CHAOS
Theory and Applications
in Applied Sciences and Engineering

e-ISSN: 2687-4539
RESEARCH ARTICLE
Vol.5 / No.1 / 2023 / pp.52-58
https://doi.org/10.51537/chaos.1204681

A Lorenz-like Chaotic OTA-C Circuit and Memristive Synchronization

Şule Zeynep Aydın [*,1], **Gökçe Nur Beken** [β,2] **and Zehra Gülru Çam Taşkıran** [§,3]

[*]Department Electrical Electronics Engineering, Marmara University, Istanbul, Türkiye, [β]Department Electrical Electronics Engineering, İstanbul Yeni Yüzyıl University, Istanbul, Türkiye, [§]Department Electronics and Communications Engineering, Yıldız Technical University, Istanbul, Türkiye.

ABSTRACT In this paper, a new set of lorenz-like hyper-chaotic equation set is obtained using the anti-control procedure. The chaoticity of the system is verified by MATLAB simulations using mathematical analysis methods. A new OTA-C circuit is designed for the new equation set. In the difference term addition technique, synchronizing the OTA-C circuit with a memristor rather than a resistor is proposed. Circuit design and synchronization are performed in PSpice simulation. The fact that the transconductance of the OTA element can be easily adjusted with a bias current provides the parameters that will make the proposed dynamic circuit a chaotic oscillator. The advantage of the proposed synchronization method is that the memristor automatically reaches the value that will provide the required weight of the differential term required for synchronization, rather than the computational methods used to determine the weight.

KEYWORDS
New chaotic system
Control parameter
Operational transconductance amplifier
Synchronization
Memristor

INTRODUCTION

Chaotic systems are nonlinear systems highly sensitive to initial conditions. It is important to create new chaotic systems due to their widespread use in secure communication, cryptography, chemical reactions, etc. In 1963, the first chaotic attractor was found by Lorenz (1963). Following that, Rössler (1976), Rabinovich and Fabrikant (1979), and Chua *et al.* (1993b) generated new chaotic equations. Many different methods have been used while producing new chaotic systems. Generating a new chaotic equation set with the control parameter method is a widely used method Deng *et al.* (2014); Zhou *et al.* (2008); Lü *et al.* (2002).

Chua's chaotic circuit design with memristor pioneered the work of chaotic circuit design. Later, in most studies, chaotic circuit design was made using the operational amplifier (OPAMP) component Fan *et al.* (2019); Sundarapandian and Pehlivan (2012); Pappu *et al.* (2017); Pehlivan and Uyaroğlu (2010); Lai *et al.* (2017); Akgul *et al.* (2016); Cao and Zhao (2021). Only a few studies on circuit implementation of the chaotic system are based on OTA Karawanich and Prommee (2022); Yildirim (2022). The advantage of OTA over OPAMP component is its high output impedance, wide band gap, and transconductance gain which can be changed with bias current. This provides an important advantage in chaotic circuits. The chaotic circuit design with OTA presented in Karawanich and Prommee (2022); Yildirim (2022) has been designed, but there is no study on its synchronization. In this study, a simpler structure is proposed by using only OTA, capacitor, and analog multiplier.

According to Carroll and Pecora (1995), Pecora and Carrol proposed the concept of first chaos synchronization, which is the foundation of chaotic secure communication. Following that, passive components such as resistors, inductors, and capacitors were used Chua *et al.* (1993a); Yao *et al.* (2020); Zhang *et al.* (2020a); Xu *et al.* (2019a); Yao *et al.* (2019). Synchronization studies are available by using active components such as Deniz *et al.* (2018); Uyaroğlu and Pehlivan (2010). Considering the important effect of the memristor in chaotic circuits, synchronization studies with memristor have become widespread in recent years. The memristor has less power consumption than other components because it is a passive component. In addition, although the memristor is nonlinear, it provides linear behavior in a certain frequency range. In this study, because of the memristor's properties, the OTA-C chaotic circuit is synchronized with the memristor.

In the literature, there is a method of synchronizing memristors by connecting them in anti-parallel. With this method, it is possible to change the receiver and transmitter, but since the structure draws current from both the receiver and transmitter sub-circuits, the original ordinary differential equation set could not be preserved on the transmitter side Gambuzza *et al.* (2015). Whereas,

Manuscript received: 15 November 2022,
Revised: 14 March 2023,
Accepted: 21 March 2023.

[1] sule.aydin@marmara.edu.tr
[2] gokcenur.beken@yeniyuzyil.edu.tr
[3] zgcam@yildiz.edu.tr (**Corresponding Author**)

in most other methods, the original equations are preserved on the transmitting side, while only different terms are involved on the receiving side. There are articles that synchronize with different connection types besides anti-parallel connection, but the same mathematical deformation is also present in them Zhang *et al.* (2020b); Escudero *et al.* (2020); Wang *et al.* (2021); Xu *et al.* (2019b).

The method proposed in this study is based on the method of adding the difference term Cuomo *et al.* (1993) which is already found in the literature, to obtain this term over the memristor rather than the resistor. Instead of finding this coefficient with an optimization algorithm and producing this term with a suitable resistor, the memristor element connected instead of the resistor, both creates this coefficient and changes its value as long as there is a synchronization error due to the error expression passing over it, and reaches the value where error-free synchronization is provided by itself. In this way, the coefficient is self-adjusted by the value change of the memristor. The researcher eliminates the time cost with this self-adaptation, and this coefficient, which can change over time due to effects such as environmental noises and aging, constantly brings itself to the required value.

