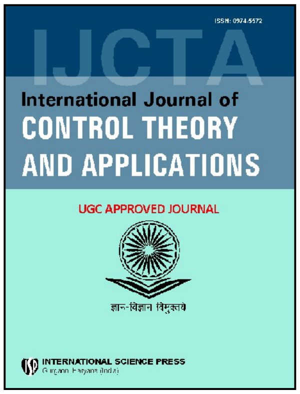

International Journal of Control Theory and Applications

ISSN : 0974-5572

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Volume 10 • Number 34 • 2017

Constructing of 3D Novel Chaotic Hidden Attractor and Circuit Implementation

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Abstract: A 3D novel chaotic hidden attractor with no equilbrium is investigated in this paper. Some dynamical properties and behaviors of this system are described in terms Lyapunov exponents, time series and phase portraits. Furthermore, An electronic circuit realization of the 3D novel chaotic hidden attractor is presented in details. Finally, the circuit experimental results of the 3D novel chaotic hidden attractor show agreement with the numerical simulations.

Keywords: A 3D novel chaotic hidden attractor, Lyapunov exponent, Electronic circuit.

1. INTRODUCTION

Chaos theory has many important applications in science and engineering such as dynamo systems [1], oscillators [2-4], lasers [5], robotics [6], chemical reactors [7], biology [8], ecology [9-10], psychology [11], speech encryption [12], memristors [13], artificial neural networks [14], text encryption [15], image encryption [16] and secure communication systems [17-21], etc.

Recently there has been interest in finding and studying of infinite number of equilibria such as equilibria located on the circle [22], square [23], ellipse [24], rounded square [25], rounded rectangle [24], line [26-27], two parallel lines [28], two perpendicular lines [28], heart shape [29], smooth curve [30] and piecewise linear curve [31]. In addition, the 3D of chaotic system with no equilibria is reported [32].

There are two types of attractor; self-excited attractor and hidden attractor. The hidden attractor is periodic or chaotic attractor in the system without equilibria or with the only stable equilibrium [33], a special case of multistability [34] and coexistence of attractors [35]. Hidden attractors are important in engineering applications because it can explain perturbations in a structure like a bridge or aircraft wing, convective fluid motion in rotating cavity [36] and model of drilling system actuated by induction motor [37].

Motivated by the above reasearches, a 3D novel hidden attractor of chaotic system is proposed in this work. The rest of the paper is organized as follow. In section 2, the analysis of novel hidden attractor system by using Runge-Kutta method and Lyapunov exponent. The circuit implementation of the proposed system is presented in section 3. Clonclusions are presented in section 4.

2. DYNAMICS AND ANALYSIS OF 3D NOVEL HIDDEN ATTRACTOR

In [26], Jafari and Sprott considered the conservative Sprott case A system

$$\left.\begin{aligned} \dot{x} &= y \\ \dot{y} &= -x + yz \\ \dot{z} &= 1 - y^2 \end{aligned}\right\} \tag{1}$$

where x, y, z are the state variables. Based on system (1), we design a novel chaotic systems without equilibrium as follows:

$$\left.\begin{aligned} \dot{x} &= y \\ \dot{y} &= axz - yz \\ \dot{z} &= y^2 - 1 \end{aligned}\right\} \tag{2}$$

Where x, y, z are the state variables and $a = 0.1$ are positive parameter. We take the initial conditions of the 3D novel chaotic system (1) as

$$x(0) = 0.1,\ y(0) = 0.1,\ z(0) = 0.1 \tag{3}$$

For the numerical simulations, the classical fourth-order Runge-Kutta method is used to solve the system (2). The 3-D portrait of the novel hidden attractor chaotic system (2) and the initial conditions (3) is depicted in Figure 1.

