Trends in Applied Sciences Research, 2012
ISSN 1819-3579 / DOI: 10.3923/tasr.2012.
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OpAmp-, CFOA- and OTA-Based Configurations to Design Multi-Scroll Chaotic Oscillators

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ABSTRACT

Continuous time chaotic oscillators have been implemented by using several commercially available electronic devices. In this study, the generic circuit topologies based on Operational Amplifier (OpAmp), Current-Feedback Operational Amplifier (CFOA) and Operational Transconductance Amplifier (OTA), are summarized. These topologies allows an electronic designer to realize chaotic oscillators modeled with piecewise-linear functions, as it is shown herein by designing saturated function series.

Key words: Multi-scroll, chaotic oscillator, circuit synthesis, operational amplifier, current-feedback operational amplifier, operational transconductance amplifier

INTRODUCTION

Nowadays, a wide number of publications dealing with chaotic oscillators and their electronic realizations have been introduced by Carbajal-Gomez *et al.* (2011) Elabbasy and El-Dessoky (2008), Fatehi Marj *et al.* (2009); Gonzales *et al.* (2000), Munoz-Pacheco and Cuautle (2009, 2010), Sanchez-Lopez *et al.* (2008, 2010, 2011), Tlelo-Cuautle (2011a, b) and Trejo-Guerra *et al.* (2009, 2010a-c, 2011). Among the active devices used in their implementation one can found operational amplifiers (OpAmps) (Munoz-Pacheco and Tlelo-Cuautle, 2009, 2010), unity-gain cells (Duarte-Villasenor *et al.*, 2011; Sanchez-Lopez *et al.*, 2008), current conveyors (Sanchez-Lopez *et al.*, 2010; Ahmed and Soliman, 2011; Tlelo-Cuautle *et al.*, 2010b; Trejo-Guerra *et al.*, 2009), Current-Feedback Operational Amplifiers (CFOAs) (Carbajal-Gomez *et al.*, 2011; Trejo-Guerra *et al.*, 2010c) and Operational Transconductance Amplifiers (OTAs) (Garcia-Ortega *et al.*, 2007; Gonzales *et al.*, 2000). All these active devices can enhance the performances of the chaotic oscillators, when they are designed at the transistor level of abstraction, e.g., using metal-oxide-semiconductor field-effect-transistors (MOSFETs) (Duarte-Villasenor *et al.*, 2011; Ibrahim *et al.*, 2011; Rashtian *et al.*, 2008; Riyadi *et al.*, 2010; Tlelo-Cuautle *et al.*, 2010a; Trejo-Guerra *et al.*, 2011, 2010a). Unfortunately, very few information on the generic topologies being used in the realization of chaotic oscillators can be found in the literature. That way, this article summarizes the OpAmp-, CFOA- and OTA-based generic topologies used in the implementation of chaotic oscillators modeled by Piecewise-linear (PWL) functions. Some related works based on saturated function series can be found by Carbajal-Gomez *et al.* (2011), Munoz-Pacheco and Tlelo-Cuautle (2009, 2010); Sanchez-Lopez *et al.* (2010, 2011), Tlelo-Cuautle (2011a, b) and Trejo-Guerra *et al.* (2010b, c).

OPAMP-, CFOA- AND OTA-BASED GENERIC TOPOLOGIES

The OpAmp is a two-port device whose ideal behavior is described by:

$$v_{out} = A_v(v_{in+} - v_{in-}) \tag{1}$$

where, A_v is the voltage-gain and v_{in+} and v_{in-} are the noninverting and inverting inputs. The CFOA has four terminals X, Y, Z and W (Duarte-Villasenor *et al.*, 2011; Tlelo-Cuautle *et al.*, 2010b). Y is an input port driving voltage, X is a bidirectional port sensing voltage from Y to X ($v_x = v_y$) and injecting current from X to Z ($i_z = i_x$). Z is a bidirectional port as X but sensing current from X to Z and injecting voltage from Z to W ($v_w = v_z$). W is an output port measuring voltage from Z. The OTA processes voltage to current. The transfer characteristic is denoted by the transconductance g_m (Garcia-Ortega *et al.*, 2007).

