Analog electronic circuit design of the Cao 4D hyperchaotic finance system

Serdar ÇİÇEK

Nevşehir Hacı Bektaş Veli University, Vocational School of Hacıbektaş, Department of Electronic and Automation, Nevşehir, TURKEY

Corresponding author e-mail: serdarcicek@nevsehir.edu.tr ; serdarcicek@gmail.com

Abstract
Chaotic and hyperchaotic systems have been used in different fields of science in recent years. Many chaotic and hyperchaotic systems with different behaviors have been introduced in the literature. Especially in chaotic system based encryption, random number generator and communication applications, hyperchaotic systems are more preferred because of their more complex characteristics. The chaotic and hyperchaotic systems introduced in the literature are generally presented only as numerical simulation. However, it is necessary to design the electronic circuit for the use of the systems in real applications. In this study, numerical simulation results of four-dimensional (4D) hyperchaotic finance system introduced by Cao in 2018 were obtained and then analog electronic circuit design was realized. Numerical simulation results and designed electronic circuit outputs have confirmed each other. As a result, it is ensured that Cao 4D hyperchaotic finance system can be used in real engineering applications.
Keywords: Chaotic system, Hyperchaotic finance system, Electronic circuit design.

1. INTRODUCTION

The behavior of events in nature is chaotic. Chaotic systems have the following characteristics: randomness, aperiodic, extreme sensitivity to initial conditions and parameter values, difficulty in predicting (Hou et al., 2012; Li et al., 2017). Therefore, chaotic and hyperchaotic systems have been used in different fields of science such as encryption (Bouhous and Kemih, 2018), communication (Werner et al., 2017), random number generator (Tuna et al., 2018), optimization (Fiori and Filippo, 2017), biology (Scharf, 2017) and finance (Tacha et al., 2016) in recent years.

Various chaotic and hyperchaotic systems have been introduced in the literature (Singh et al., 2018; Liu et al., 2018). Hyperchaotic systems are preferred for some engineering applications because they are more difficult to predict and show more randomness than chaotic systems (Zhang and Li, 2013). Therefore, the real circuit designs of these hyperchaotic systems are needed. But, these systems are generally introduced as simulations only. However, it is necessary to design the electronic circuit for the use of the systems in real applications.

Active electronic devices such as OPAMP (Operational Amplifier) (Munoz-Pacheco et al., 2018; Ma et al., 2017; Hu et al., 2016), CCII (Second Generation Current Conveyor) (Peng et al., 2014), CFOA (Current Feedback Operational Amplifier) (Jothimurugan et al., 2014) were used in analog electronic circuit realization of chaotic systems. In most of the designs, the OPAMP devices was used.

In this study, firstly, the simulation of 4D hyperchaotic finance system introduced by Cao in 2018 was simulated in Matlab-Simulink program. Then the analog electronic circuit design of the hyperchaotic finance system was realized and the electronic circuit outputs and the simulation results were compared.

2. NUMERICAL SIMULATION OF THE CAO 4D HYPERCHAOTIC FINANCE SYSTEM

The mathematical expression of the 4D hyperchaotic financial system introduced by Cao in 2018 is given in Eq. (1) (Cao, 2018). System variables are: x is the interest rate, y is the investment demand, z is the price exponent and w is the average profit margin. The system has positive parameters a, b, c, d and k.

$$\begin{aligned} \dot{x} &= z + (y - a)x + w \\ \dot{y} &= 1 - by - x^2 \\ \dot{z} &= -x - cz \\ \dot{w} &= -dxy - kw \end{aligned} \tag{1}$$

System (1) is simulated numerically in Matlab-Simulink program. The parameter values in the system are as follows: a = 0.9, b = 0.2, c = 1.5, d = 0.2, k = 1. The initial conditions of the system (1) are x_0=1, y_0=2, z_0=0.5, w_0=0.5. Simulation results of the system x, y, z state variables are shown in Figure 1. Figure 2 shows the phase portraits of the system.