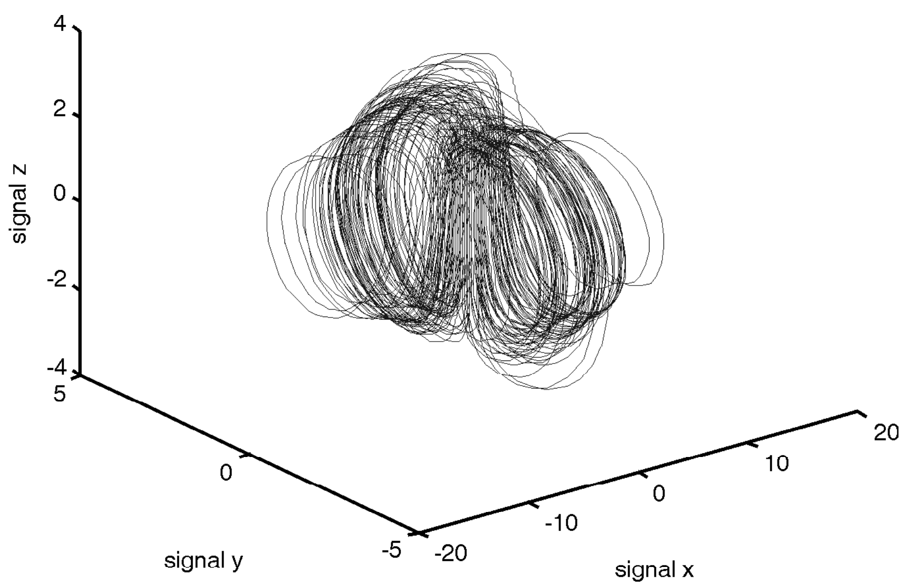

Figure 1: The chaotic attractor of the novel 3D hidden attractor chaotic system in R^3

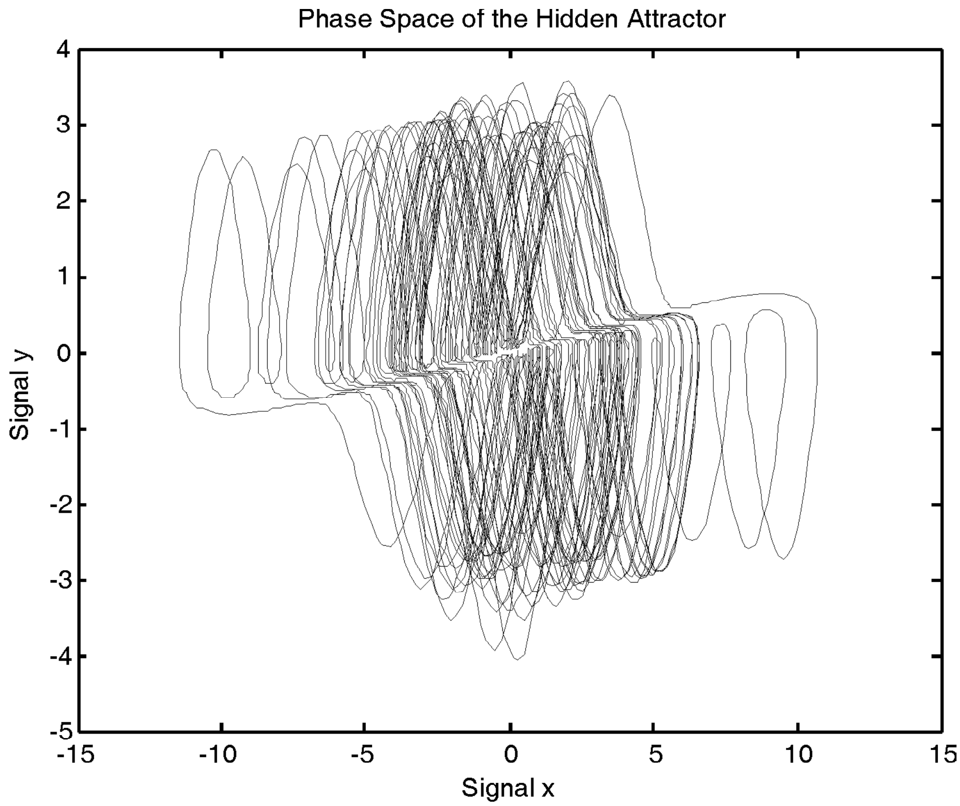

Figure 2: The 2-D projection of the novel 3D hidden attractor chaotic system on (x, y) plane

