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Rich Variety of Bifurcation and Chaos in a Simple Non-Source Free Electronic Circuit with a Diode

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Abstract

A very simple nonlinear parallel forced LCR circuit is proposed as Balamurugan-Sengodan-Daniel (BSD) circuit includes linear inductors, capacitor, locally active resistor and a diode driven by a sinusoidal voltage source. By varying the amplitude of the external signal, we identify the familiar quasiperiodic routes to chaos as well as period doubling sequences, windows, and so on. The performance of the proposed system is demonstrated experimentally and proved with Poincaré map results.

Keywords: Bifurcation, Chaos, Nonlinear Electronic Circuits.

Introduction

Over the past decade, a variety of nonlinear autonomous and non-autonomous chaotic circuits exhibiting chaotic behavior have been demonstrated. Most of them are lower order in nature which depends the energy storing elements used in it. Chua's circuit is a simple electronic circuit that exhibits classic chaos theory behavior[1-4]. A number of different electronic circuits consisting of their real, nonlinear physical devices such as varactor diodes, neon bulbs etc., or piecewise-linear elements like nonlinear resistors, nonlinear capacitors have been used to generate the chaos and to study different properties such as period-doubling bifurcations, period adding sequences, quasiperiodicity and intermittent transitions. The use and nature of the autonomous circuits are well performed, a number of numerical and theoretical investigations have been carried out on this regards to generate the chaos and nature of nonlinear dynamics.

Further it is important to explore the dynamics of higher order circuit under the influence of an external sinusoidal signal. However up to now such a non-source free version of higher order nonlinear circuit with own diode as a nonlinear element seems not to have been investigated as far as author's knowledge goes. The result of our system exhibits much stronger chaotic signal, period doubling as well as quasiperiodicity, to name a few. Due to the same, this system may be used as a chaos generator in chaos analog communication as well as chaos code generator for chaos shift keying (CSK) in cryptography[5-6].

Realization of the BSD (Balamurugan- Sengodan- Daniel) circuit.

The realization of the proposed simple non-autonomous, namely, BSD circuit, is depicted in Fig 1. It consists of two linear inductors, a linear capacitor, linear negative conductance, diode and sinusoidal voltage source. The basic difference between Chua's circuit and the present BSD circuit is that, here Chua's diode is replaced by a combination of a p-n junction diode and a negative conductance. The V-I characteristic of the diode is approximated by the two segment piecewise-linear function[7-8]. The governing equation of this circuit is represented by the following non-autonomous differential equations:

$$L_1 \frac{di_{L1}}{dt} = -Ri_{L1} - V + f \sin \omega t \tag{1}$$

$$L_2 \frac{di_{L2}}{dt} = V \tag{2}$$

$$C \frac{dv}{dt} = i_{L1} - i_{L2} - i_d - i_g \tag{3}$$

where 'f' is the amplitude and ω is the angular frequency of the external periodic force.

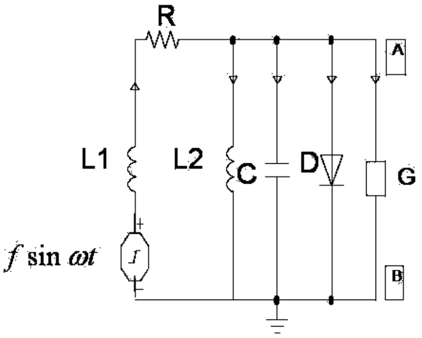


Figure 1: Realization of the BSD (Balamurugan- Sengodan- Daniel) non-autonomous circuit. Here diode 'D' is the nonlinear element.