OTA-C circuit is designed by using fewer components of the proposed new chaotic equation. A new contribution has been made to the literature by synchronizing the designed chaotic OTA-C circuit with the memristor. In this study, the derivation and analysis of the new set of chaotic equations are explained. Designing the OTA-C circuit of the new chaotic equation is given. The synchronization of the designed circuit with the memristor is given. Finally, the results of the study are evaluated.

A NEW SET OF CHAOTIC EQUATIONS AND ANALYSIS

A new chaotic equation is derived by applying the anti-control procedure to the Lorenz equation. The Lorenz equation is shown in the Equation 1. In the equation, $\dot{x}, \dot{y}, \dot{z}$ are state variables, σ, p, β are parameters.

$$\begin{aligned} \dot{x} &= \sigma(y - x) \\ \dot{y} &= x(p - z) - y \\ \dot{z} &= xy - \beta z \end{aligned} \tag{1}$$

The anti-control method is applied to the Lorenz equation.

$$\begin{aligned} \dot{x} &= \sigma(y - x) + u = \sigma(y - x) + l_1 x + l_2 y + l_3 z \\ \dot{y} &= x(p - z) - y \\ \dot{z} &= xy - \beta z \end{aligned} \tag{2}$$

Here, $u = 1_1 x + 1_2 y + 1_3 z$ is the linear feedback controller.

The Jacobian matrix of the Equation 2 evaluated at a random point is given in 3.

$$J = \begin{bmatrix} -\sigma + l_1 & \sigma + l_2 & l_3 \\ p & -1 & -x \\ y & x & -\beta \end{bmatrix} \tag{3}$$

l_2, l_3 do not contribute to the Lyapunov exponents of the system, since they do not contribute to the eigenvalues.

Thus, parameters are chosen as $l_2 = 1_3 = 0$. In this case, the control parameter is $u = 1_1 x$. The new Lorenz-like chaotic equation is obtained in the Equation 4.

$$\begin{aligned} \dot{x} &= \sigma(y - x) + l_1 x \\ \dot{y} &= x(p - z) - y \\ \dot{z} &= xy - \beta z \end{aligned} \tag{4}$$

The new system is chaotic when parameter values $\sigma = 10, p = 28, \beta = 8/3, l_1 = 1$. At initial conditions $x(0) = 0.9, y(0) = 0.5, z(0) = 0.1$, the attractors of the system are in Figure 1. As time passes, the orbits around this created attractor scan the entire space, never passing a point they passed. The chaotic state of the new system is investigated by time series, frequency analysis, Jacobian matrix, Lyapunov exponents, and bifurcation diagram analysis.

State variables are observed over time; state variables that exhibit irrational behavior are referred to as chaotic. The time series results of the system are given in Figure 2. Depending on its sensitivity to different initial conditions and parameter values, it can exhibit various behaviors such as equilibrium and periodicity.

The frequency spectrum of chaotic signals is continuous in a wide range. The frequency spectrum of each state variable obtained for the new chaotic system is given in Figure 3.

The jacobian matrix Equation 5 obtained from each equation in the differential equation set is given.

$$J = \begin{bmatrix} -\sigma + l_1 & \sigma + l_2 & l_3 \\ p & -1 & -x \\ y & x & -\beta \end{bmatrix} \tag{5}$$

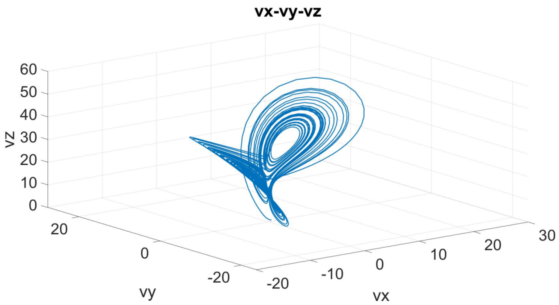
The divergence value is obtained from the jacobian matrix $\nabla V = -\sigma + l_1 - 1 - \beta = -38/3$. Since it is $\nabla V < 0$, the behavior of the system is chaotic at the right initial conditions. Lyapunov exponents are expressions of interactions and differences between trajectories of phase space characteristics formed under close initial conditions. If the largest exponent is negative, the system converges to a value over time and becomes independent of initial conditions Özer and Akın (2005). If the largest exponent is positive, the distance between the orbits increases and the system is sensitive to initial conditions, that is, chaotic. If there are multiple positive Lyapunov exponents, the system is hyperchaotic Wolf *et al.* (1985). The new system's Lyapunov exponents are shown in Figure 4. The Lyapunov exponents obtained with the parameters of the system selected as $\sigma = 10, p = 28, \beta = 8/3, l_1 = 1$ are $L_1 = 8.38652, L_2 = 0.632274, L_3 = -21.6813$. Since there are two positive Lyapunov exponents, the new set of equations is hyperchaotic.

By using Lyapunov Exponents, the Lyapunov dimension or Kaplan-Yorke dimension can be calculated as in Equation 6, Grassberger and Procaccia (1983).