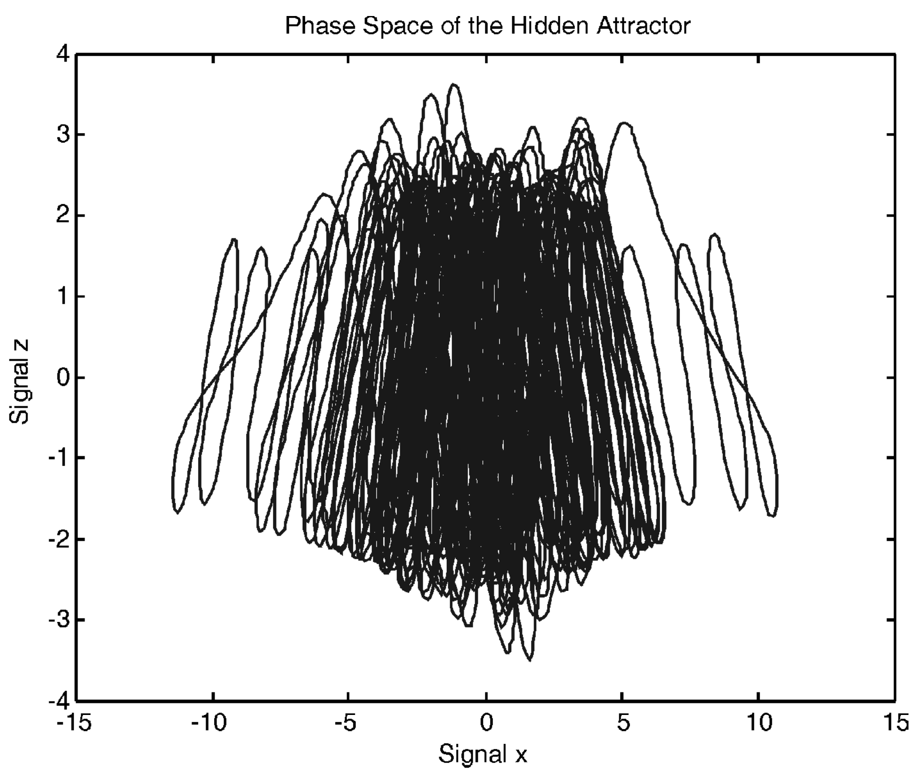

Figure 3: The 2-D projection of the novel 3D hidden attractor chaotic system on (x, z) plane

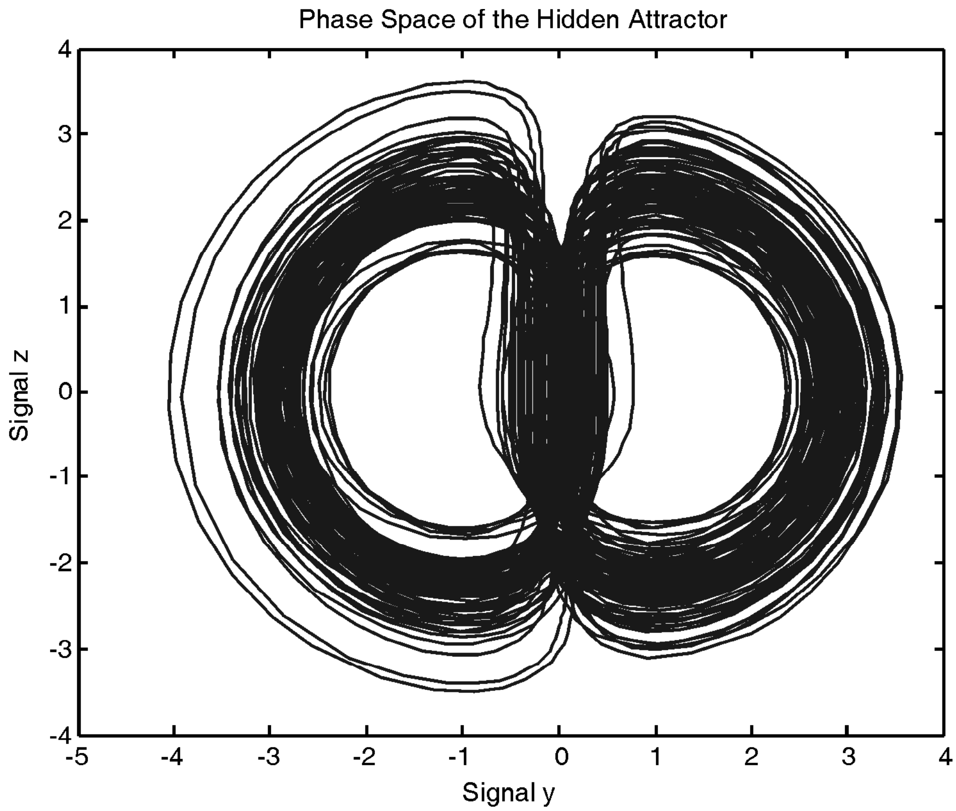

Figure 4: The 2-D projection of the novel 3D hidden attractor chaotic system on (y, z) plane

