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A Novel 5D-Dimentional Hyperchaotic System and its Circuit Simulation by EWB

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Abstract: This paper reports a new five dimensional hyperchaotic system. The dynamical behaviors of this new hyper chaotic system are proved by not only performing numerical simulation and brief theoretical analysis but also by conducting an electronic circuit experiment. The hyperchaotic circuit is designed and realized by the Multisim software.

Keywords: hyperchaotic system, Lyapunov exponents, Circuit simulation, Double-wing hyperchaotic attractor.

1 Introduction

Since Rossler [1] first introduced the Rossler hyperchaotic system, which meant that the system possesses more than one positive Lyapunov exponent, many chaotic systems have been reported in nonlinear field, people focus on studying and constructing hyperchaotic systems, defined as a chaotic system with more than one positive Lyapunov exponent. There exist some well-known hyperchaotic systems such as hyperchaotic Rossler system [2] , hyperchaotic Chen system [2] and so on [3,4,5,6,7,8]. Since hyperchaotic system has the characteristics of high capacity, high security, and high efficiency, it has been broadly applied in nonlinear circuits, secure communications, lasers, neural networks, biological systems, and so on [9,10] . In this Letter, we propose a new 5D hyperchaotic system; which also exhibits complex and abundant hyper chaotic dynamic behaviors. The electronic circuit realizing the 5D hyperchaotic system is designed and realized by the Multisim software.

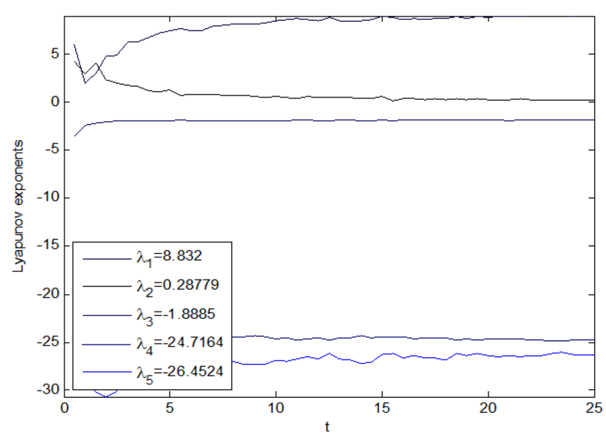

Fig. 1 Lyapunov exponents of the new hyperchaotic system (1)

2 A new 5D hyper chaotic system

This new hyper chaotic system can be described by the following five-dimensional autonomous differential equation:

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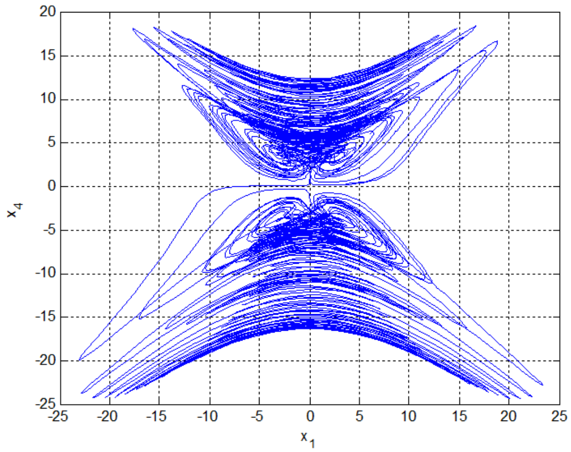
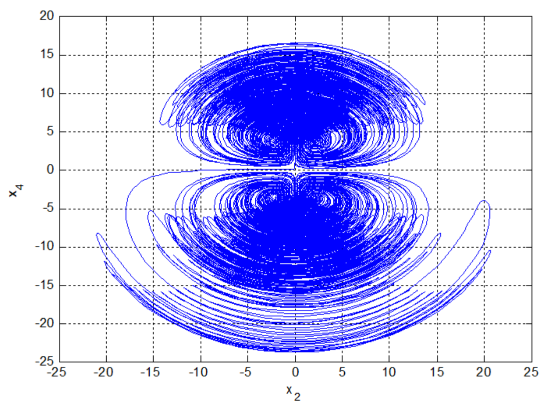
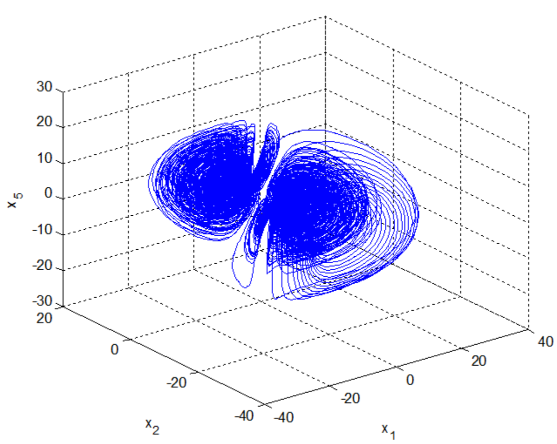