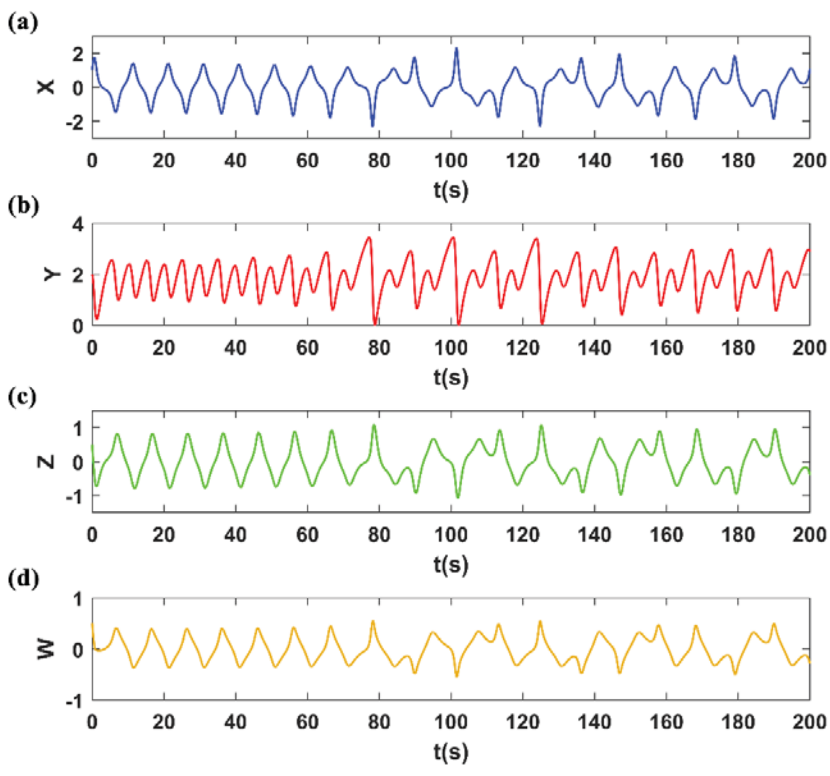

Figure 1. Simulation results of the system state variables against to time (a) x (b) y (c) z (d) w

