Chaos in Modified CFOA-Based Inductorless Sinusoidal Oscillators Using a Diode

Buncha Munmuangsaen and Banlue Srisuchinwong

Sirindhorn International Institute of Technology, Thammasat University
Pathum-Thani 12000, Thailand
E-mail: banlue@siit.tu.ac.th

Abstract: Two modified inductorless sinusoidal oscillators are presented as two chaotic oscillators. The active component employs a current-feedback operational amplifier (CFOA) whereas the nonlinear component employs a simple diode. Numerical and PSpice simulations are demonstrated in terms of chaotic attractors. A bifurcation diagram is also included.

Keywords: Chaos, Nonlinear circuit and system, RC oscillator.

1. Introduction

The design and development of autonomous chaotic oscillators over the past three decades have been increasing due to a variety of applications in, for example, spacecraft trajectory control, stabilization of the intensity of a laser beam, noise radars and sonar [1], synchronization [2, 3] and secure communications [4, 5, 6]. One of the best known chaotic circuits is Chua's circuit [7] as well as its variants [8, 9], using a Chua's diode. However, an active nonlinear resistor such as the Chua's diode is not recommended by [10] because it does not follow the design rules of [10]. Instead, a passive nonlinear component for chaos has been suggested using either a diode or a junction field effect transistor (JFET) [10].

A current-feedback operational amplifier (CFOA) is currently recognized as a versatile alternative to the traditional op amp for its excellent performance in high-speed and high slew-rates analog signal processing, and therefore does not suffer from the finite gain bandwidth product typically encountered in the conventional voltage op amps [11]. A chaotic oscillator has been designed using a modified CFOA-based sinusoidal oscillator with two capacitors and an inductor for a third-order chaotic system [11]. Such a chaotic oscillator has subsequently been further investigated by [12] using three capacitors. The nonlinear device of both chaotic oscillators has exploited a two-terminal nonlinear resistor formed by a JFET (J2N4338). However, chaos has not successfully found in [12] using a single diode as a nonlinear component.

In this paper, chaos in two modified CFOA-based inductorless sinusoidal oscillators is presented. The active element employs the CFOA whereas the

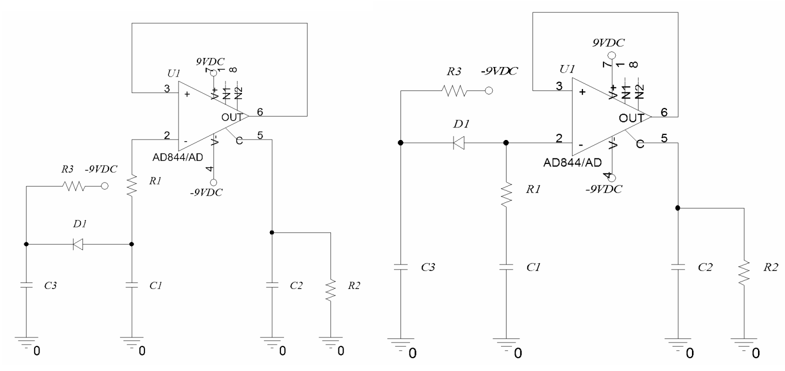
Received: 5 April 2012 / Accepted: 8 October 2012

ISSN 2241-0503

nonlinear component employs a single diode. Chaos can be found by replacing a JFET resistor of [12] with a sub-circuit consisting of a diode and a resistor.

2. Circuit Implementation

Figures 1(a) and 1(b) show two proposed chaotic oscillators using a single diode as a nonlinear device. Both circuits are modified CFOA-based inductorless sinusoidal oscillators which almost resemble the existing circuits reported in [12], except that the JFET nonlinearity of [12] is replaced with a new sub-circuit consisting of a diode D_1 and a resistor R_3. The latter is connected to a negative DC supply.



(a) (b)

Fig. 1 Modified CFOA-based inductorless sinusoidal oscillators using a diode for : (a) the first chaotic oscillator, (b) the second chaotic oscillator.