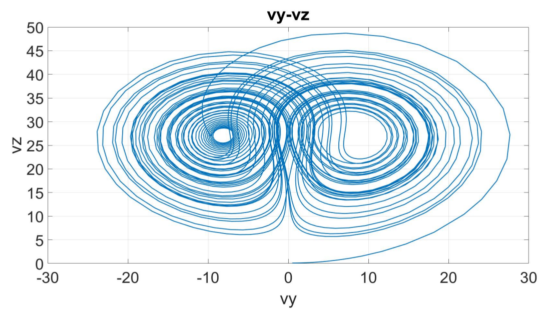
$$D_{ky} = j + \frac{1}{|L_{j+1}|} \Sigma_{i=1}^{j} L_i \tag{6}$$

j is the largest integer for witch $0 \leq L_1 + ... + L_n$. For the proposed circuit $j = 2$ and the Kaplan-Yorke dimension D_{ky} can be calculated as 7.

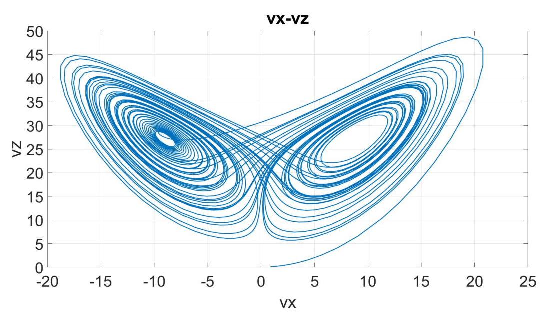
$$D_{ky} = 2 + \frac{L_1 + L_2}{|L_3|} = 2,41597 \tag{7}$$



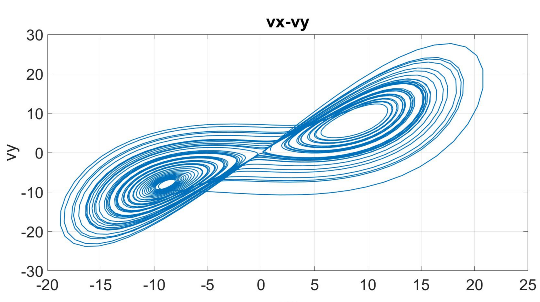
(a) $V_x - V_y - V_z$ chaotic attractor.



(b) $V_y - V_z$ chaotic attractor.



(c) $V_x - V_z$ chaotic attractor.



(d) $V_x - V_y$ chaotic attractor.

Figure 1 Phase portraits of the system

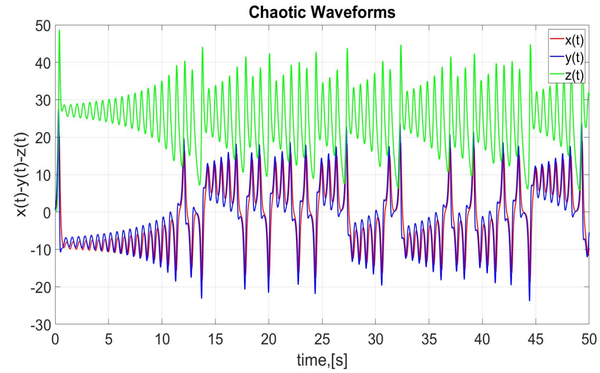


Figure 2 Time series of the system.

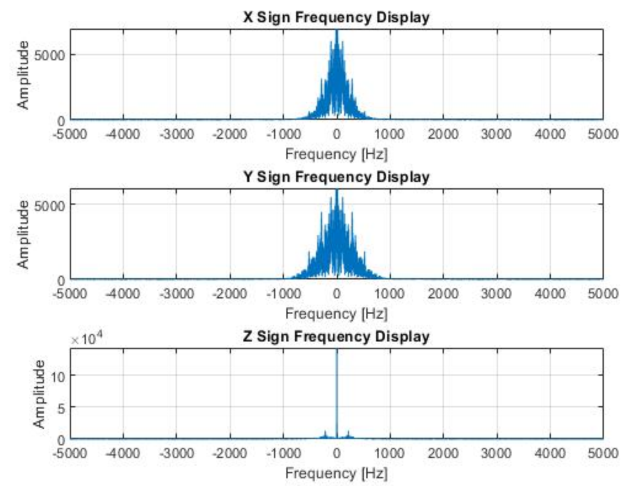


Figure 3 Frequency spectrum of the system.

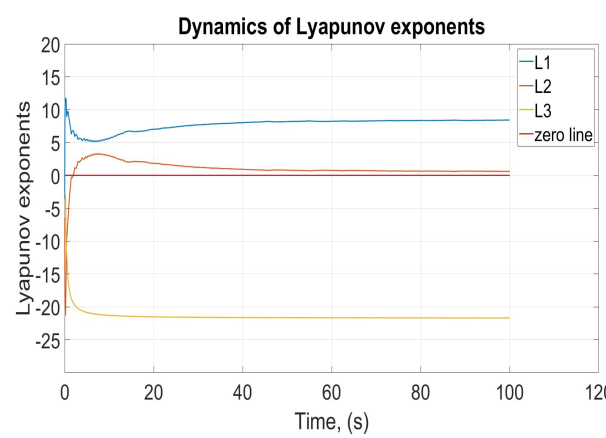


Figure 4 Lyapunov exponents of the system.

