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Experimental and numerical realization of chaotic phenomena in a simple-3d new autonomous nonlinear electronic circuit

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ABSTRACT

The simple third-order chaotic dynamics of a new autonomous oscillator circuit was studied by measuring its responsible in the form of phase-portrait, power spectrum and chaotic time series. The circuit consists of just three linear elements (two capacitors and one inductor), one linear negative conductance and cubic nonlinearity exhibiting the symmetrical piecewise-linear *v-i* characteristics. The power spectrums are presented to confirm the lower dimensions of strong chaotic nature of the oscillations of the circuit. The performance of the circuit is investigated by means of experimental and numerical confirmation of the appropriate differential equations. The features of the obtained results are respected for various engineering system such as chaos communication systems with robustness against various interferences.

Introduction

In the present report the behavior of a third-order new autonomous oscillator circuit has been studied. This circuit consists of two active elements, one linear negative conductance and smooth cubic nonlinearity exhibiting symmetrical piecewise-linear *v-i* characteristics, two linear capacitances (C_1 and C_2) and one linear inductor (L) is also included in the circuit, serves as the control parameters [1-5].

Most chaotic and bifurcation effect cited in the literature have been observed in electrical circuits. They include the period-doubling route to chaos [6], the intermittency route to chaos [7], and the quasi-periodicity route to chaos and of course the crisis [8-10]. This popularity is attributed to the advantages which electric circuits offer to experimental chaos studies, such as robustness and convenient implementation.

In this work we introduce a new autonomous third-order oscillator circuit that realizes period-doubling route to chaos followed by periodic window and then to lower dimensions of strong chaos through boundary crisis etc. We consider that such complicated chaotic time waveforms are expected to be utilized for realization of several chaotic applications such as chaos communication system with robustness against various interferences including multi user access.

Experimental realization of the new autonomous oscillator circuit

The experimental realization of the simple-3D new autonomous oscillator is shown in Fig.1. The negative conductance ($-G_1$) and the symmetrical cubic nonlinearity is designed by the help of two signal diodes is used to introduce symmetrical cubic nonlinearities [11]-[12]. The characteristics of the negative conductance are mathematically represented by $i = -G_1V_1$. The *v-i* characteristics of the global nonlinearity which can therefore be approximated by a cubic function of the form with $a < 0$ and $b > 0$.

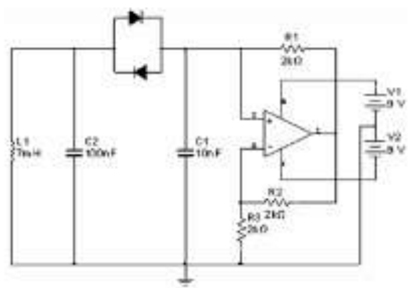

Fig. 1 Simple third-order new autonomous oscillator circuit.

$$f(V) = v + aV + bV^3$$

The constant term *v* describes the input current offset of the op-amp which can be practically adjusted to zero using the potentiometer (v = 0).

By applying Kirchhoff's laws to the equivalent circuit of Fig.1 we obtain the following set of differential equations:

$$C_1\frac{dV_1}{dt} = G_1V_1 + f(V_2 - V_1)$$

$$C_2\frac{dV_2}{dt} = i_L - f(V_2 - V_1)$$

$$L\frac{di_L}{dt} = -V_2 \qquad (1)$$

While V_1 and V_2 are the voltages across the capacitors C_1 and C_2, and i_L denote the current through the inductance (L) respectively, the term $f(V_2\text{-}V_1)$ representing the characteristics of the symmetrical cubic nonlinearity can be expressed mathematically as

$$f(V_2 - V_1) = a(V_2 - V_1) + b(V_2 - V_1)^3 \qquad (1.1)$$

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The simple-3D new autonomous oscillator circuit is also truly chaotic oscillator. This is because, there is no locally active resistance (*R*) in this circuit, only varying that the inductance (*L*) value, this circuit exhibits a very interesting dynamical phenomena like period-doubling bifurcation sequence leading to chaos, period-doubling window and then to lower dimensions of strong chaos through boundary condition [13].