The proposed chaotic oscillator shown in Figure 1(a) is described by a set of differential equations as follows :

$$
\begin{aligned}
C_1\dot{V}_{C1} &= \left(\frac{V_{C2}-V_{C1}}{R_1}\right)-I_D \\
C_2\dot{V}_{C2} &= \left(\frac{V_{C2}-V_{C1}}{R_1}\right)-\frac{V_{C2}}{R_2} \\
C_3\dot{V}_{C3} &= I_D-\left(\frac{V_{C3}+9}{R_3}\right)
\end{aligned}
\tag{1}
$$

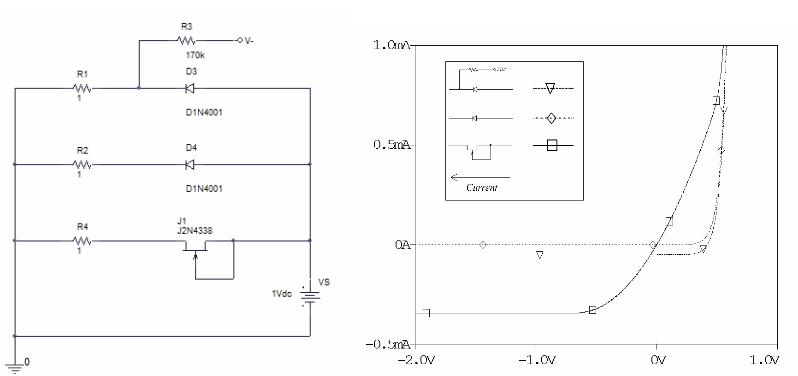
where the overdot denotes a time (t) derivative. The voltages across capacitors C_1, C_2, and C_3 are V_{C1}, V_{C2}, and V_{C3}, respectively. A diode current $I_D = I_S\{exp[(V_{C1}-V_{C3})/nV_T] - 1\}$ where I_S is the reverse saturation current, n is the nonideality factor, and V_T is the thermal voltage of 25.85 mV at room temperature (300K). The proposed chaotic oscillator shown in Figure 1(b) is described by another set of differential equations as follows:

$$
\begin{aligned}
C_1\dot{V}_{C1} &= \frac{V_{C2}-V_{C1}}{R_1} \\
C_2\dot{V}_{C2} &= \left(\frac{V_{C2}-V_{C1}}{R_1}\right)-\left(\frac{V_{C2}}{R_2}\right)+I_D \\
C_3\dot{V}_{C3} &= I_D-\left(\frac{V_{C3}+9}{R_3}\right)
\end{aligned}
\tag{2}
$$

where the diode current $I_D = I_S\{exp[(V_{C2}-V_{C3})/nV_T] - 1\}$

3. Simulation Results

The CFOA can be implemented using the commercially available AD844. The diode D_1 is 1N4001 using PSpice parameters $I_S = 14.11\times10^{-9}$ A and n = 1.984. The junction capacitance of 1N4001 is typically 15 pF and, for simplicity, may be neglected compared to the much larger values of C_1, C_2 and C_3. For a PSpice simulation, Figure 2(a) shows a circuit diagram of (*i*) a diode circuit (D_4, R_2), (*ii*) a nonlinear JFET resistor (J_1, R_4), and (*iii*) a sub-circuit consisting of a diode and resistors (D_3, R_1, R_3). Figure 2(b) shows a comparison of the three simulation results of current-voltage characteristics in (*i*), (*ii*) and (*iii*) where the currents on the vertical axis are through R_2, R_4 and R_1, respectively, and the voltage on the horizontal axis is *Vs*, which is swept linearly from -2V to +1V with an increment of 0.01 V. It should be noted that the current in (*i*) is always positive whereas the current in (*ii*) can be either positive or negative. This may probably be the reason why the authors in [12] could not find chaos in their proposed oscillators using only a diode in (*i*). With a new sub-circuit in (*iii*), the current in (*iii*) can be either positive or negative, as shown in Figure 2, and chaos can be quickly found without changing the connections of other components.



(a) (b)

Fig. 2 (a) A circuit diagram of three circuits using (*i*) a diode circuit (D_4, R_2), (*ii*) a nonlinear JFET resistor (J_1, R_4), and (*iii*) a sub-circuit consisting of a diode and resistors (D_3, R_1, R_3), (b) A comparison of three simulation results.

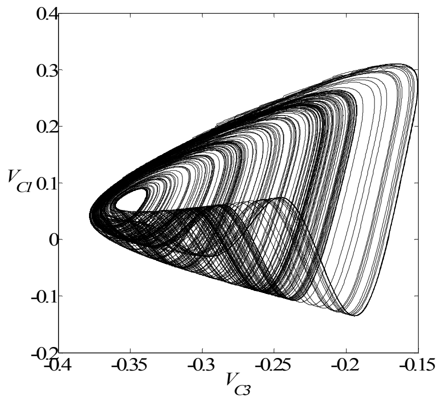


Fig. 3. A numerical result of a chaotic attractor projected onto $V_{C3}-V_{C1}$ plane of equation (1).