For original Lorenz system with the well-known coefficients $\sigma = 10, p = 28, \beta = 8/3$, and $L_1 = 0.054129, L_2 = 0.727225, L_3 = -14.448021$, j is also equal to 2 and the Kaplan-Yorke dimension,

$$D_{ky} = 2 + \frac{L_1 + L_2}{|L_3|} = 2,05408 \tag{8}$$

Thus, the new chaotic system has a larger Kaplan-Yorke dimension than the original Lorenz system.

The bifurcation diagram is the points at which the variables x and y intersect the equation's solution curve on the plane formed by the two variables for each value of the parameter p.The bifurcation diagram obtained for $1 < p < 350$ and initial conditions (0.9,0.5,0.1) in the new set of equations is shown in Figure 5.

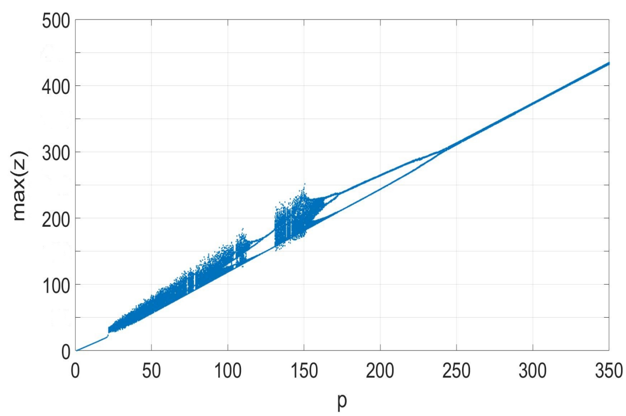


Figure 5 Bifurcation diagram of the system.

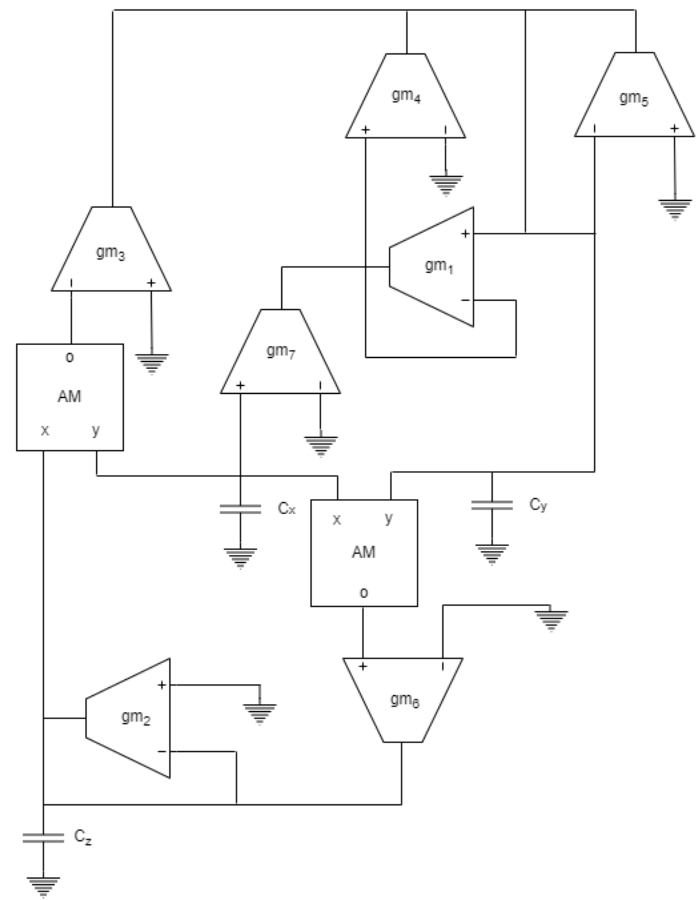


Figure 6 OTA-C chaotic circuit of the system.

OTA-C CHAOTIC CIRCUIT DESIGN

The new chaotic equation set circuit design is created using OTA, analog multiplier (AM), and capacitor components. While generating the OTA-C circuit, each chaotic state variable is represented by voltage state variables corresponding to a capacitor voltage. The expressions of the derivatives of these state variables are tried to be formed as the sum of the terms of the current magnitudes divided by the capacitor values, according to $\frac{dv_C(t)}{dt} = \frac{1}{C} i_C(t)$ and the defining equation of the OTA $I_o = g_m(V_+ - V_-)$. A circuit as in Figure 6 is obtained electrically by collecting the currents at the nodes to which the grounded capacitors are connected. The equation set with the circuit parameters is obtained in the Equation 9.

$$\begin{aligned} \frac{dV_x}{dt} &= \frac{g_{m_1}}{C_x}(V_y - V_x) + \frac{g_{m_2}}{C_x}V_x \\ \frac{dV_y}{dt} &= \frac{g_{m_3}}{C_y}V_x - \frac{kg_{m_4}}{C_y}V_xV_z - \frac{g_{m_5}}{C_y}V_y \\ \frac{dV_z}{dt} &= \frac{kg_{m_6}}{C_z}V_xV_y - \frac{g_{m_7}}{C_z}V_z \end{aligned} \tag{9}$$

Taken as $C_x = C_y = C_z = 10nF, g_{m_1} = 100\mu S, g_{m_2} = 27\mu S, g_{m_3} = 1mS, g_{m_4} = 280\mu S, g_{m_5} = g_{m_7} = 10\mu S, g_{m_6} = 1nS$.

