C9 Unravel the general characteristics of chaotic systems by exploring chaotic circuits

SUPPLEMENTARY INFORMATION

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Contents

1 Materials and instruments

Table S1: **Materials and instruments**

Name	Total	Model and parameters
Anaconda	1	*version* 4.10.3
Multisim	1	*version* 16.0
LTspice	1	*version* 17.0.34
Breadboard	1	
Various Electric components		(Details in next section)

2 Exp.1 Chua's circuit

2.1 Main parameters

2.1.1 Numerical calculation

Parameters of different patterns adopted in the numerical calculation are summarized in Tab. S2. These parameters can also be explored in the Jupyter Notebook provided in the thesis.

Table S2: **Parameters of different patterns, numerical calculation**

pattern	m_1	m_2	α	β
line	-2.0	-1.3	26	12
limit ring	-0.5	1.0	13	13
double attractors	-1.1	-0.7	21	36
1st single attractor	-1.1	-0.7	21	31
2nd single attractor	-1.1	-0.7	21	15

2.1.2 Simulation

To generate different chaotic patterns, we adjusted the resistance value of R_7. The different resistance values of the corresponding patterns for the two circuits are summarized in Tab. S3 and Tab. S4, respectively.

2.1.3 Experiment

We built the two circuits and adjusted the resistance value of R_7 to get different chaotic patterns. Parameters of electric components are summarized in Tab. S5 Different resistance value of corresponding patterns for the two circuits are summarized in Tab. S6 and Tab. S7, respectively.

Table S3: **Parameters of different patterns, simulation of circuit I**

pattern	R_7
line	$0.00\% \times 2k\Omega$
limit ring	$76.8\% \times 2k\Omega$
double attractors	$86.8\% \times 2k\Omega$
1st single attractor	$94.8\% \times 2k\Omega$
2nd single attractor	$96.0\% \times 2k\Omega$

Table S4: **Parameters of different patterns, simulation of circuit II**

pattern	R_7
line	$0.00\% \times 2k\Omega$
limit ring	$52.0\% \times 2k\Omega$
double attractors	$78.0\% \times 2k\Omega$
1st single attractor	$80.6\% \times 2k\Omega$
2nd single attractor	Missing

Table S5: **Parameters of electric components**

Name	Total	Value
L_1	1	$21.005mH$
C_1	1	$10.277nF$
C_2	1	$91.104nF$
R_1	1	218.43Ω
R_2	1	220.13Ω
R_3	1	$22.060k\Omega$
R_4	1	$21.923k\Omega$
R_5	1	$2.2012k\Omega$
R_6	1	$3.2625k\Omega$
R_7	1	$Max1.9650k\Omega$

Table S6: **Parameters of different patterns, experiment of circuit I**

pattern	R_7
line	0.00Ω
limit ring	1498.20Ω
double attractors	1880.32Ω
1st single attractor	1907.20Ω
2nd single attractor	Misssing

Table S7: **Parameters of different patterns, experiment of circuit II**

pattern	R_7
line	0.00Ω
limit ring	1408.01Ω
double attractors	1563.20Ω
1st single attractor	1661.41Ω
2nd single attractor	1802.03Ω

3 Exp.2 Lorentz's circuit

3.1 Main parameters

3.1.1 Numerical calculation

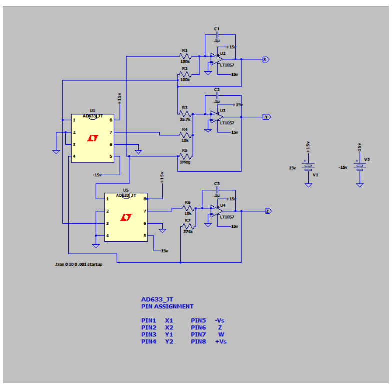
Parameters for generating the Lorentz butterfly in the numerical calculation are summarized in Tab. S8. These parameters can also be explored in the Jupyter Notebook provided in the thesis.

Table S8: **Parameters of Lorentz butterfly, numerical calculation**

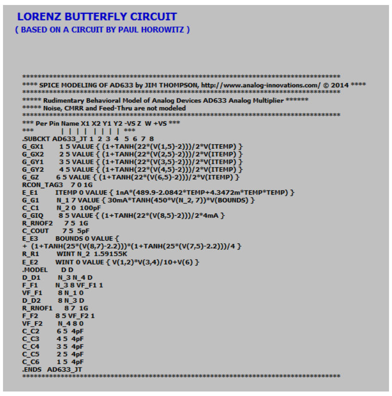
pattern	α	β	γ
butterfly	10.0	28.0	2.8

3.1.2 Simulation

The simulation circuit (Fig. S1a) and the corresponding parameters (Fig. S1b) to generate the Lorentz butterfly in LTspice are shown below. This schematic referenced Jim's work, who kindly provided his schematic on his website(www.chaotic-circuits.com). We especially thanks to him.



(a) The schematic



(b) Parameters

Figure S1: **Simulation of the Lorentz circuit**

4 Reflection question

4.1 Application of chaotic circuits

1. As mentioned in the thesis, when investigating other much more complex chaotic systems, it is a pretty effective way to create and operate on an electronic ”analog” instead of directly working with the actual system, which may be difficult or impossible to control.

2. Chaotic systems can be used for socalled chaos encryption, which means hiding data signals within a chaotic signal to ensure the security[1].

3. They can also be used for true random bit generation taking advantages of their long-term unpredictability[2].

4. In robotics, chaotic signals are being used in neural control networks or as chaotic path generators [3].

5 Data and code availability

Data and code are available at https://github.com/Zweig-Wong/SYSU-PHY-EXP

Reference

1. C. Tanougast, in *Chaos-Based Cryptography*, ed. by L. Kocarev, S. Lian, red. by J. Kacprzyk (Springer Berlin Heidelberg, Berlin, Heidelberg, 2011), vol. 354, pp. 297–330, ISBN: 978-3-642-20541-5 978-3-642-20542-2, (2022; http://link.springer.com/10.1007/978-3-642-20542-2_9) (cit. on p. 5).
2. R. M. Nguimdo *et al.*, *Optics Express* **20**, 28603, ISSN: 1094-4087, (2022; https://opg.optica.org/oe/abstract.cfm?uri=oe-20-27-28603) (Dec. 17, 2012) (cit. on p. 5).
3. S. Steingrube, M. Timme, F. Wörgötter, P. Manoonpong, *Nature Physics* **6**, 224–230, ISSN: 1745-2473, 1745-2481, (2022; http://www.nature.com/articles/nphys1508) (Mar. 2010) (cit. on p. 5).