In Table 1-4, we summarize the generic topologies for realizing linear operations.

The saturated function series can be modeled by PWL functions (Munoz-Pacheco and Tlelo-Cuautle, 2009, 2010). For instance, Eq. 1 is a PWL approximation of a saturated function serie, as already shown by Carbajal-Gomez *et al.* (2011), Munoz-Pacheco and Tlelo-Cuautle (2009, 2010) and Trejo-Guerra *et al.* (2010b, c):

$$f(x;k,h,p,q) = \begin{cases} (2q+1)k & x > qh+1 \\ k(x-ih)+2ik & |x-ih| \le 1, -p \le i \le q \\ (2i+1)k & ih+1 < x < (i+1)h-1, -p \le i \le q-1 \\ -(2p+1)k & x < -ph-1 \end{cases} \tag{2}$$

Using the finite gain model of the OpAmp, as shown in Fig. 1 (Munoz-Pacheco and Tlelo-Cuautle, 2010), Eq. 2 can be implemented using electronic devices. The description of Fig. 1 is given by Eq. 3. Equation 4 describes a negative shift operation, requiered to generate the saturated functions. Some circuit realizations of PWL functions are already given by

Table 1: OPAMP-, CFOA- and OTA-based inverter.

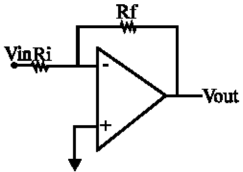
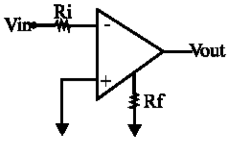
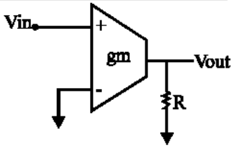
		
$v_{out} = -\frac{R_f}{R_i} v_{in}$	$v_{out} = -\frac{R_f}{R_i} v_{in}$	$v_{out} = g_m R v_{in}$

Table 2: OPAMP-, CFOA- and OTA-based integrator

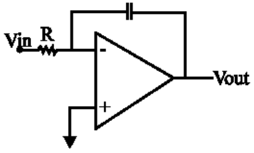
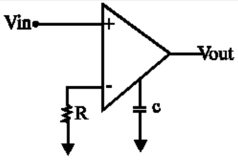
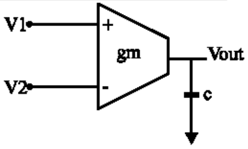
		
$v_{out} = -\frac{1}{RC}\int v_{in}\,dt$	$v_{out} = \frac{1}{RC}\int v_{in}\,dt$	$v_{out} = \frac{g_m}{C}\int (v_1 - v_2)\,dt$

Table 3: OPAMP-, CFOA- and OTA-based adder

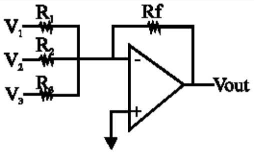
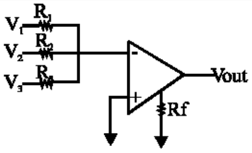
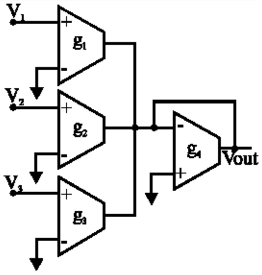
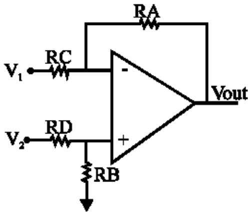
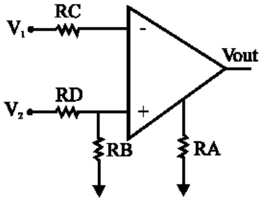
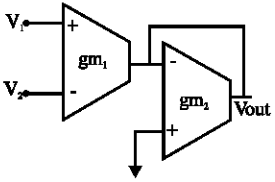
		