While performing PSpice simulations of the circuit in Figure 6, the ideal OTA model realized with discrete elements and the AD633 integrated circuit macro model as analog multiplier were used. The multiplier constant of the AD633 IC is $k = 0.1$ V^{-1}. The simulation results of the voltage values of the state variables of the circuit according to time are given in Figure 7. Chaotic attractors are also shown in Figure 8.

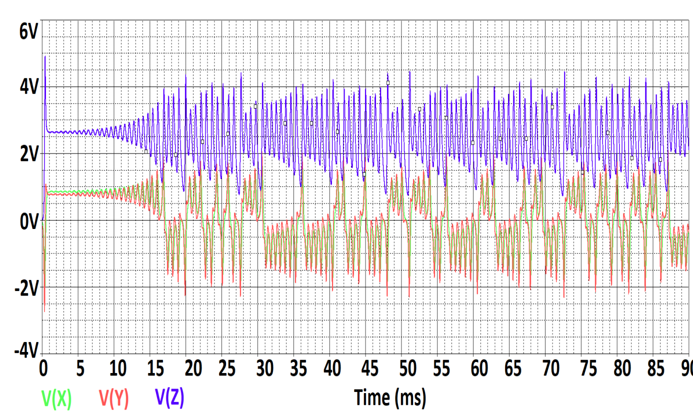
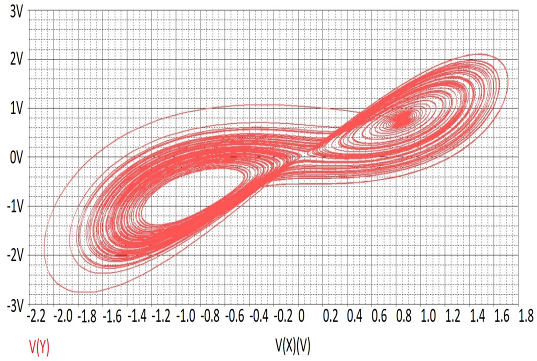


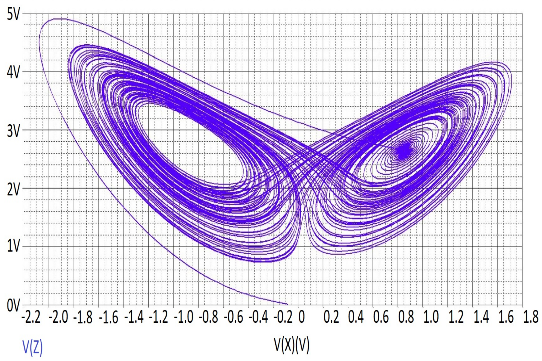
Figure 7 Time series of the simulated system.

SYNCHRONIZATION OF OTA-C CIRCUIT WITH MEMRISTOR

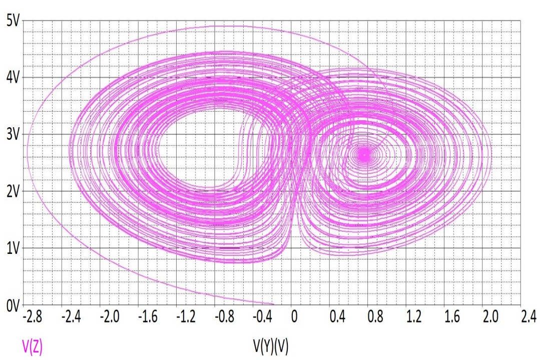
The synchronization of two chaotic circuits with different initial conditions is provided by a memristor and a circuit with OTA by adding the difference term attached to it (Sambas *et al.* 2013).



(a) $V_x - V_y$ chaotic attractor.



(b) $V_x - V_z$ chaotic attractor.



(c) $V_y - V_z$ chaotic attractor.

Figure 8 Phase portraits of the simulated system.

According to this method, the equation of the receiver is as in Equation 10.

$$
\begin{aligned}
\overset{\circ}{V}_{x_r} &= \sigma(V_{y_r} - V_{x_r}) + V_{x_r} \\
\overset{\circ}{V}_{y_r} &= V_{x_r}(p - V_{z_r}) - V_{y_r} \\
\overset{\circ}{V}_{z_r} &= V_{x_r}V_{y_r} - \beta V_{z_r} - \xi(V_{z_t} - V_{z_r})
\end{aligned}
\tag{10}
$$

To ensure that the circuits are both chaotic and synchronized, the value of ξ should be either optimized or observed by drawing a bifurcation diagram of the error as shown below. According to the bifurcation diagram in the Figure 9, synchronization is provided in the proposed circuit for ξ>1.8.

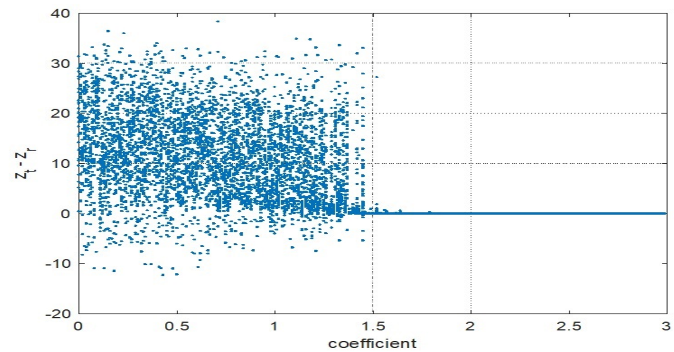


Figure 9 Bifurcation diagram of the error.

