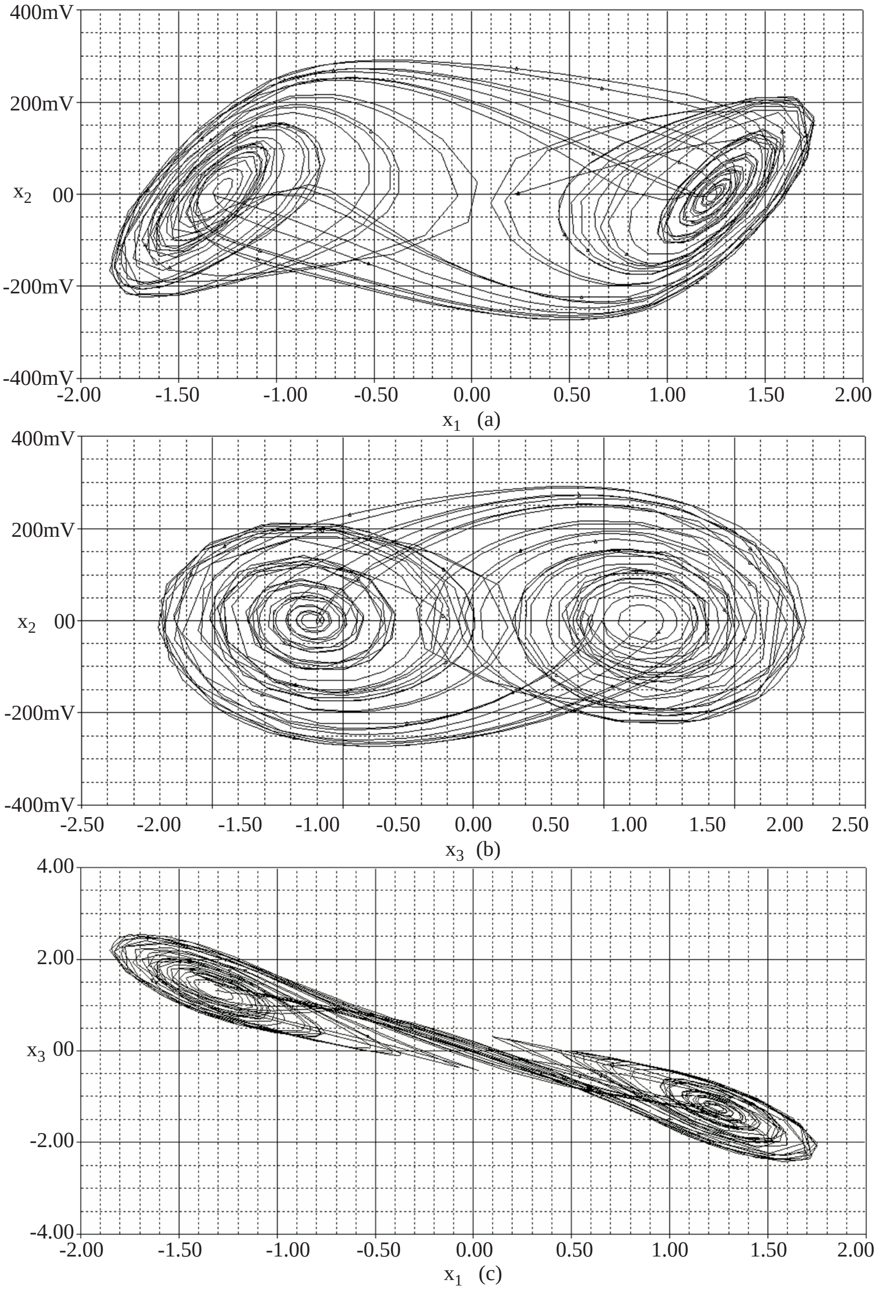


Figure 10. The chaotic attractors of proposed FTFN realization of SC-CNN-based circuit observed in (a) x_1-x_2 plane, (b) x_3-x_2 plane, (c) x_1-x_3 plane.

To perform PSpice simulations, a CMOS realization of FTFN, is used in literature with the same parameters [12]. While the chaotic waveforms and double scroll attractors of the proposed circuit are illustrated in Figure 9 and in Figure 10, respectively.