Experimental setup of the circuit

The entire block diagram of the experimental setup is shown in Fig.2. For the experimental study, we are getting the external oscillatory signal from the function generator (15 MHz) of Hewlett Packard model 33120 A. The dynamical behavior of the circuit is observed using the help of the cathode ray oscilloscope (Philips PM 3206, 15 MHz). To start our experiment, we fix the values of each circuit element. This we do from our experience about the values available in the literature. Thus the inductance and capacitance are chosen in the range of mH and nF respectively. The resistance and frequency are chosen in the range of ohm (Ω) to kilo ohm (kΩ) and hertz (Hz) to kilo hertz (KHz) respectively. We carry out the experiments by fixing the values of the elements except the amplitude of the external source, which is actually varied during the experiment. The values are given by L1=101.3 mH, L2=61.9 mH, C =10 nF, R=492 ohm, G=0.45 ms and the frequency f = 5.5 KHz. Here as mentioned the amplitude of the forced signal is the variable one. Thus the amplitude is treated as the control parameter for the circuit. Fig.3. shows the laboratory realization of negative conductance G. In this circuit, an operational amplifier (Op-Amp) IC 741 is used with three 2K linear resistors. The positive ($V^{+} = +9V$) and negative ($V^{-} = -9V$) voltage are given to pin numbers seven and four of the Op-Amp IC 741 respectively. A and B are the positive and negative terminals of the negative conductance G. The X-Y terminal of CRO is connected to trace the attractors projected on the CRO screen. We selected the circuit parameters of negative conductance [9-10] as R1=R2=R3= 2 KΩ.

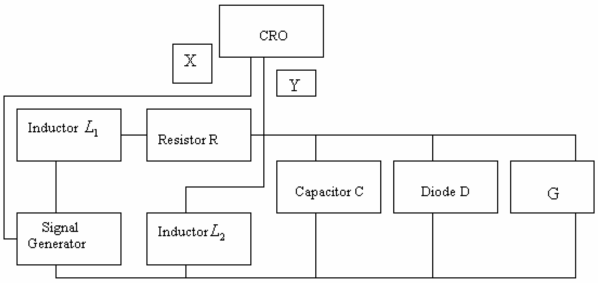


Figure 2: Block diagram of the total experimental setup of BSD circuit.