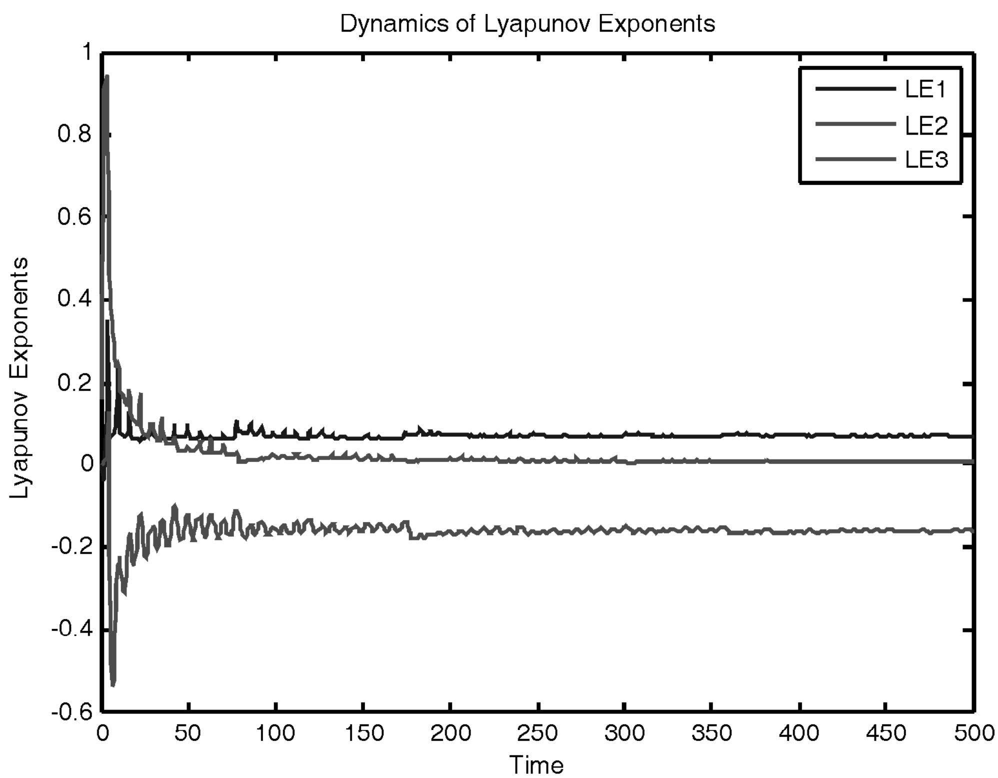

Figure 5: Lyapunov exponents of the novel 3D hidden attractor chaotic system

The 2-D portraits (projections on the three coordinate planes) of the novel 3D hidden attractor chaotic system (2) are depicted in Figures 2-4. Convergence curves of Lyapunov exponents of system (2) for a = 0.1 with LE1 (blue), LE2 (green), LE3 (red) as illustrated in Figure 5. The equilibrium point of system (2) is found by solving

$$0 = y \tag{4}$$

$$0 = axz - yz \tag{5}$$

$$0 = y^2 - 1 \tag{6}$$

From equation (4) and (5), this leads to $x = y = 0$ which is inconsistent with equation (6). Thus, in system (2), there is no equilibrium. It should be noted that the novel 3D hidden attractor (2) is dissipative with an exponential contraction rate $\frac{dV}{dt} = e^{-(-z)t}$ since.

$$\nabla V = \frac{\partial \dot{x}}{\partial x} + \frac{\partial \dot{y}}{\partial y} + \frac{\partial \dot{z}}{\partial z} = -z \tag{7}$$

