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# *Design and Implementation of Chua's Controller for Industrial Mixers*

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**บทคัดย่อ** — ระบบการผสมในอุตสาหกรรมเป็นสิ่งที่สำคัญมากในอุตสาหกรรมยาและอุตสาหกรรมอาหาร ปัญหาของระบบผสมในอุตสาหกรรมคือความไม่มีประสิทธิภาพ การสิ้นเปลืองพลังงาน และราคาของอุปกรณ์ที่มีราคาสูง ในงานวิจัยนี้จึงศึกษาวิธีการสร้างอุปกรณ์ทางกลที่มีราคาถูกและสามารถใช้ในระบบผสมที่มีประสิทธิภาพกว่าระบบเดิมโดยอาศัยสัญญาณอลวนเพื่อสร้างรูปแบบการผสมที่เหมาะสม ทำการเปรียบเทียบสัญญาณรูปแบบเดิมกับสัญญาณอลวน จากการทดลองสัญญาณอลวนแบบ Chua's มีประสิทธิภาพมากที่สุด โดยในการจำลองการทำงานใช้โปรแกรม Scilab และทำการทดสอบหาอัตราส่วนการครอบคลุมพื้นที่ของระบบผสม

***คำสำคัญ – อลวน, การผสมแบบอลวน, การผสมอุตสาหกรรม, มอเตอร์***

*Abstract— Industrial Mixers are one of the most important mixing equipments in chemical drug and food industries. The main problem of conventional industrial mixing is ineffective in energy consumption and expensive device. In this paper is study mixing independently of the mechanisms used to create the motion and study chaotic signal for industrial mixing process. Mixing effective compared between conventional signal with chaotic signal by Chua's control. The chaotic signal by Chua's controller was saving energy, low cost, and compatible with formal processed. The results are simulated with Scilab software and compared with the chaotic ratio in coverage area.*

***Keywords - chaos; chaotic Mixing; industrial mixing; motor,***

## I. INTRODUCTION

In chaos theory and fluid dynamics, chaotic mixing is a process by which flow tracers develop into complex fractals under the action of a fluid flow. The flow is characterized by an exponential growth of fluid filaments. Even very simple flows, such as the blinking vortex, or finitely resolved wind fields can generate exceptionally complex patterns from initially simple tracer field.

Chaos theory is a branch of mathematics and it is focused on the behavior of dynamical systems that are highly sensitive to initial conditions. 'Chaos' is an interdisciplinary theory stating that within the apparent randomness of chaotic complex systems, there are underlying patterns, constant feedback loops, repetition, self-similarity, fractals, self-organization, and reliance on programming at the initial point known as sensitive dependence on initial conditions. The butterfly effect describes how a small change in one state of a deterministic nonlinear system can result in large differences in a later state, e.g. a butterfly flapping its wings in Brazil can cause a hurricane in Texas.[1]

Small differences in initial conditions (such as those due to rounding errors in numerical computation) yield widely diverging outcomes for such dynamical systems a response popularly referred to as the butterfly effect rendering long-term prediction of their behavior impossible in general.[2][3] This happens even though these systems are deterministic, meaning that their future behavior is fully determined by their initial conditions, with no random elements involved.[4] In other words, the deterministic nature of these systems does not make them predictable.[5][6] This behavior is known as deterministic chaos, or simply chaos. The theory was summarized by Edward Lorenz as:[7]

## II. CHUA'S ATTRACTOR

Chua's attractor is a simple electronic circuit that exhibits classic chaotic behavior. It produces an oscillating waveform that, unlike an ordinary electronic oscillator, never repeats. It was invented in 1983 by Leon O. Chua, who was a visitor at Waseda University in Japan at that time.[8] The ease of construction of the circuit has made it a ubiquitous real-world example of a chaotic system, leading some to declare it a paradigm for chaos.[9]

The Chua attractor is defined by the system of following equations:

$$\begin{aligned} \frac{dx}{dt} &= a(y - x - f(x)) \\ \frac{dy}{dt} &= b(x - y + z) \\ \frac{dz}{dt} &= -cy \end{aligned} \tag{1}$$