(a) projection on the plan x_1-x_4



(b) projection on the plan x_2-x_4



(c) 3D view (x_1-x_2-x_5)

Fig. 2 The Five dimensional hyperchaotic attractors

$$\begin{aligned} \dot{x}_1 &= a_1(x_2 - x_1) + x_2x_3x_4x_5 \\ \dot{x}_2 &= a_2(x_1 + x_2) - x_1x_3x_4x_5 \\ \dot{x}_3 &= -x_3 + 0.1\ x_1^2 \\ \dot{x}_4 &= -a_3x_4 + x_1x_2x_3x_5 \\ \dot{x}_5 &= -a_4(x_5 - x_4) + a_5x_1 + x_1x_2x_3x_4 \end{aligned} \quad (1)$$

Where : x_1, x_2, x_3,x_4 and x_5 are state variables, a_1, a_2, a_3, a_4 and a_5 are all positive real parameters. When the values of the parameters in system (1) are selected as $a_1 = 37$, $a_2 = 14.5$, $a_3 = 10.5$, $a_4 = 15$ and $a_5 = -9.5$, this system becomes hyperchaotic. Lyapunov exponents of the new hyperchaotic system are presented in figure 1 and the five dimensional hyper chaotic attractors are presented in figure 2.

3 Basic dynamical behaviours of the new hyperchaotic system

3.1 Dissipation

The divergence of the new 5D system (1) is :

$$\nabla V = \frac{\partial \dot{x}_1}{\partial x_1} + \frac{\partial \dot{x}_2}{\partial x_2} + \frac{\partial \dot{x}_3}{\partial x_3} + \frac{\partial \dot{x}_4}{\partial x_4} + \frac{\partial \dot{x}_5}{\partial x_5} \quad (2)$$

$$\nabla V = -(a_1 - a_2 + a_3 + a_4 + 1) \quad (3)$$

According to the ranges of the system parameters, we obtain that

$-(a_1 - a_2 + a_3 + a_4 + 1) < 0$, and thus the system is a dissipative system. All orbits of the system converge to a specific subset of zero volume as $t \to \infty$ exponentially$\frac{dV}{dt} = e^{-(a_1 - a_2 + a_3 + a_4 + 1)}$.

3.2 Symmetry

The new system (1) is symmetry with respect to the x_3 axis; which is invariant under the following coordinate transformation
$(x_1,\ x_2, x_3, x_4, x_5) \to (-x_1,\ -x_2, x_3, -x_4, -x_5)$

3.3 Equilibrium

the new hyperchaotic system (1) has unique equilibrium point$S_0(0, 0, 0, 0, 0)$. For this latter, the system (1) is linearized, and the Jacobian matrix is given by :

$$J_0 = \begin{bmatrix} -a_1 & a_1 & 0 & 0 & 0 \\ a_2 & a_2 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -a_3 & 0 \\ a_5 & 0 & 0 & a_4 & -a_5 \end{bmatrix} \quad (4)$$