In this study, it is suggested that the necessity of optimizing the resistance value is eliminated by replacing the fixed resistor with the memristor element. The proposed method is to start from any state of the memristor and wait for the desired coefficient to occur spontaneously due to the nature of the memristor. In this way, when the coefficient needs to be updated due to a change in the circuit due to time or environmental factors, it will automatically reach the needed value and be synchronized again.

The weight of the difference term addition circuit is self-adjusted by the value change of the memristor. The synchronization circuit is given in Figure 10. Accordingly, for Equation 10, it will be $\xi = \frac{1}{C_z(M||R)}$. Due to the nature of the memristor, as long as there is an error, the memristance value will change in the direction of reducing the error, since $V_{z_t} - V_{z_r} = 0$ after synchronization is achieved, no current will flow from this part of the circuit and the circuits will operate synchronously.

The parameter values of the receiver and transmitter circuits are the same. The initial conditions of the receiver circuit are $v_x(0) = 0.05V, v_y(0) = 0.01V, v_z(0) = 0.05V$, the initial conditions of the transmitter circuit are $v_x(0) = 0.09V, v_y(0) = 0.05V, v_z(0) = 0.01V$. The value of the resistor connected in parallel with the memristor is $R = 30k\Omega$. Synchronization is realized over the z state variable of the receiver and transmitter circuit. The simulation results are shown in Figure 11. Circuits synchronized at $75ms$. It is shown that this is the contribution of the OTA-C design of the chaotic circuit and the memristor circuit model used in synchronization.

In the memristor simulations, the PSpice code of the memristor model proposed by Joglekar was used (Haron *et al.* 2014). This model has been proposed for titanium dioxide memristor nanostructures (Joglekar and Wolf 2009). The window function associated with the p exponent is used to provide the necessary nonlinearity. The p parameter is usually between 1 and 100. It is defined by Equations 11 and 12, where the memristor model represents the Joglekar window (Joglekar and Wolf 2009):

$$f_j(x) = 1 - (2x - 1)^{2p} \tag{11}$$

$$
\begin{aligned}
\frac{dx}{dt} &= kif(x) \\
v &= i[R_{ON}x + R_{OFF}(1-x)] \\
k &= \frac{\mu R_{ON}}{D^2}
\end{aligned}
\tag{12}
$$

where x is the memristor state variable, $f(x)$ is the window function, $p = 10$ is a parameter of the Window Function, $k = 1000$ is a constant dependent on memristor physical parameters, $\mu = 10^{-14}m^2/(Vs)$ is the ionic drift mobility, $D = 10nm$ is the memristor length, i is the memristor current, v is the applied voltage, $R_{ON} = 100\Omega$ and $R_{OFF} = 16k\Omega$ are the ON and OFF resistances of the memristor.