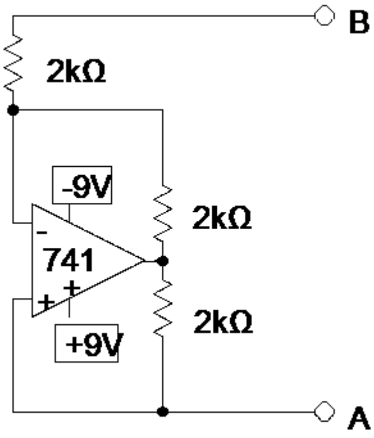
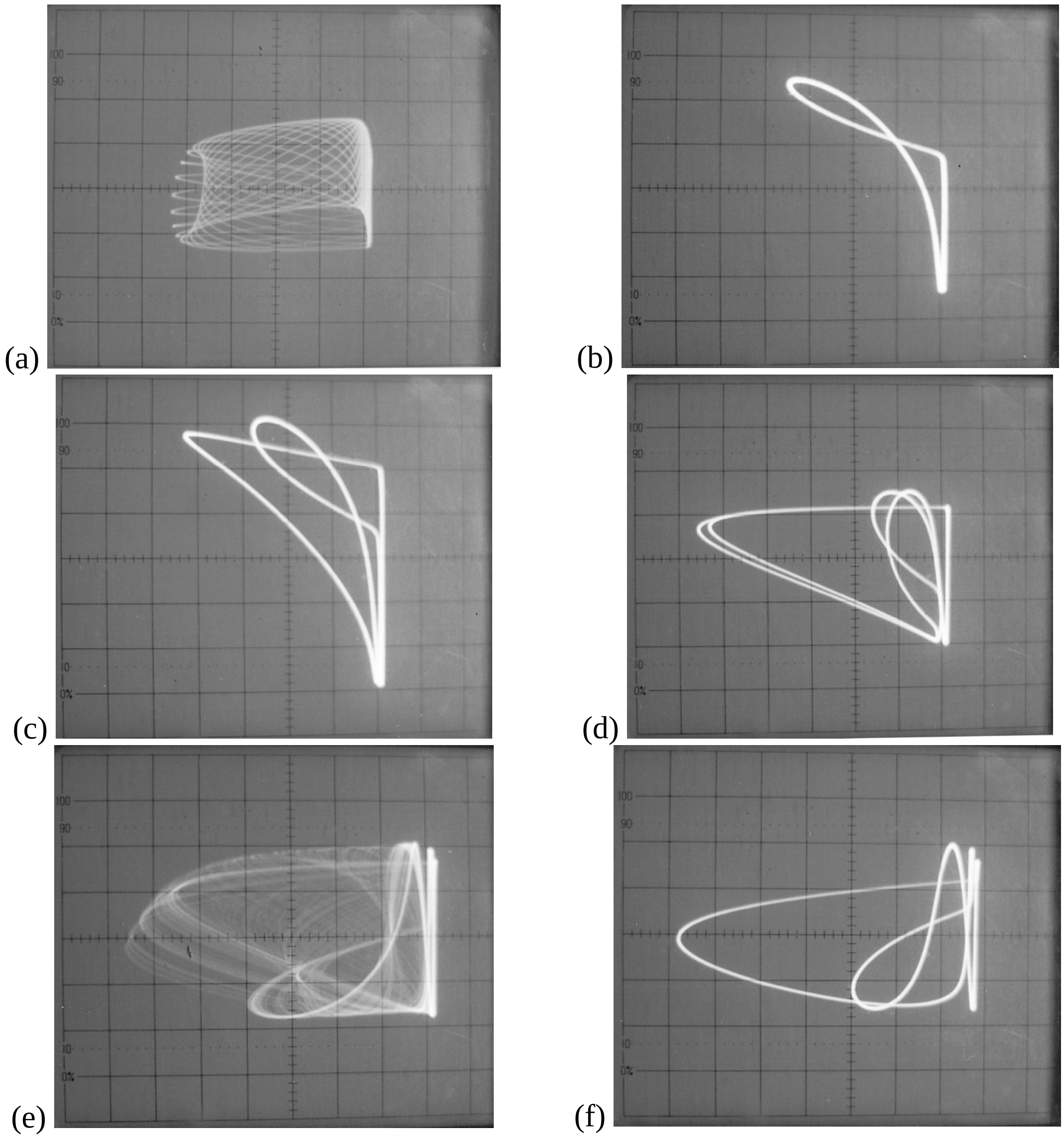


Figure 3: Laboratory realization of the negative conductance.

Observations and Experimental results

By increasing the amplitude of the periodic signal from 50 mV , the circuit is found to exhibit a sequence of bifurcations, starting from quasiperiodic attractor, period-doubling, chaos, period window, reverse period-doubling and boundary crisis etc. These outputs are traced by CRO. We give below the details of experimental observations made in the CRO screen for different range of the amplitude of the external periodic signal. The experimental observations are found in Fig 4.

1. For small values of F (~ 50 mV), quasiperiodicity occurs. This quasi periodicity is stable for 50< F <168 mV.
2. When the amplitude is increased to F=168 mV, the quasiperiodicity becomes unstable and a period 1T orbit is born and is stable in the range of amplitude 168< F <280 mV. As the parameter F is further increased, period 2T, 4T…. orbits are found to occur leading to onset of chaos.