4. Conclusion

A FTFN realization of SC-CNN-based circuit has been introduced. By using FTFN instead of VOA, an alternative circuit realization of SC-CNN-based circuit has done. From simulation results, the chaotic dynamics and the chaotic attractors observed in FTFN-based circuits are harmonious to the ones observed in original circuits.

In literature the realization of inductorless Chua's circuit using FTFN-based non-linear resistor and inductance simulator is also presented [14]. In that study, FTFN is only used in realization of a part of Chua's circuit as non-linear resistor and inductance simulator. But in this study the whole circuit is realized by using FTFN as an active element.

From another point of view, in literature it has been shown that SC-CNN-based circuit can easily used as a chaos generator in chaos synchronization and chaos based secure communication systems [6,7,15]. With this study, the chaos synchronization and secure communication applications will be able to convenient to the integration process by using FTFN-based SC-CNN circuit as CMOS based FTFN blocks are presented in literature [12].

References

[1] L.O. Chua, C.W. Wu, A. Huang and G.A. Zhong, "Universal circuit for studying and generating chaos", IEEE Trans. Circuits& Syst., CAS-40, (10), pp. 732-745,1993.

[2] L.O. Chua and L Yang, "Cellular neural networks: Theory", IEEE Trans. Circuits& Syst., 35, pp. 732-745, 1988.

[3] L.O. Chua., CNN: A Paradigm for complexity, World Scientific Series on Nonlinear Science, Series A- Vol. 31, World Scientific Publishing, 1998.

[4] P. Arena, S. Baglio, L. Fortuna and G. Manganaro, "Chua's circuit can be generated by CNN cells", IEEE Trans. Circuits& Syst.-I, 42, (2), pp.123-125, 1995.

[5] R. Caponetto, M. Criscione, L. Fortuna, D. Ochipinti, and L. Occhipinti, "Programmable chaos generator, based on CNN architectures, with applications in chaotic communications", Proc. of CNNA'98, pp. 124-129, 14-17 April, London, England, 1998.

[6] R. Kılıç, M. Alçı and E. Günay, "A SC-CNN-based chaotic masking system with feedback", Int. J. Bifurcation and Chaos, 14, (1), pp. 245-256, 2004.

[7] E. Günay, M. Alçı, R. Kılıç, "A Chaos Synchronization Study: Continuous & Impulsive Synchronization Between SC-CNN-Based Circuit and Chua's Circuit", Proceeedings of the 2003 Workshop on Nonlinear Dynamics of Electronic Systems, pp.97-100, 2003.

[8] M. Higashimura, "Realisation of Current-Mode Transfer Function Using Four-Terminal Floating Nullor", Electronic Letters, Vol. 27, no.2, pp. 170-171, 1991.

[9] M.T. Abuelma'atti, H.A. Al-Zaher, "Current- Mode Sinusoidal Oscillators Using Two FTFNs", Proc. Natl. Sci. Counc. ROC(A), Vol. 22, No. 6, pp. 758-764, 1998.

[10] I.A. Awad and A.M. Soliman, "Inverting Second Generation Current Conveyors: the missing building blocks, CMOS realizations and applications", Int. Journal of Electronics, 86, (4), pp. 413-432,1999.

[11] A.M. Soliman, "Generation of Current Conveyor-Based All-Pass Filters From Op Amp-Based Circuits", IEEE Transaction on Circuit Systems-II:Analog and Digital Signal Processing, 44, 324-330, 1997.

[12] U. Çam & H. Kuntman, "A new CMOS realization of four terminal floating nullor (FTFN)", Int. Journal of Electronics, 87, (7), pp. 809-817, 2000.

[13] L. Odess, H. Ur, "Nullor Equivalent Networks of Nonideal Operational Amplifiers and Voltage-Controlled Sources", IEEE Transactions on Circuits and Systems, 27, pp. 231-235, 1980.

[14] R. Kılıç, U. Çam, M. Alçı, H. Kuntman, E. Uzunhisarcıklı, "Realization of Inductorless Chua's Circuit Using FTFN-Based Nonlinear Resistor and Inductance Simulator", Frequenz, 58, 1-2, pp. 1-4, 2004.

[15] R. Kılıç, "Chaos Synchronization in SC-CNN-Based Circuit and an Interesting Investigation: Can A SC-CNN-Based Circuit Behave Synchronously With The Original Chua's Circuit?", Int. J. Bifurcation and Chaos, 14, (3), pp. 1071-1083, 2004.