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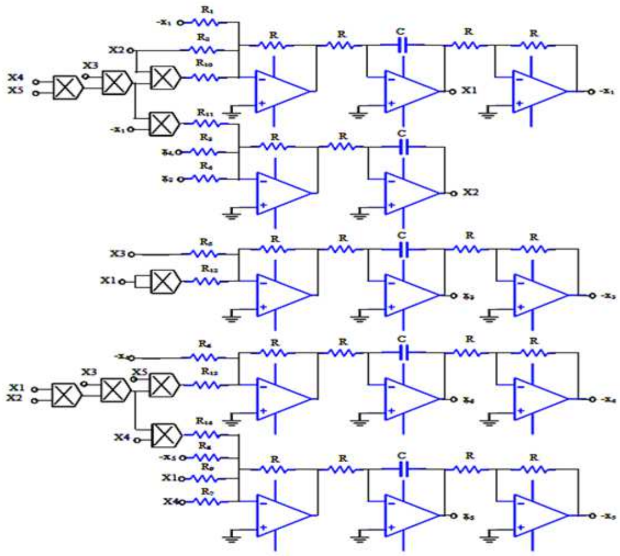


Fig. 3 Diagram of implantation of the system (1), where all the active devices are supplied by ±15V, fixed resistors: R=10KΩ, R_1=R_2=2.70KΩ, R_3=R_4=6.45KΩ, R_5=100KΩ, R_6=9.52 KΩ, R_7=R_8=6.67 KΩ, R_9=10.52 KΩ, R_{12}=100 KΩ, R_{10}=R_{11}=R_{13}=R_{14}= 100Ω

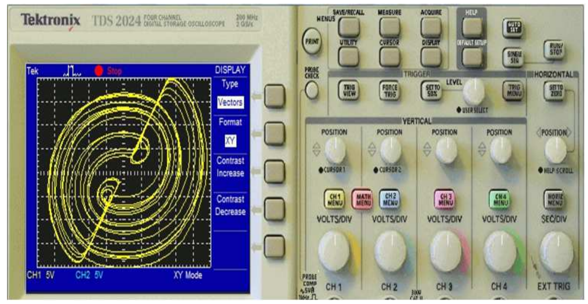
To gain its eigenvalues, let $|\lambda I - J_0| = 0$, Then these eigenvalues corresponding to equilibrium $S_0(0,0,0,0,0)$ will be obtained as follows: λ_1 = -45.8847, λ_2 = -1; λ_3 = -10.5, λ_4 =9.5, λ_5 =23.3847. Where: (λ_1, λ_2, λ_3) are negative real roots and (λ_4,λ_5) are positive real roots; Therefore, equilibrium $S_0$is unstable.

4 Electronic circuit implementation

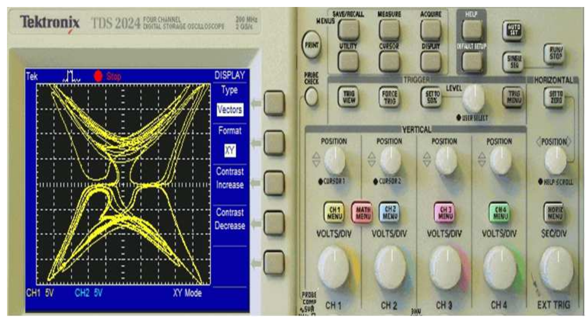
To physically realize the five dimensional hyper chaotic systems, an analogue circuit designed in Multisim software is shown in figure 3. The circuit consist of the five channels to realize the integration addition and substation of the state variables x_1, x_2, x_3, x_4 and x_5.