$v_{out} = -R_f(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3})$	$v_{out} = -R_f(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3})$	$v_{out} = \frac{1}{g_4}(g_1 v_1 + g_2 v_2 + g_3 v_3)$

Table 4: OPAMP-, CFOA- and OTA-based subtractor

		
If RA = RB = RC = RD, then	If RA = RB = RC = RD then	
$v_{out} = v_2 - v_1$	$v_{out} = v_2 - v_1$	$v_{out} = \frac{g_{m1}}{g_{m2}}(v_1 - v_2)$

Basic topologies to implement saturated function series

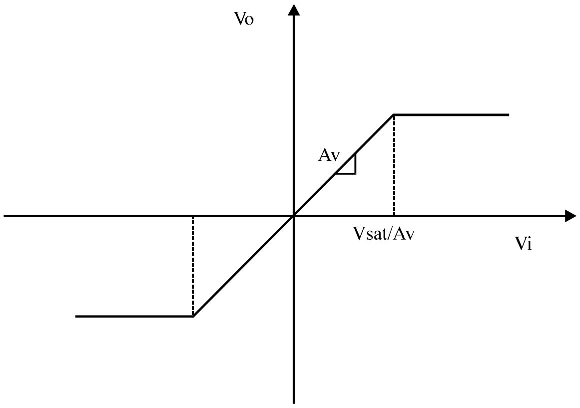


Fig. 1: Finite gain behavior of the OpAmp

Carbajal-Gomez *et al.* (2011), Munoz-Pacheco and Tlelo-Cuautle (2010), Sanchez-Lopez *et al.* (2010), Tlelo-Cuautle (2011a, b) and Trejo-Guerra *et al.* (2010c):

$$v_0 = \frac{Av}{2}\left(\left|vi + \frac{Vsat}{Av}\right| - \left|vi - \frac{Vsat}{Av}\right|\right) \tag{3}$$

$$Vo = \frac{Av}{2}\left(\left|Vi + \frac{Vsat}{Av} + E\right| - \left|Vi - \frac{Vsat}{Av} + E\right|\right) \tag{4}$$

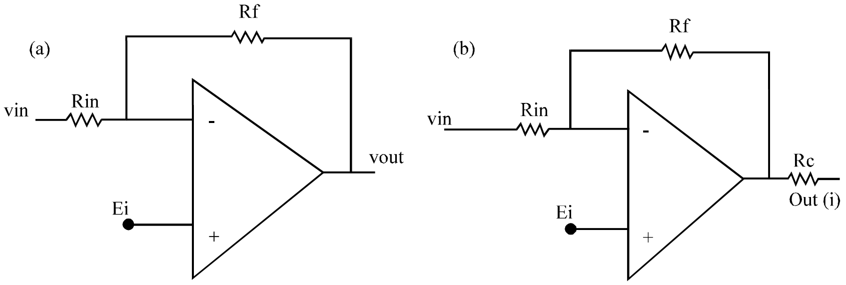


Fig. 2(a-b): (a) OpAmp basic cell and (b) Transforming voltage to current through R_c

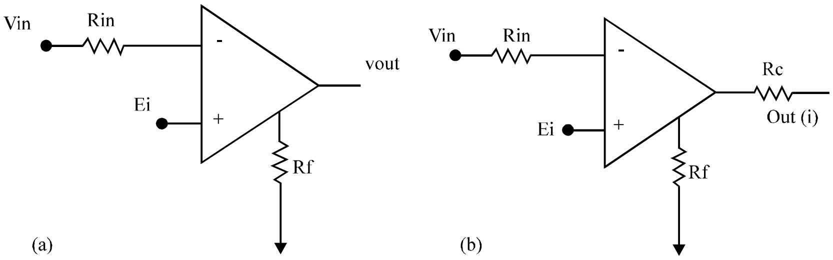


Fig. 3(a-b): (a) CFOA basic cell and (b) Transforming voltage to current through R_c