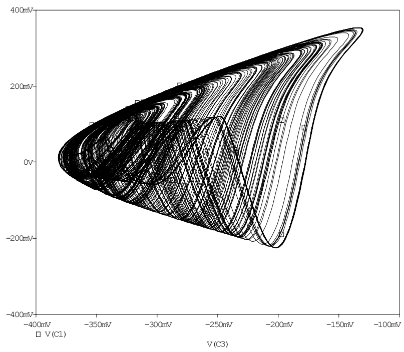


Fig. 4. A PSpice simulation of a chaotic attractor projected onto $V_{C3}-V_{C1}$ plane of the oscillator shown in Figure 1(a).

Figure 3 shows a numerical result of a chaotic attractor projected onto a $V_{C3}-V_{C1}$ plane of equation (1) using a fourth-order Runge-Kutta integrator with a fixed step size of 0.1μs. The same values of components reported in [12] are used except R_3, i.e. $C_1 = C_2 = 10$ nF, $C_3 = 18$ nF, $R_1 = 220\ \Omega$, $R_2 = 1.5$ kΩ, and $R_3 = 170$ kΩ. Figure 4 shows a PSpice simulation of a chaotic attractor projected onto $V_{C3}-V_{C1}$ plane of the oscillator shown in Figure 1(a) with the same values of components reported in [12] except $R_3 = 180$ kΩ. As shown in Figure 4, the PSpice simulation runs up to 30 ms with a fixed step size of 0.5 μs. The results in the first 20 % are discarded to ensure that the solution is on the attractor. Initial conditions are $(V_{C1}, V_{C2}, V_{C3})_{t=0} = (0, 0, 0)$. The numerical and PSpice results are in a similar manner.

It can be seen from Figures 1(a) and 1(b) that R_3 is connected in series with the diode D_1. This enables R_3 to control the current of D_1 in DC operation (by opening C_1, C_2, and C_2). Therefore R_3 can be exploited as a tunable bifurcation parameter. As an example, Figure 5 depicts a bifurcation diagram of the peak of V_{C3} (V_{C3}−max) of Figure 1(a) versus R_3 varied from 140 to 220 kΩ. A period-doubling route to chaos is evident. There are various periodic windows immersed in chaos.

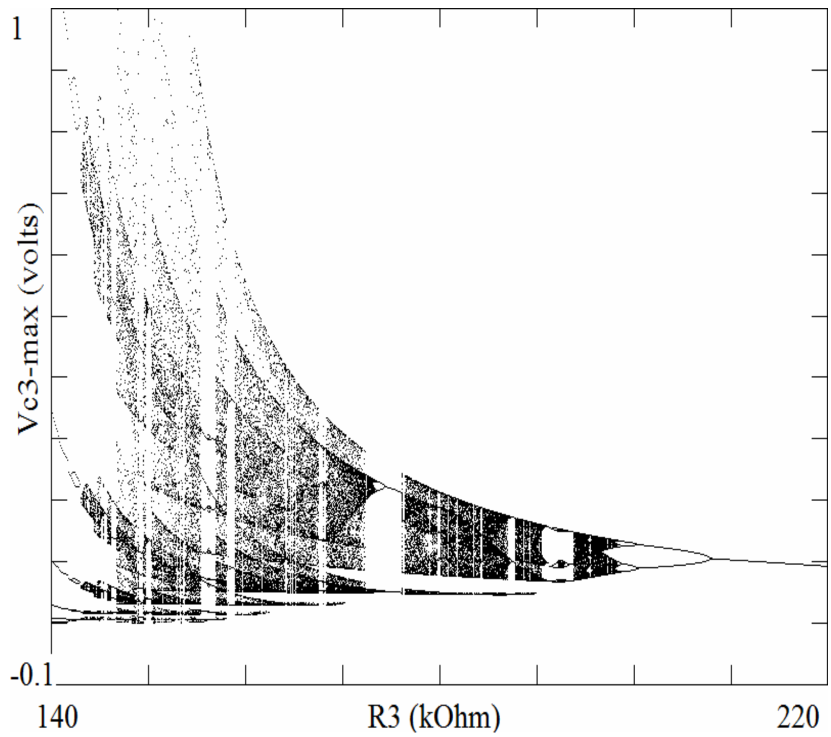


Fig. 5. A bifurcation diagram of the peak of V_{C3} of Figure 1(a).

Figure 6 shows a numerical result of a chaotic attractor projected onto a V_{C3}−V_{C2} plane of equation (2) using a fourth-order Runge-Kutta integrator with a fixed step size of 0.1μs, C_1 = 10 nF C_2 = 11 nF, C_3 =5 nF, R_1= 220 Ω, R_2 = 2.7 kΩ, and R_3 = 220 kΩ. Figure 7 illustrates a PSpice simulation of a chaotic attractor projected onto V_{C3}−V_{C2} plane of the oscillator shown in Figure 1(b) with the same values of components used in Figure 6. The PSpice simulation runs up to 20 ms with a fixed step size of 0.1 μs. The results in the first 20 % are discarded to ensure that the solution is on the attractor. Initial conditions are $(V_{C1}, V_{C2}, V_{C3})_{t=0}$ = (0, 0, 0).