3. CIRCUIT REALIZATION OF THE 3D NOVEL HIDDEN ATTRACTOR

In this section, we design an electronic circuit modeling of the 3D novel hidden attractor chaotic system (2). The circuit in Figure 6 has been designed following an approach based on operational amplifiers where the state variables x, y, z of the system (2) are associated with the voltages across the capacitors C_1, C_2 and C_3, respectively. The nonlinear term of system (2) are implemented with the analog multiplier. By applying Kirchhoff's laws to the designed electronic circuit, its nonlinear equations are derived in the following form:

$$\left.\begin{aligned} \dot{x} &= \frac{1}{C_1 R_1} y \\ \dot{y} &= \frac{1}{10 C_2 R_2} xz - \frac{1}{10 C_2 R_3} yz \\ \dot{z} &= \frac{1}{10 C_3 R_4} y^2 - \frac{1}{C_3 R_5} V_A \end{aligned}\right\} \tag{8}$$

Eqs (2) match Eqs. (8) when the circuit components are selected as follows: $R_3 = R_4 = 1k\text{W}$, $R_1 = R_2 = R_5 = R_6 = R_7 = R_8 = R_9 = R_{10} = R_{11} = 10k\text{W}$, $C_1 = C_2 = C_3 = 10nF$. The circuit has three integrators by using Op-amp TL082CD in a feedback loop and two multipliers IC AD633. The supplies of all active devices are $\pm\, 15V$. we obtain the experimental observations of system (8) as shown in Figures 7-9. As compared with Figures 2-4, a good qualitative agreement between the numerical simulation and the MultiSIM 10.0 results of the 3D novel hidden attractor chaotic system is confirmed

4. CONCLUSIONS

In this article, we discussed the qualitative properties of the 3D novel hidden attractor chaotic system. Using Runge-Kutta method and Lyapunov exponent analysis. When selecting $a = 0.1$, the proposed system (2) displays chaotic behavior. An electronic circuit realization of the 3D novel hidden attractor chaotic system has been presented in detail that shows agreement of the circuit and numerical simulations for the new chaotic system.