Where: $f(x) = m_1 x + 0.5(m_0 - m_1)(|x+1| - |x-1|)$

The Chua attractor with parameter values:

$x_0=0.1, y_0=0.1, z_0=0.1, a=15.6, b=1, c=25.28, m0=-8/7, m1=-5/7$

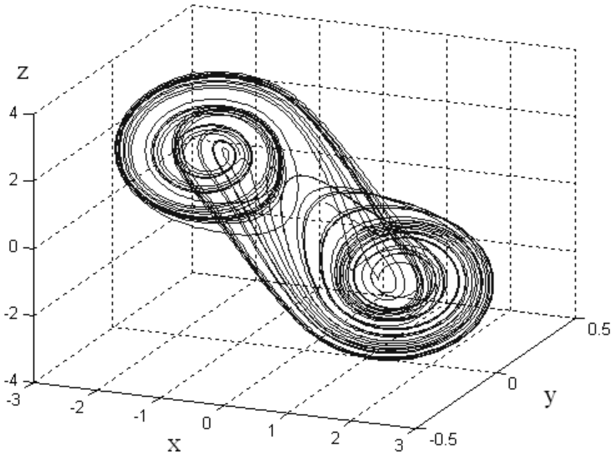

Figure 1. Chua attractor (Scilab Simulated)

## III. THE CHUA’S CIRCUIT

Chua's circuit is a simple electronic circuit that exhibits classic chaos theory behavior. It was introduced in 1983 by Leon O. Chua. [10][11]

In the figure 2 it is shown how Chua's circuit looks like. Cl and C2 are the parameters of the conductors. R is the changeable resistance and L is the constant value of the coil.

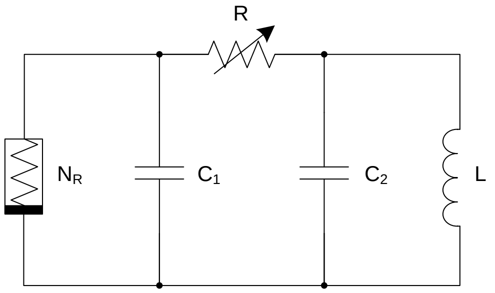

Figure 2. The schematic of Chua's circuit

Chaotic dynamics can be described in many different differential equations that can be built into an electrical circuit. An example of an electrical circuit, which is used in this research, is Chua's circuit. The differential equations of Chua's circuit are shown in equation (1).

$$\begin{aligned} C_1 \frac{dV_{C1}}{dt} &= \frac{1}{R}\left(V_{C2} - V_{C1}\right) - f\left(V_{C1}\right) \\ C_2 \frac{dV_{C2}}{dt} &= \frac{1}{R}\left(V_{C1} - V_{C2}\right) + i_L \\ L\frac{di_L}{dt} &= -V_{C2} \end{aligned} \tag{1}$$

$N_R$ is the value of the negative resistance. The measured values are $V_{C1}$, $V_{C2}$ and $i_L$. These values can be measured, which will give experimental results. But they can also theoretical be calculated by the differential equations above. The value of $N_R$ is depended on $f(V_{C1})$. Equation (2) is $f(V_{C1})$.

$$f\left(V_{C1}\right) = G_b V_{N_R} + \frac{1}{2}\left(G_a - G_b\right)\left(\left|V_{N_R} + B_p\right| - \left|V_{N_R} - B_p\right|\right) \tag{2}$$

The figure 3 shows Low frequency Chua's circuit. Chua's circuit can be generated by two signals: double scroll ($V_{C1}$) and single scroll ($V_{C2}$). This research selects double scroll ($V_{C1}$) in the figure 4 to chaotic mixing.