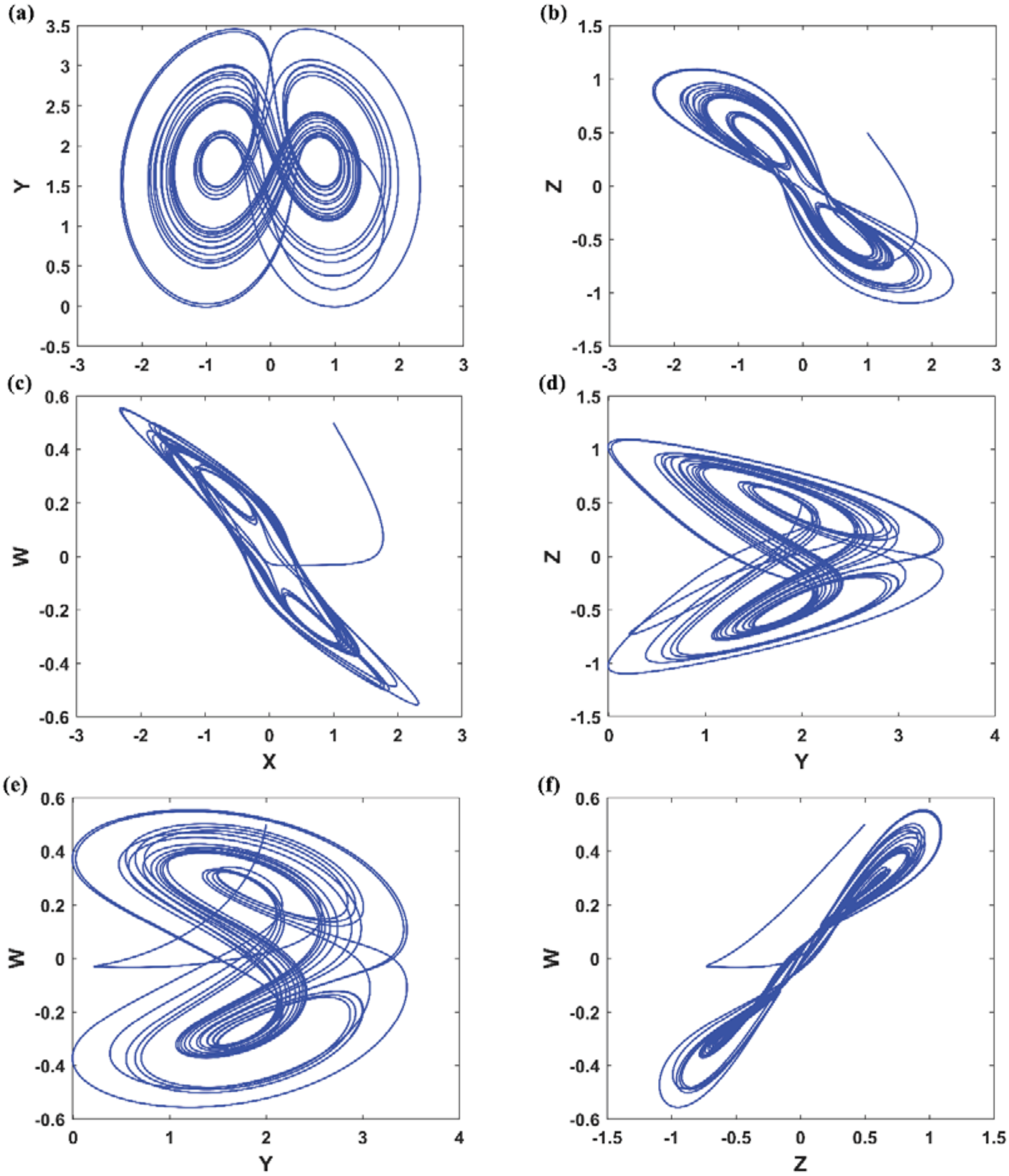

Figure 2. The chaotic system (1) phase portraits (a) *x* versus *y* (b) *x* versus *z* (c) *x* versus *w* (d) *y* versus *z* (e) *y* versus *w* (f) *z* versus *w*

3. ELECTRONIC CIRCUIT DESIGN OF THE CAO 4D HYPERCHAOTIC FINANCE SYSTEM

In this section, the electronic circuit design of the Cao 4D hyperchaotic financial system (Cao, 2018) is designed in the OrCAD-PSpice program. The design is based on TL081 OPAMP IC. AD633 IC is used for multiplication. The designed circuit is supplied with ±12Vdc power supply. The circuit has analog devices as: six TL081 ICs, three AD633 ICs, four capacitors and seventeen resistors. The designed electronic circuit schematic of the system (1) is given in Figure 3. The component values of the circuit are given in Table 1.