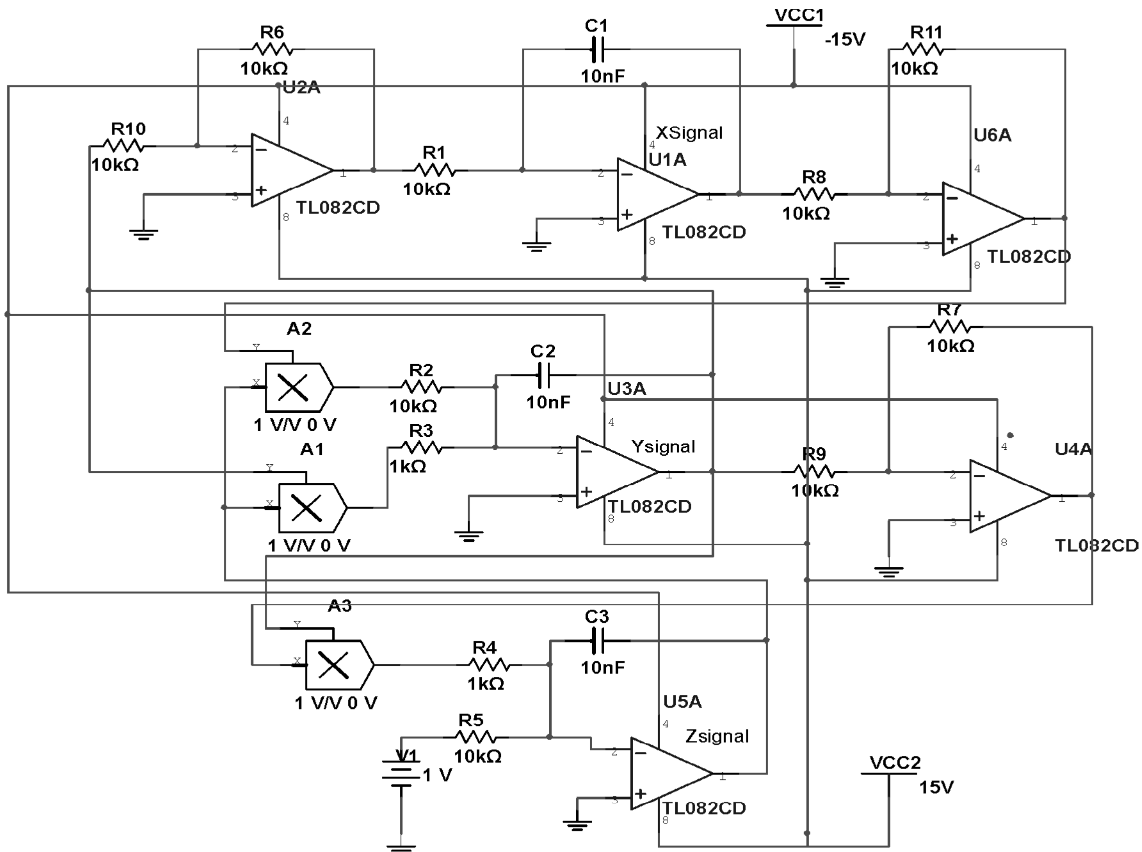

Figure 6: Electronic circuit schematic of the novel 3D hidden attractor chaotic system

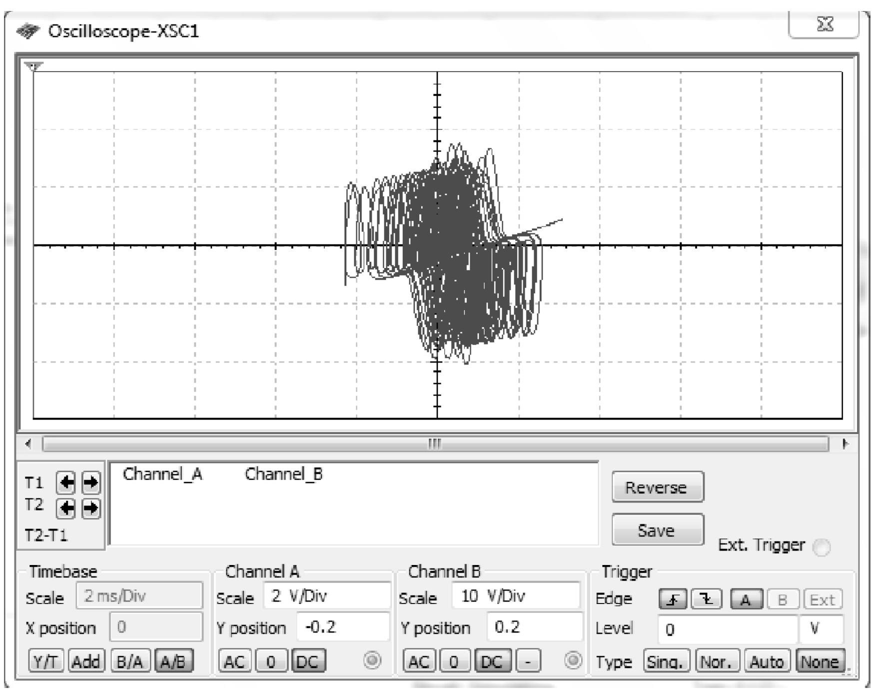

Figure 7: 2-D projection of the novel 3D hidden attractor chaotic system in *x-y* plane using MultiSIM 10.0