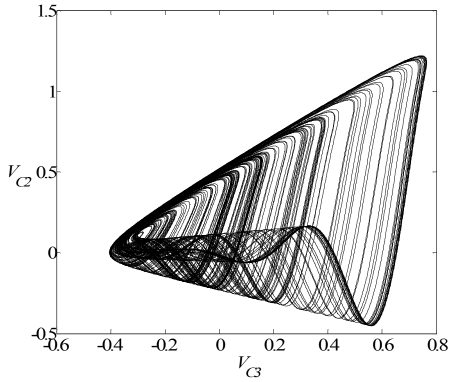


Fig. 6. A numerical result of a chaotic attractor projected onto $V_{C3}-V_{C2}$ plane of equation (2).

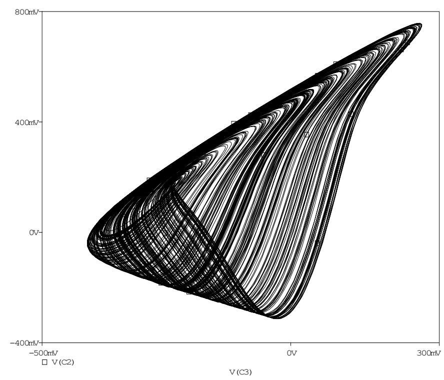


Fig. 7. A PSpice simulation of a chaotic attractor projected onto $V_{C3}-V_{C2}$ plane of the oscillator shown in Figure 1(b).

4. Conclusions

Two chaotic oscillators have been presented through the use of two modified CFOA-based inductorless sinusoidal oscillators. A CFOA has been exploited as the active component whereas a single diode has been exploited as the nonlinear component. Numerical and PSpice simulations have been demonstrated with chaotic attractors. A bifurcation diagram has been studied.

Acknowledgments: This work was supported by telecommunications research and industrial development institute (TRIDI), NBTC, Thailand (grant TARG 2553/002), and the national research university project of Thailand, office of higher education commission.

References

1. T. Kilias, K. Kelber, A. Mogel, and W. Schwarz. Electronic chaos generators−design and applications. *Int J Electron* 79: 737-753, 1995.
2. T. L. Carroll and L. M. Pecora. Synchronizing chaotic circuits. *IEEE Trans Circuits Syst* 38: 453-456, 1991.
3. B. Munmuangsaen and B. Srisuchinwong. A new Lorenz-like chaotic attractor and its synchronization. *CCDC*2009: 1508-1512, 2009.
4. K. M. Cuomo, A. V. Oppenheim and S. H. Strogatz. Synchronization of Lorenz-based chaotic circuits with applications to communications. *IEEE Trans Circuit Syst 40*: 626-633, 1993.
5. L. Kocarev, K. S. Halle, K. Eckert and L. O. Chua. Experimental demonstration of secure communications via chaotic synchronization. *Int J Bifurcat Chaos* 2: 709-713,1992.
6. B. Srisuchinwong, B. Munmuangsaen. A highly chaotic attractor for a dual-channel single-attractor, private communication system. In: C. H. Skiadas, I. Dimotikalis and C. Skiadas, Eds, *Chaos Theory: Modeling, Simulation and Applications: Selected Papers from the CHAOS2010 International Conference.* World Scientific, Singapore, pp. 399-405, 2011.
7. L. Fortuna, M. Frasca, and M. G. Xibilia. Chua's *Circuit Implementations: Yesterday, Today and Tomorrow,* World Scientific, Singapore, 2009.
8. E. Bilotta and P. Pantano. *A Gallery of Chua Attractors*, World Scientific, Singapore, 2008.
9. L. O. Chua and G. Lin. Canonical realization of Chua's circuit family. *IEEE Trans Circuits Syst* 37: 885-902, 1990.
10. A. S. Elwakil and M. P. Kennedy. A semi-systematic procedure for producing chaos from sinusoidal oscillators using diode-inductor and FET-Capacitor composites. *IEEE Trans Circuits Syst* 47: 582-590, 2000.
11. A. S. Elwakil and M. P. Kennedy. Chaotic oscillator derived from sinusoidal oscillator based on the current feedback op amp. *Analog Integ Circuits Signal Proc* 24: 239-251, 2000.
12. P. Bernát and I. Baláž. RC autonomous circuit with chaotic behaviour. *Radioengineering* 11: 1-5, 2002.