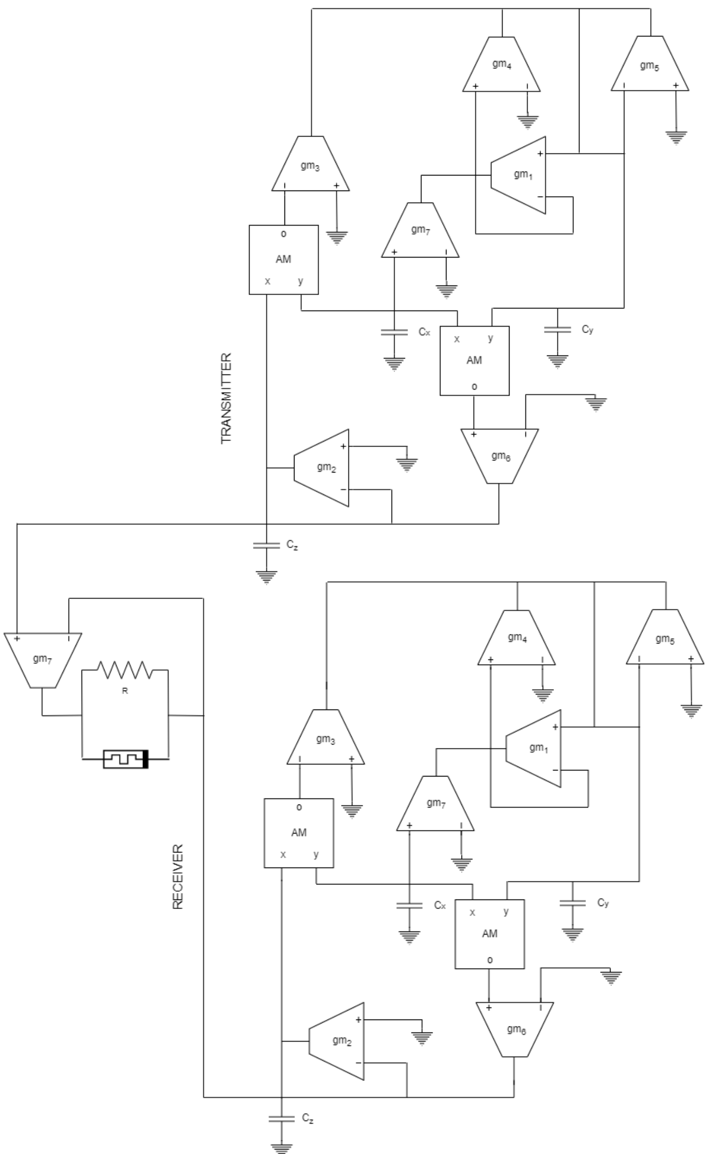
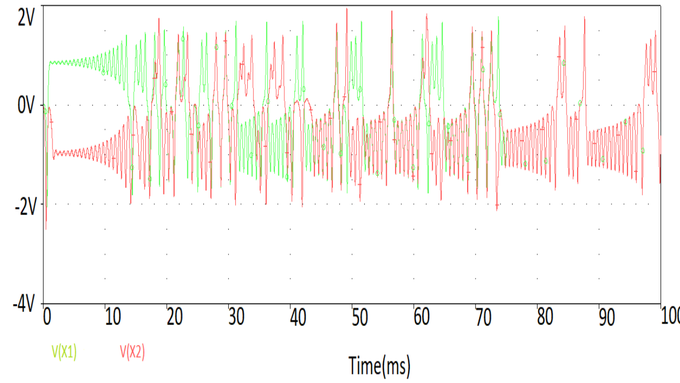
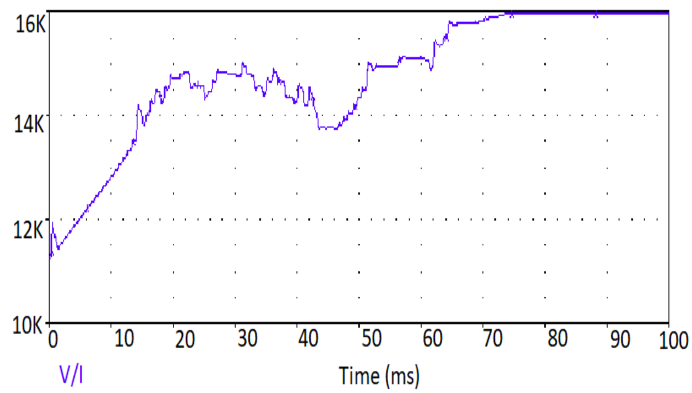


Figure 10 Synchronization of chaotic OTA-C circuits.



(a) Synchronization of transmitter and receiver signals v_{xt} and v_{xr} according to Figure 10.



(b) Memristance value change.

Figure 11 OTA-C chaotic synchronization charts.

CONCLUSION

In this study, a new chaotic equation set is obtained from the Lorenz equation using the anti-control procedure. Then, the circuit of this equation set is designed. Ideal OTA, capacitor, and analog multiplier are used in the designed circuit. This provides it less costly in case of physical implementation. The synchronization of the circuit was realized in a short time of $75ms$ using the memristor and differential receiver circuit with OTA. At the same time, the use of a memristor component provided low power consumption and time-saving.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Availability of data and material

Not applicable.

LITERATURE CITED

Akgul, A., I. Moroz, I. Pehlivan, and S. Vaidyanathan, 2016 A new four-scroll chaotic attractor and its engineering applications. Optik **127**: 5491–5499.

Cao, H.-Y. and L. Zhao, 2021 A new chaotic system with different equilibria and attractors. The European Physical Journal Special Topics **230**: 1905–1914.

Carroll, T. L. and L. M. Pecora, 1995 Synchronizing chaotic circuits. In *Nonlinear Dynamics in Circuits*, pp. 215–248, World Scientific.

Chua, L. O., M. Itoh, L. Kocarev, and K. Eckert, 1993a Chaos synchronization in chua's circuit. Journal of Circuits, Systems, and Computers **3**: 93–108.

Chua, L. O., C. W. Wu, A. Huang, and G.-Q. Zhong, 1993b A universal circuit for studying and generating chaos. i. routes to chaos. IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications **40**: 732–744.

Cuomo, K. M., A. V. Oppenheim, and S. H. Strogatz, 1993 Synchronization of lorenz-based chaotic circuits with applications to communications. IEEE Transactions on circuits and systems II: Analog and digital signal processing **40**: 626–633.

Deng, K., J. Li, and S. Yu, 2014 Dynamics analysis and synchronization of a new chaotic attractor. Optik **125**: 3071–3075.

Deniz, H. I., Z. G. C. Taskiran, and H. Sedef, 2018 Chaotic lorenz synchronization circuit design for secure communication. In *2018 6th International conference on control engineering & information technology (CEIT)*, pp. 1–6, IEEE.

Escudero, M., I. Vourkas, and A. Rubio, 2020 Alternative memristor-based interconnect topologies for fast adaptive synchronization of chaotic circuits. Chaos, Solitons & Fractals **138**: 109974.

Fan, T., X. Tuo, H. Li, and P. He, 2019 Chaos control and circuit implementation of a class of double-wing chaotic system. International Journal of Numerical Modelling: Electronic Networks, Devices and Fields **32**: e2611.