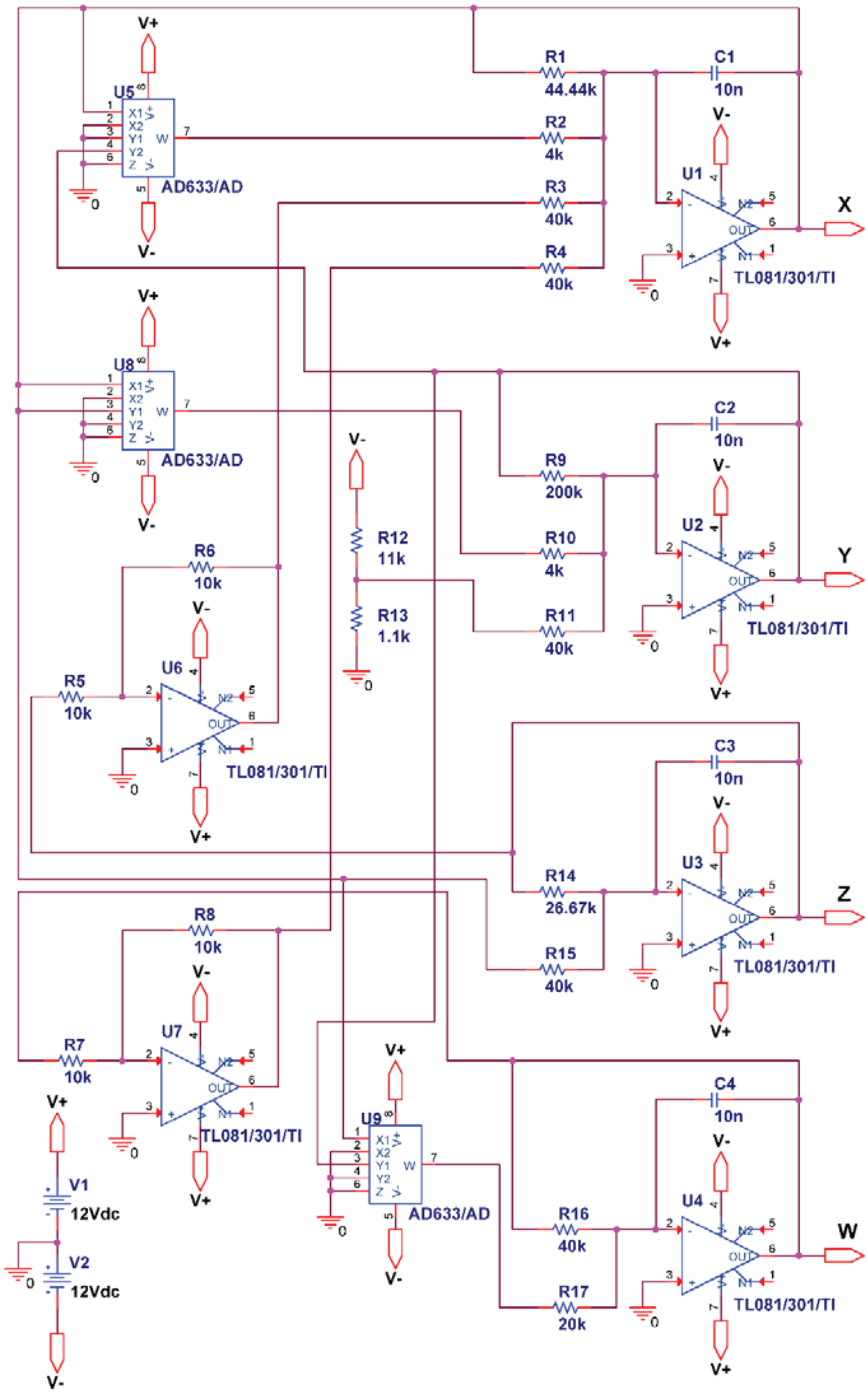

Figure 3. The designed electronic circuit schematic of the Cao 4D hyperchaotic financial system

Table 11. The component values of the circuit

Device Name	Value
U1, U2, U3, U4, U6, U7	TL081
U5, U8, U9	AD633
C, C2, C3, C4	10 nF
R1	44.44 kΩ
R2, R10	4 kΩ
R3, R4, R11, R15, R16	40 kΩ
R5, R6, R7, R8	10 kΩ
R9	200 kΩ
R12	11 kΩ
R13	1.1 kΩ
R14	26.67 kΩ
R17	20 kΩ

The state variables outputs (*x*, *y*, *z*, *w*) of the designed electronic circuit are shown in Figure 4. The phase portraits of the designed electronic circuit are given in Figure 5. Simulation outputs (Figure 2) and electronic circuit outputs (Figure 5) confirm each other.

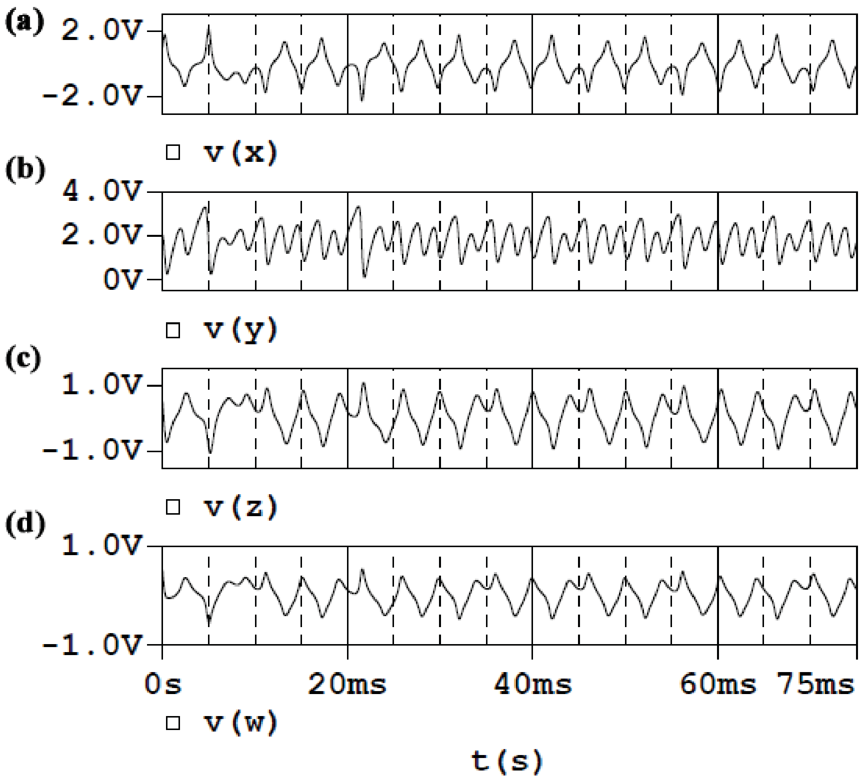

Figure 4. The state variables against to time outputs of the designed electronic circuit (a) *x* (b) *y* (c) *z* (d) *w*