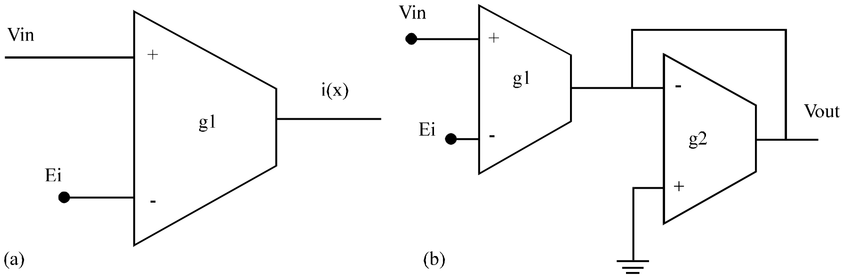


Fig. 4(a-b): (a) OTA basic cell and (b) Transforming voltage to voltage through g_2

The basic cell to implement the saturated function series using OpAmps is shown in Fig. 2, where, E_i indicates positive or negative shift described by E in Eq. 3 (Munoz-Pacheco and Tlelo-Cuautle, 2010). The basic cell to implement the saturated function series using CFOA and OTA are shown in Fig. 3 and 4, respectively. For the last case, the basic cell in Fig. 4(a), i(x) denotes the output current I_o which is described by:

$$Io = \frac{g_m}{2}\left(\left|Vi + \frac{Isat}{g_m} + E\right| - \left|Vi - \frac{Isat}{g_m} + E\right|\right) \tag{5}$$

SCROLLS CHAOTIC OSCILLATOR

Here, we just review the realization of multi-scroll chaotic oscillators from (Tlelo-Cuautle, 2011a, b). Lets us consider the dynamical system described by the state equations (Chattopadhyay *et al.*, 2011; Munoz-Pacheco and Tlelo-Cuautle, 2009, 2010), given by Eq. 5, where, f (x: k, h, p, q) is defined by Eq. 1 and x, y and z are the state variables, with a = b = c = d = real positive constants.

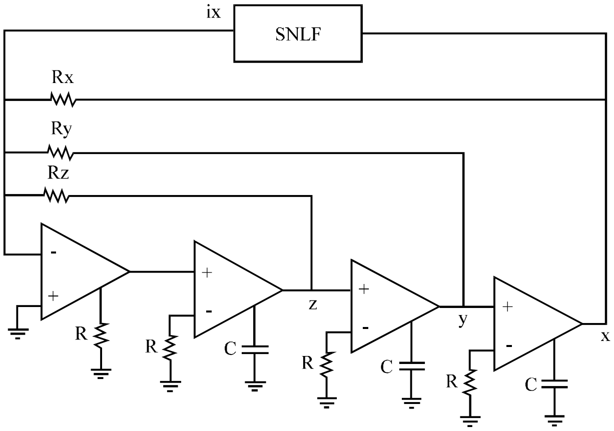


Fig. 5: Multi-scroll chaotic oscillator implemented with CFOAs

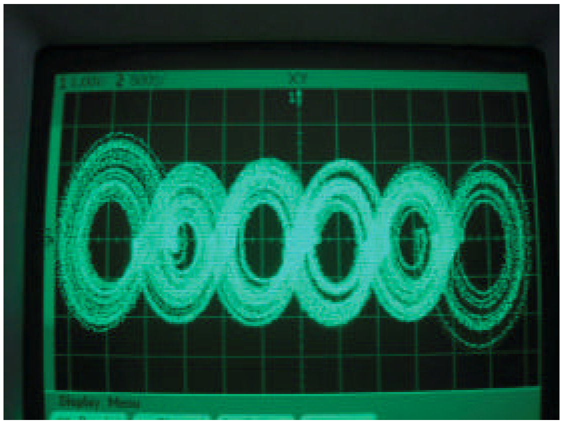


Fig. 6: 6-scrolls attractor from Fig. 5

$$\begin{aligned}\dot{x} &= y\\ \dot{y} &= z\\ \dot{z} &= -ax - by - cz + df\left(x;k,h,p,q\right)\end{aligned} \tag{5}$$