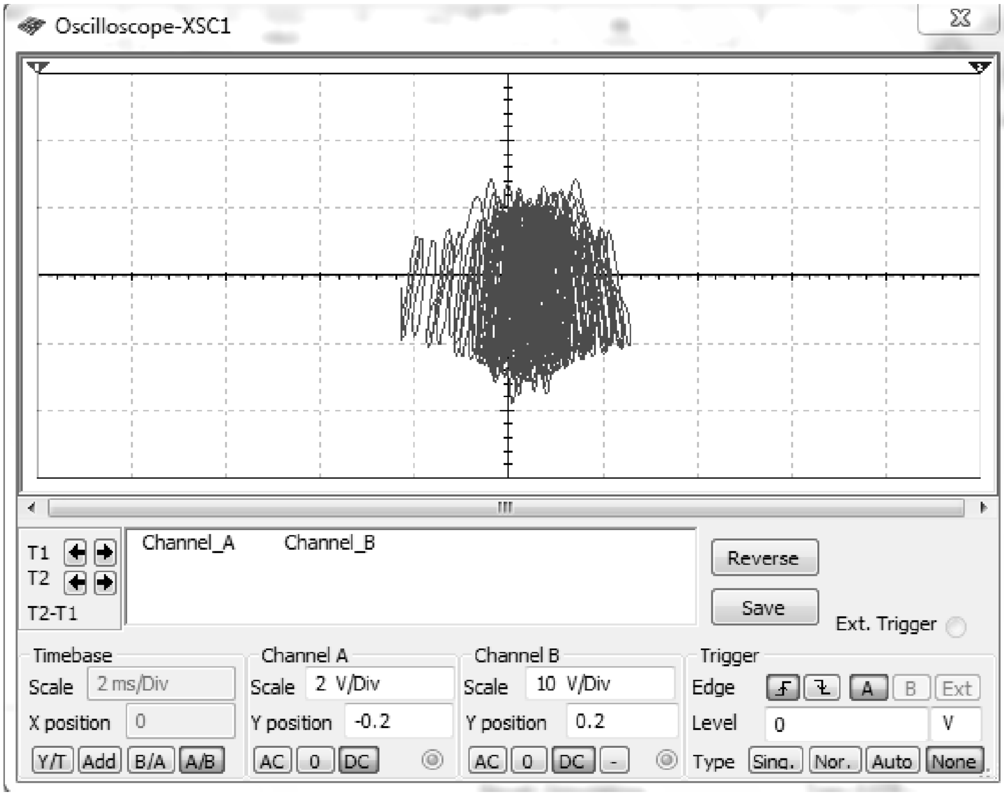

Figure 8: 2-D projection of the novel 3D hidden attractor chaotic system in *x-z* plane using MultiSIM 10.0

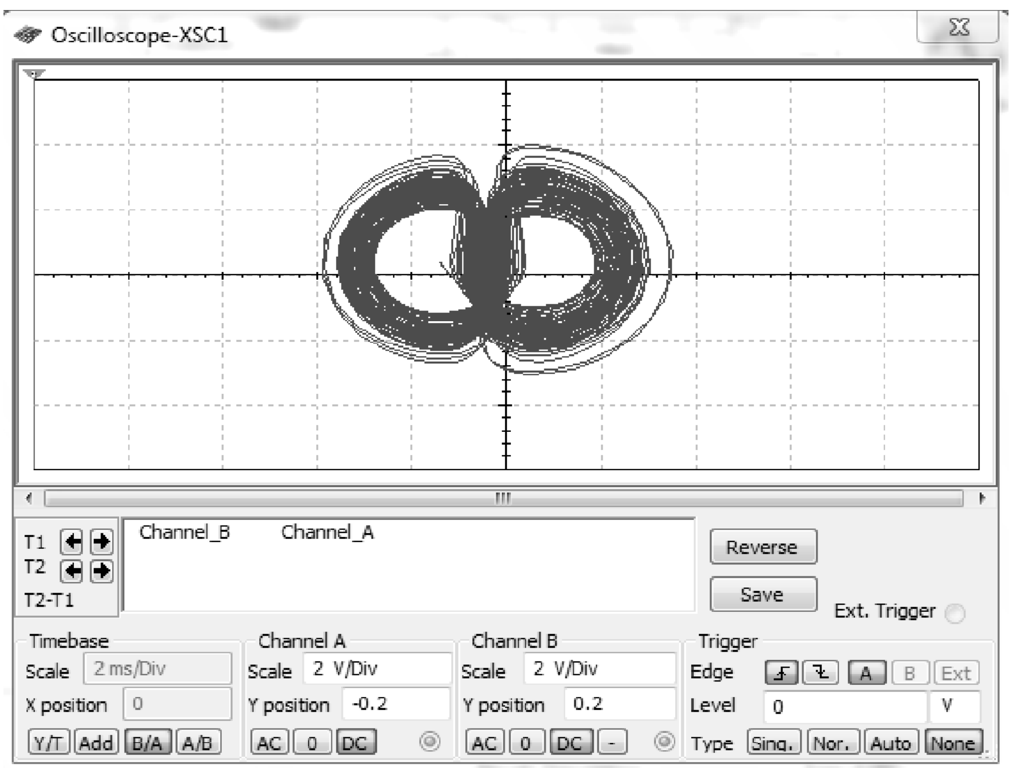

Figure 9: 2-D projection of the novel 3D hidden attractor chaotic system in *y-z* plane using MultiSIM 10.0

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