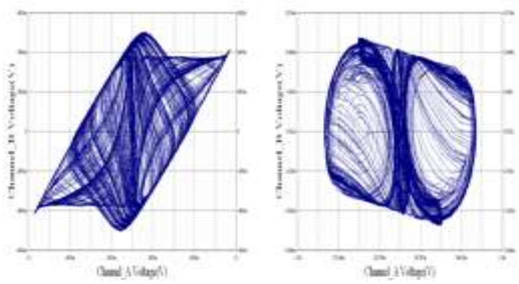
However in the parameter regimes investigated, important features like period-doubling window, lower dimensions of strong chaos have not been reported.

Experimental Observations: Period-doubling route to chaos via period-doubling window

For our present experimental study we have chosen the following typical values of the circuit in Fig.1: C_1 = 10*nF*, C_2 = 100*nF*. The negative conductance G_1 = -0.5*mS* and cubic nonlinear resistance $a < 0$ and $b > 0$. Here the variable inductor (*L*) is assumed to be the control parameter.

By increasing the value of *L* from 1*mH* to 10*mH*, the circuit behavior of Fig.1 is found to transmit from a period doubling route to chaos, and then to period doubling window through lower dimensions of strong chaos followed by boundary crisis etc. The projection of the attractors on the $(V_1 - V_2)$ and current sensing resistor with voltage plane of Cathode Ray Oscilloscope are shown in Fig.2 for various values of control parameter *L*.

Fig.3 shows the experimental chaotic time series were registered using a Cathode Ray Oscilloscope for discrete values of *L* serving as the control parameter.



(a) (b)

Fig 2. Typical experimental phase portraits of the system corresponding to different regimes.

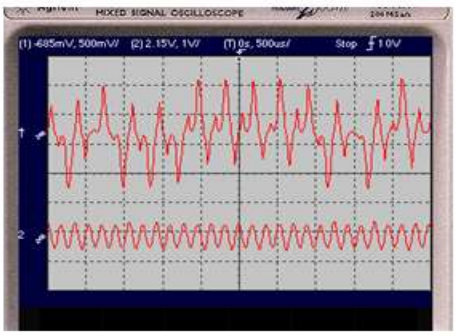
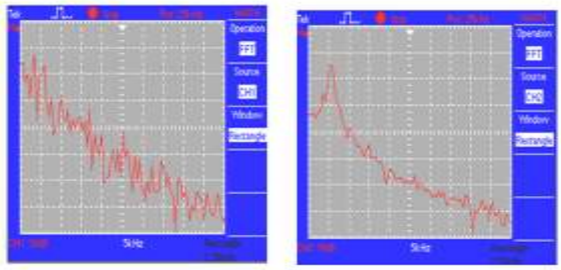


Fig. 3 Time-domain measurements of the proposed new autonomous third-order chaotic oscillator.

The simple third-order new autonomous oscillator circuit with the symmetrical cubic nonlinearity can produce lower dimensions of strong chaos see in Fig.4, from which we observe clearly that there are broad-band power spectrum.

The power spectrum corresponding to the voltages $V_1(t)$ and $V_2(t)$ waveform across the capacitors C_1 and C_2 respectively, which resembles broad-band spectrum noise.

Numerical realization of the new autonomous oscillator circuit



(a) (b)

Fig. 4 Power spectrum of the signals V1(t) and V2(t) from the circuit of new autonomous third-order chaotic oscillator.