The CFOA-based realization is shown in Fig. 5, where the PWL function named SNLF is implemented using the basic cell shown in Fig. 3. The experimental result is shown in Fig. 6. This chaotic oscillator can be used to implement secure communication systems as the ones designed and shown by Carbajal-Gomez *et al.* (2011), Gonzales *et al.* (2000), Munoz-Pacheco and Tlelo-Cuautle (2010); Tlelo-Cuautle (2011a, b) and Trejo-Guerra *et al.* (2009).

CONCLUSION

This study was devoted to show the generic circuit topologies based on OpAmps, CFOAs and OTAs and used in the design of multi-scroll chaos generators. The realization of saturated functions series was also described by using the three active devices, from a PWL function approach. As a result, an electronic designer has at his disposal three kinds of circuit topology realizations of multi-scroll chaotic oscillators.

ACKNOWLEDGMENTS

This study is partially supported by UATLXPTC-088 and UPPUE-PTC-033 funded by PROMEP-México, 131839Y funded by CONACyT and by project TIC-2532 funded by Consejería de Innovación, Ciencia y Empresa, Junta de Andalucía, Spain.

REFERENCES

Ahmed and M. Soliman, 2011. Generalized, floating and self adjoint differential voltage current conveyor. Trends Applied Sci. Res., 6: 700-709.

Carbajal-Gomez, V.H., E. Tlelo-Cuautle, R. Trejo-Guerra, C. Sanchez-Lopez and J.M. Munoz-Pacheco, 2011. Experimental synchronization of multiscroll chaotic attractors using current-feedback operational amplifiers. Nonlinear Sci. Lett. B: Chaos, Fractal Synchronization, 1: 37-42.

Chattopadhyay, A.B., A. Choudhury and A. Nargund, 2011. State variable model of a solar power system. Trends Applied Sci. Res., 6: 563-579.

Duarte-Villasenor, M.A., E. Tlelo-Cuautle and L.G. de la Fraga, 2011. Binary genetic encoding for the synthesis of mixed-mode circuit topologies. Circuits, Syst. Signal Process., 10.1007/s00034-011-9353-2

Elabbasy, E.M. and M.M. El-Dessoky, 2008. Synchronization and adaptive synchronization of hyperchaotic Lu dynamical system. Trends Applied Sci. Res., 3: 129-141.

Fatehi Marj, H., R. Asgharian and N. Pariz, 2009. Adaptive control of chaotic rossler system via synchronization. Trends Applied Sci. Res., 4: 98-106.

Garcia-Ortega, J.M., E. Tlelo-Cuautle and C. Sanchez-Lopez, 2007. Design of current-mode Gm-C filters from the transformation of opamp-RC filters. J. Applied Sci., 7: 1321-1326.

Gonzales, O.A., G. Han, J.P. de Gyvez and E. Sanchez-Sinencio, 2000. Lorenz-based chaotic cryptosystem: A monolithic implementation. IEEE Trans. Circuits Syst. Fundamental Theory Appl., 47: 1243-1247.

Ibrahim, A.A., A.R.A. Aziz, E.Z.Z. Abidin and S.A. Zulkifli, 2011. The operation of free piston linear generator engine using MOSFET and IGBT drivers. J. Applied Sci., 11: 1791-1796.

Munoz-Pacheco, J.M. and E.Tlelo-Cuautle, 2009. Automatic synthesis of 2D-n-scrolls chaotic systems by behavioral modeling. J. Applied Res. Technol., 7: 5-14.

Munoz-Pacheco, J.M. and E. Tlelo-Cuautle, 2010. Electronic Design Automation of Multi-Scroll Chaos Generators. Bentham Sciences Publishers, Dubai, UAE., eISBN: 978-1-60805-165-6.