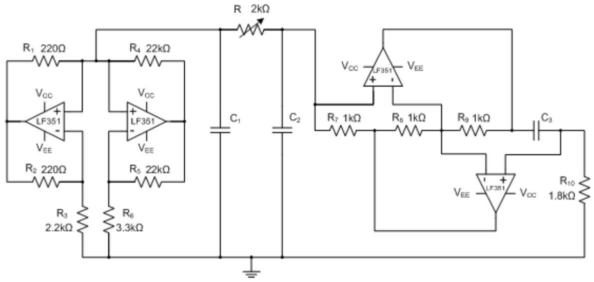

Figure. 3. Low frequency Chua's circuit ($L_{eq}$)

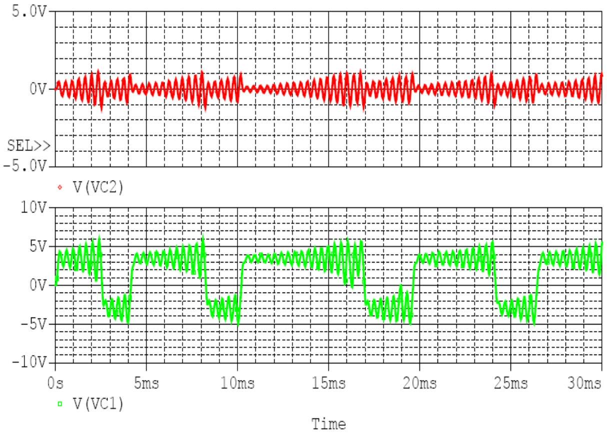

Figure. 4. Chua's signal Double scroll $V_{C1}$ (Lower), Single scroll $V_{C2}$ (Upper)

## IV. DESIGNAND IMPLEMENTATION

In this section, signal generators and signal regulator are explained. The control signals in this experimental are DC signal at 2, 3, 4 VDC, Sine wave 5 Vp-p at 1,5,10 Hz, Chua's Single Scroll at Leq 1.80,5.94,8.46 *H*, and Chua's Double Scroll at Leq 1.80,5.94,8.46 *H* respectively. The modules can be adjusted offset level by control signal, after that we modulated DC signal, Sine wave signal, Chua's chaotic signal by PWM method. The last step, the mixed signals are used to drive DC motor as shown in figure 5.

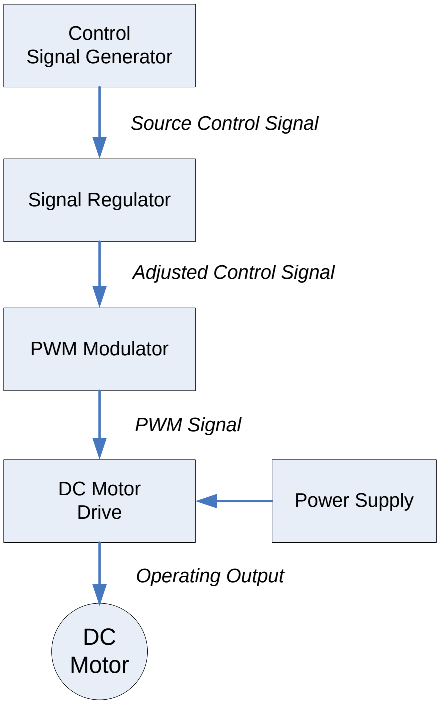

Figure 5. Chaotic Mixing Step

The motor is setting on the top of mixing equipment and The agitator is a shaft with a propeller attached with conventional paddle. the two components that provide for good mixing are radial and axial flow. A propeller with pitched blades promotes this behavior. In figure 6 shows the mixing experimental set-up.

Pulse width modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off as shown on the figure 7.This experimental used the SG3524(Regulating pulse-width modulators) for generated PWM signal from control signal as shows in figure 8.

Figure 6. Mixing experimental set-up.