Gambuzza, L. V., A. Buscarino, L. Fortuna, and M. Frasca, 2015 Memristor-based adaptive coupling for consensus and synchronization. IEEE Transactions on Circuits and Systems I: Regular Papers **62**: 1175–1184.

Grassberger, P. and I. Procaccia, 1983 Measuring the strangeness of strange attractors. Physica D: nonlinear phenomena **9**: 189–208.

Haron, N. Z., N. Arshad, and F. Salehuddin, 2014 Performance analysis of memristor models for rram cell array design using silvaco eda. Jurnal Teknologi **68**.

Joglekar, Y. N. and S. J. Wolf, 2009 The elusive memristor: properties of basic electrical circuits. European Journal of physics **30**: 661.

Karawanich, K. and P. Prommee, 2022 High-complex chaotic system based on new nonlinear function and ota-based circuit realization. Chaos, Solitons & Fractals **162**: 112536.

Lai, Q., A. Akgul, C. Li, G. Xu, and Ü. Çavuşoğlu, 2017 A new chaotic system with multiple attractors: Dynamic analysis, circuit realization and s-box design. Entropy **20**: 12.

Lorenz, E. N., 1963 Deterministic nonperiodic flow. Journal of atmospheric sciences **20**: 130–141.

Lü, J., G. Chen, and S. Zhang, 2002 Dynamical analysis of a new chaotic attractor. International Journal of Bifurcation and chaos **12**: 1001–1015.

Özer, A. and E. Akın, 2005 Tools for detecting chaos. Sakarya Üniversitesi Fen Bilimleri Enstitüsü Dergisi **9**: 60–66.

Pappu, C. S., B. C. Flores, P. S. Debroux, and J. E. Boehm, 2017 An electronic implementation of lorenz chaotic oscillator synchronization for bistatic radar applications. IEEE Transactions on Aerospace and Electronic Systems **53**: 2001–2013.

Pehlivan, I. and Y. Uyaroğlu, 2010 A new chaotic attractor from general lorenz system family and its electronic experimental implementation. Turkish Journal of Electrical Engineering and Computer Sciences **18**: 171–184.

Rabinovich, M. I. and A. L. Fabrikant, 1979 Stochastic self-modulation of waves in nonequilibrium media. J. Exp. Theor. Phys **77**: 617–629.

Rössler, O. E., 1976 An equation for continuous chaos. Physics Letters A **57**: 397–398.

Sambas, A., W. Mada Sanjaya, M. Mamat, and O. Tacha, 2013 Design and numerical simulation of unidirectional chaotic synchronization and its application in secure communication system. Journal of Engineering Science and Technology Review **6**: 66–73.

Sundarapandian, V. and I. Pehlivan, 2012 Analysis, control, synchronization, and circuit design of a novel chaotic system. Mathematical and Computer Modelling **55**: 1904–1915.

Uyaroğlu, Y. and İ. Pehlivan, 2010 Nonlinear sprott94 case a chaotic equation: synchronization and masking communication applications. Computers & Electrical Engineering **36**: 1093–1100.

Wang, Y., F. Min, Y. Cheng, and Y. Dou, 2021 Dynamical analysis in dual-memristor-based fitzhugh–nagumo circuit and its coupling finite-time synchronization. The European Physical Journal Special Topics **230**: 1751–1762.

Wolf, A., J. B. Swift, H. L. Swinney, and J. A. Vastano, 1985 Determining lyapunov exponents from a time series. Physica D: nonlinear phenomena **16**: 285–317.

Xu, Y.-m., Z. Yao, A. Hobiny, and J. Ma, 2019a Differential coupling contributes to synchronization via a capacitor connection between chaotic circuits. Frontiers of Information Technology & Electronic Engineering **20**: 571–583.

Xu, Y.-m., Z. Yao, A. Hobiny, and J. Ma, 2019b Differential coupling contributes to synchronization via a capacitor connection between chaotic circuits. Frontiers of Information Technology & Electronic Engineering **20**: 571–583.

Yao, Z., J. Ma, Y. Yao, and C. Wang, 2019 Synchronization realization between two nonlinear circuits via an induction coil coupling. Nonlinear Dynamics **96**: 205–217.

Yao, Z., P. Zhou, A. Alsaedi, and J. Ma, 2020 Energy flow-guided synchronization between chaotic circuits. Applied Mathematics and Computation **374**: 124998.

Yildirim, M., 2022 Optical color image encryption scheme with a novel dna encoding algorithm based on a chaotic circuit. Chaos, Solitons & Fractals **155**: 111631.

Zhang, X., C. Wang, J. Ma, and G. Ren, 2020a Control and synchronization in nonlinear circuits by using a thermistor. Modern Physics Letters B **34**: 2050267.

Zhang, X., F. Wu, J. Ma, A. Hobiny, F. Alzahrani, *et al.*, 2020b Field coupling synchronization between chaotic circuits via a memristor. AEU-International Journal of Electronics and Communications **115**: 153050.

Zhou, W., Y. Xu, H. Lu, and L. Pan, 2008 On dynamics analysis of a new chaotic attractor. Physics Letters A **372**: 5773–5777.

How to cite this article: Aydın, S. Z., Beken, G. N., and Taskiran, Z. G. C. A Lorenz-like Chaotic OTA-C Circuit and Memristive Synchronization. *Chaos Theory and Applications*, 5(1), 52-58, 2023.