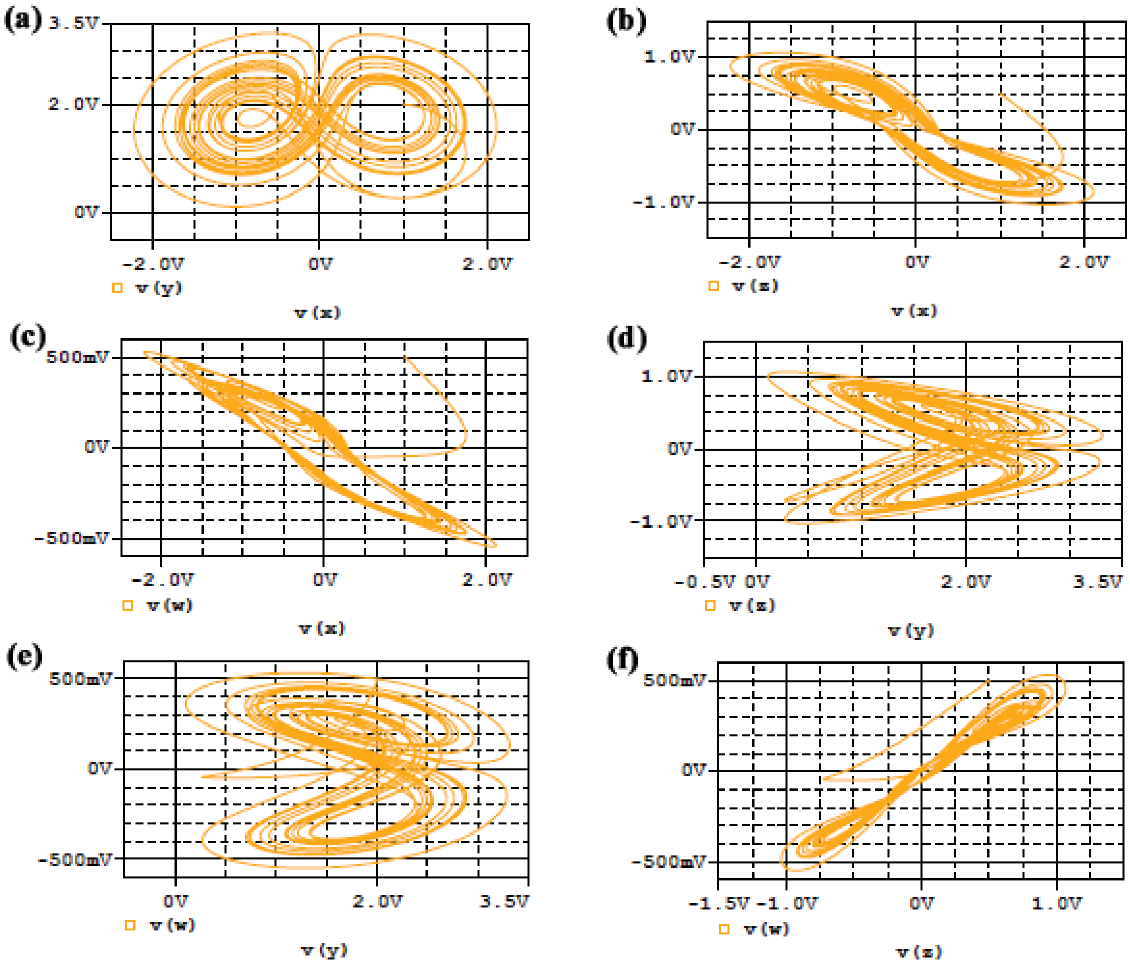

Figure 5. The phase portraits of the designed electronic circuit (a) *x* versus *y* (b) *x* versus *z* (c) *x* versus *w* (d) *y* versus *z* (e) *y* versus *w* (f) *z* versus *w*

4. DISCUSSION AND CONCLUSION

There is also a need for electronic designs to be used in engineering applications for the new introduced and only numerical simulated chaotic systems. So, in this study, firstly, the numerical simulation results of 4D hyperchaotic financial system introduced by Cao in 2018 in the Matlab-Simulink program were obtained. Then, the electronic circuit design of the hyperchaotic system was designed in the OrCAD-PSpice program. When Figure 2 and Figure 5 were examined, it was seen that simulation results and the electronic circuit (Figure 3) outputs confirmed each other. As a result, the electronic circuit design has been obtained in order for the chaotic system to be used in real engineering applications. The electronic design can be used in various engineering applications based on chaotic systems. In order to use the system in digital applications, embedded system based design can be made with devices such as microcontroller, FPGA.

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