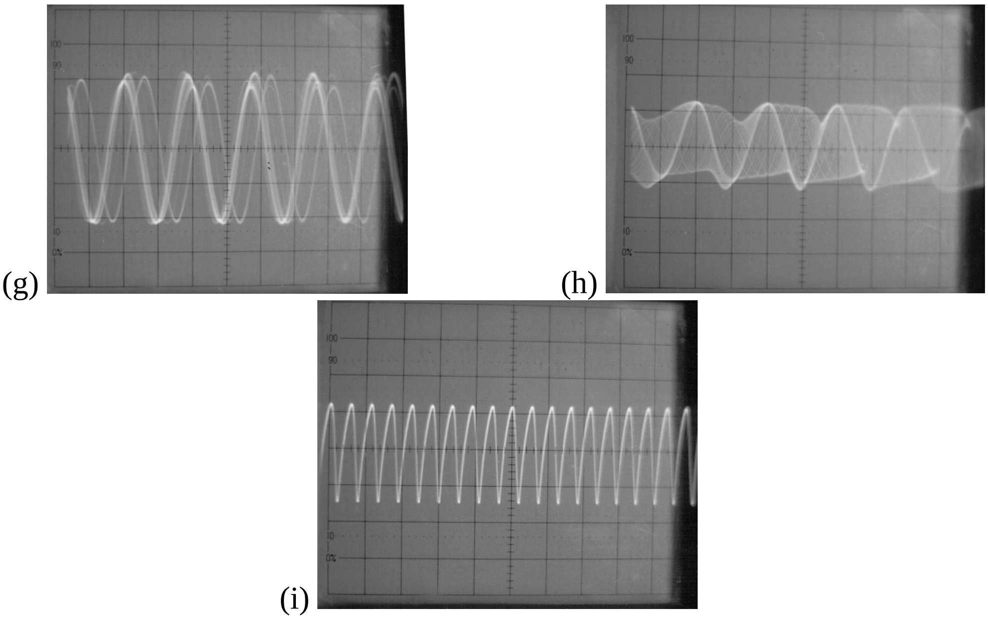


Figure 4: Experimental observations of BSD Circuit: (a) Quasiperiodicity, (b) Period-1T, (c) Period-2T, (d) Period-4T, (e) Chaos, (f) Period-5 Windows (g) Waveform of quasiperiodicity, (h) Waveform of Chaos, (i) External periodic signal.

3. The amplitude of the external periodic signal F is further increased the period 2T orbit at F=280 mV and it is stable in the range 280 < F < 335 mV.
4. When the amplitude of the circuit is kept as further increased, period 4T orbit is born at the amplitude value F=335 mV and is stable in the range of 344 < F < 344 mV.
5. The chaotic attractor is stable up to 397 mV. And it is maintained the same in the range of 344 < F < 397 mV.
6. After that the system exhibits period 5 windows. When the amplitude of the periodic signal is kept at 397 mV, period 5 windows occur and it is stable in the range 397 < F < 434 mV. Finally, the system goes to the boundary crisis when the amplitude value exceeds 475 mV.