For a convenient numerical analysis of the experimental systems given by Eqns.(1), we rescale the parameters as $V_1 = \frac{x_1}{\sqrt{bR}}$, $V_2 = \frac{x_2}{\sqrt{bR}}$, $i_L = \frac{x_3}{\sqrt{bR^3}}$, $t = \tau R C_2$, $\upsilon = \frac{C_2}{C_1}$, $\beta = \frac{C_2 R^2}{L}$, $\alpha = a R$, $\gamma = G_1 R$ and then redefine τ as *t*. Then the normalized equations of the third-order new autonomous oscillator circuit (Fig.1) are

$$\dot{x}_1 = \upsilon(\gamma x_1 + \alpha(x_2 - x_1) + (x_2 - x_1)^3)$$
$$\dot{x}_2 = x_3 - \alpha(x_2 - x_1) - (x_2 - x_1)^3$$
$$\dot{x}_3 = -\beta x_2 \qquad (2)$$

Where $f(x_2 - x_1) = \alpha(x_2 - x_1) + (x_2 - x_1)^3$ (2.1)

The dynamics of Eqns.(2) now depends on the parameter *α*, *β*, *γ* and *υ*.

The experimental results have been verified by computer simulation of the normalized Eqns.(2) using the standard fourth-order Runge-Kutta method for a specific choice of system parameters employed in the laboratory experiments. That is, in the actual experimental set up the inductor *L* is varied from *L* = 1*mH* upwards to 10*mH*.

Therefore in the numerical simulation we study the corresponding Eqns.(2) for *L* in the range *L* = (1*mH*, 10*mH*). From our numerical investigations, we find that for the value of *L* above 1*mH*, limit cycle motion is obtained, when the value of *L* is increased, particularly in the range *L* = 7*mH* the system displays a double band chaotic motion and then to period-doubling window through lower dimensions of strong chaos followed by boundary crisis etc.,. These numerical results are summarized in the phase portraits given in the $(x_1 - x_2)$, and $(x_2 - x_3)$ planes are shown in Fig.5. Figure 6. Shows the numerical chaotic time series were registered using a discrete value of *L* serving as the control parameter. It is gratifying to note that the numerical results agree qualitatively very well with that of the laboratory experiments.

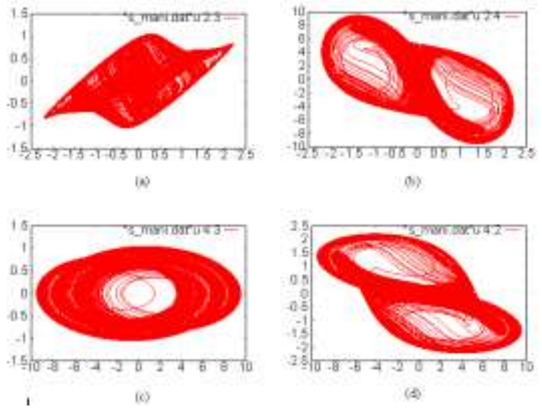


Fig. 5 Typical numerical phase portraits of the system corresponding to different regimes.

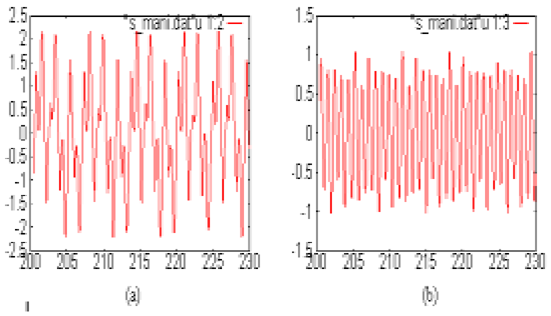


Fig. 6 Numerical time-domain measurements of the proposed new autonomous third-order chaotic oscillator.

Conclusions

It appears that the new autonomous oscillator circuit presented in this paper is one of the simplest third-order systems reported so far. Its simplicity arises from the fact that (i) The negative conductance is a simple op-amp impedance converter. (ii) The symmetrical cubic nonlinearity is synthesized from mere two signal diodes. (iii) The circuit equations are the most simple because of there is no locally active resistor (R) in the circuit, where the inductance (L) as the control parameter. The attractive features of this circuit are the presence of period-doubling route to chaos, period-doubling window through lower dimensions of strong chaos followed by boundary condition etc. It is of further interest to study these aspects also in this system as well as the intermittency route to chaos and synchronization of coupled chaotic circuits of the present system for improved high security communication systems.

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