Rashtian, M., O. Hashemipour and K. Navi, 2008. Design of a low-voltage high-speed switched-capacitor filters using improved auto zeroed integrator. J. Applied Sci., 8: 1771-1775.

Riyadi, M.A., J.E. Suseno and R. Ismail, 2010. The future of non-planar nanoelectronics MOSFET devices: A review. J. Applied Sci., 10: 2136-2146.

Sanchez-Lopez, C., A. Castro-Hernandez and A. Perez-Trejo, 2008. Experimental verification of the Chuas circuit designed with UGCs. IEICE Electron. Express, 5: 657-661.

Sanchez-Lopez, C., R. Trejo-Guerra, J.M. Munoz-Pacheco and E. Tlelo-Cuautle, 2010. N-scroll chaotic attractors from saturated functions employing CCII+s. Nonlinear Dynamics, 61: 331-341.

Sanchez-Lopez, C., J.M. Munoz-Pacheco, E. Tlelo-Cuautle, V.H. Carbajal-Gomez and R. Trejo-Guerra, 2011. On the trade-off between the number of scrolls and the operating frequency of the chaotic attractors. Proceedings of the IEEE International Symposium on Circuits and Systems, May 15-18, 2011, Rio de Janeiro, Brazil, pp: 2950-2953.

Tlelo-Cuautle, E., I. Guerra-Gomez, M.A. Duarte-Villasenor, L.G. de la Fraga and G. Flores-Becerra *et al.*, 2010a. Applications of evolutionary algorithms in the design automation of analog integrated circuits. J. Applied Sci., 10: 1859-1872.

Tlelo-Cuautle, E., C. Sanchez-Lopez and D. Moro-Frias, 2010b. Symbolic analysis of (MO)(I)CCI(II)(III)-based analog circuits. Int. J. Circuit Theory Appl., 38: 649-659.

Tlelo-Cuautle, E., 2011a. Analog Circuits: Applications, Design and Performance. Nova Science Publishers, Inc., New York, ISBN: 9781613243558.

Tlelo-Cuautle, E., 2011b. Chaotic Systems. InTech Publisher, USA., ISBN: 978-953-307-564-8, Pages: 310.

Trejo-Guerra, R., E. Tlelo-Cuautle, C. Cruz-Hernandez and C. Sanchez-Lopez, 2009. Chaotic communication system using Chua's oscillators realized with CCII+s. Int. J. Bifurcations Chaos, 19: 4217-4226.

Trejo-Guerra, R., E. Tlelo-Cuautle, C. Sanchez-Lopez, J.M. Munoz-Pacheco and C. Cruz-Hernandez, 2010a. Realization of multiscroll chaotic attractors by using current-feedback operational amplifiers. Revista Mexicana de Fisica, 56: 268-274.

Trejo-Guerra, R., E. Tlelo-Cuautle, J.M. Munoz-Pacheco, C. Cruz-Hernandez and C. Sanchez-Lopez, 2010b. Operating Characteristics of MOSFETs in Chaotic Oscillators. In: Transistors: Types, Materials and Applications, Fitzgerald B.M. (Ed.). NOVA Science Publishers Inc., New York, pp: 97-118.

Trejo-Guerra, R., E. Tlelo-Cuautle, J.M. Munoz-Pacheco, C. Sanchez-Lopez and C. Cruz-Hernandez, 2010c. On the relation between the number of scrolls and the Lyapunov exponents in PWL-functions-based n-scroll chaotic oscillators. Int. J. Nonlinear Sci. Numer. Simul., 11: 903-910.

Trejo-Guerra, R., E. Tlelo-Cuautle, M. Jimenez-Fuentes, J.M. Munoz-Pacheco and C. Sanchez-Lopez, 2011. Multiscroll floating gate based integrated chaotic oscillator. Int. J. Circuit Theory Appl., DOI: 10.1002/cta.821.