The type of operation amplifier by us is LM741CN and the type of the multiplier is AD633JN. For this type of realization and because the gain of the multiplier AD633JN is 0.1, the corresponding state equations are giver by:

$$\begin{aligned}
R_0C\frac{dx_1}{dt} &= \frac{-R}{R_1}x_1 + \frac{R}{R_2}x_2 + \frac{1}{1000}\frac{R}{R_{10}}x_2x_3x_4x_5\\
R_0C\frac{dx_2}{dt} &= \frac{R}{R_3}x_1 + \frac{R}{R_4}x_2 - \frac{1}{1000}\frac{R}{R_{11}}x_1x_3x_4x_5\\
R_0C\frac{dx_3}{dt} &= \frac{-R}{R_5}x_3 + \frac{1}{10}\frac{R}{R_{12}}x_1^2\\
R_0C\frac{dx_4}{dt} &= \frac{-R}{R_6}x_4 + \frac{1}{1000}\frac{R}{R_{13}}x_1x_2x_3x_5\\
R_0C\frac{dx_5}{dt} &= \frac{R}{R_7}x_4 - \frac{R}{R_8}x_5 + \frac{R}{R_9}x_1 + \frac{1}{1000}\frac{R}{R_{14}}x_1x_2x_3x_4
\end{aligned} \quad (5)$$



(a) x_1 - x_2 plane



(b) x_1 - x_4 plane

Fig. 4 the experimental results observed on the digital oscilloscope with EWB

According to the equations (1) and (5) we have:

$$R_0C = 0.1, \frac{R}{R_1} = \frac{R}{R_2} = 3.7, \frac{R}{R_3} = \frac{R}{R_4} = 1.55$$

$$\frac{R}{R_5} = 0.1, \frac{R}{R_6} = 1.05, \frac{R}{R_7} = \frac{R}{R_8} = 1.5$$

$$\frac{R}{R_9} = 0.95, \frac{R}{1000R_{10}} = 0.1, \frac{R}{1000R_{11}} = 0.1$$

$$\frac{R}{1000R_{13}} = 0.1, \frac{R}{1000R_{14}} = 1, \frac{R}{10R_{12}} = 0.01$$

5 Conclusion

In summary, a novel 5D hyperchaotic system has been introduced in this letter. Same basic proprieties of this new system are analyzed and an analogue circuit is built for realizing the new hyperchaotic system with Mulstisim software and verifying, showing a good agreement between system simulation and experimental results.

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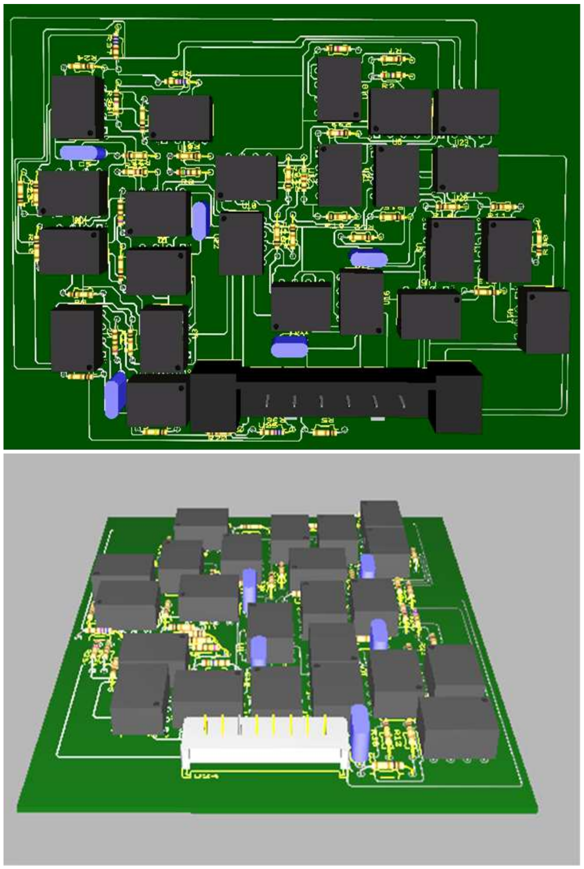

Fig. 5 Circuit design with Multiboard

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