Proof of the experimental results by Poincaré Map

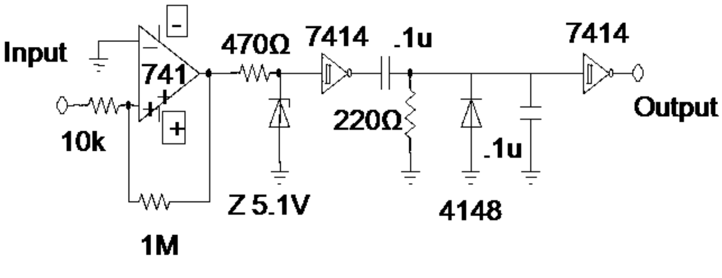
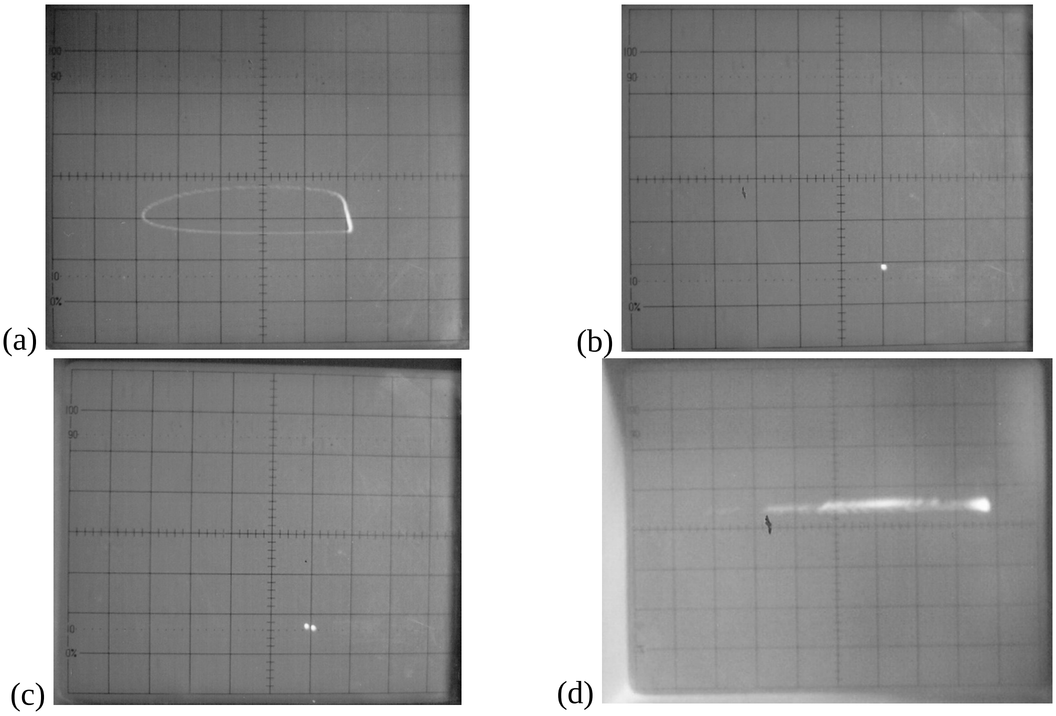


Figure 5: Realization of the Poincaré Map circuit.

In order to confirm the different experimental results obtained for a choice of circuit parameters including strong chaos in the CRO, we trace a live picture of the corresponding Poincaré map of the projected attractor. For this we construct the circuit given in Fig.5 and connect it to our nonlinear circuit. Here the Schmitt Hex inverter Buffer IC 7414, and the operational amplifier IC 741 are used. Among the 14 pins of IC 7414, one can use pin number 'one' as a input terminal and 'two' as a output terminal. And pins seven and 14 are the ground (GND) and the positive voltage (+5V dc) terminals respectively. In the experimental setup, the Poincaré map is connected to our nonlinear circuit, in the Fig.1. The external oscillatory source, which is used in our BSD circuit, is also feed to the Poincaré map circuit as an input. The output of the mapping circuit is connected with the Z-input terminal of the CRO. A live picture of the corresponding Poincaré map of the projected attractor has been produced by this circuit. Fig.6 shows the output of the Poincaré map for each attractor of our nonlinear circuit. These stroboscopic maps are produced by triggering the beam of the oscilloscope at the driving frequency, $\gamma (= \omega / 2\pi)$ (Z- Modulation)[11].



(a) (b) (c) (d)

Figure 6: Poincaré Map of Fig 4. (a) Quasiperiodicity, (b) Period-1T, (c) Period-2T, (d) Chaos.

Conclusion

A simple non-autonomous, higher order chaotic circuit namely BSD circuit has been introduced. Under the influence of the external signal, and a new nonlinear element named p-n junction diode, we found rich variety nonlinear characteristics. The live pictures of the corresponding Poincaré map of the projected attractors have also been studied. In view of the appearance of several ubiquitous routes to chaos such as quasiperiodicity, period doubling and intermittency in such a single but simple electronic circuit, one can make use of the circuit in varied investigations on chaotic dynamics and applications, including multiple cascaded heterogenous chaotic systems.

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