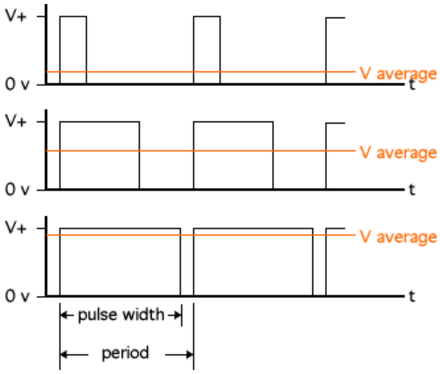

Figure 7. PWM signal

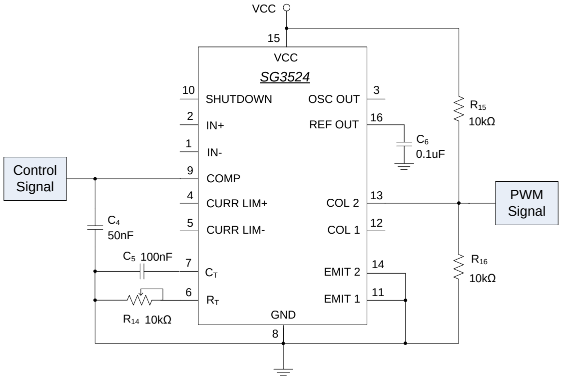

Figure 8. Regulating PWM

## V. EXPERIMENTAL RESULTS

In experimental figure 7, we used DC, Sine and Chua's signals to compare mixing efficiency. Figure 6 shows pulse width modulation (PWM) signal. We used plastic ball to observe moving effect from DC, Sine and Chua's signals as shown in figure 14-25. Figure 8-10 shows Chua's signal single scroll $L_{eq}$ = 1.80$H$, 5.94$H$, and 8.46$H$ respectively. Figure 11-13 shows Chua's signal double scroll $L_{eq}$ = 1.80$H$, 5.94$H$, and 8.46$H$ respectively.

Signal generator

| | | |
|---|---|---|
| 1. | DC | @ 2, 3, 4 $V_{DC}$ |
| 2. | Sine Wave 5 Vp-p | @ 1,5,10 Hz |
| 3. | Chua's Single Scroll | @$L_{eq}$ 1.80,5.94,8.46 $H$ |
| 4. | Chua's Double Scroll | @$L_{eq}$ 1.80,5.94,8.46 $H$ |

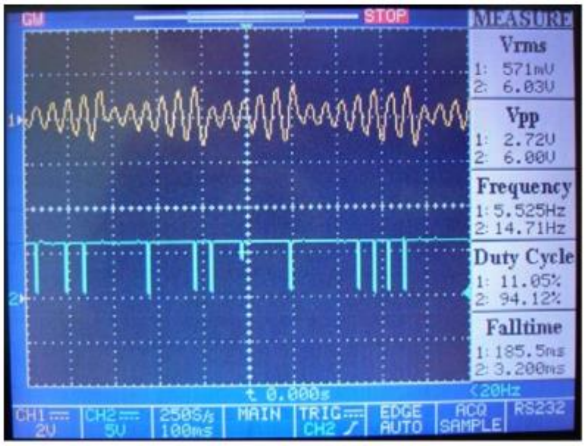

Figure 9. Single scroll C1 = 1 $\mu F$, C2 = 10 $\mu F$, $L_{eq}$ = 1.80 $H$

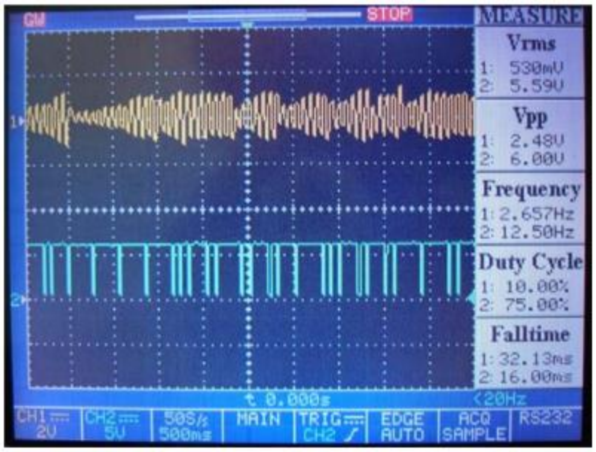

Figure 10. Single scroll C1 = 3.3 $\mu F$, C2 = 33 $\mu F$, $L_{eq}$ = 5.94 $H$

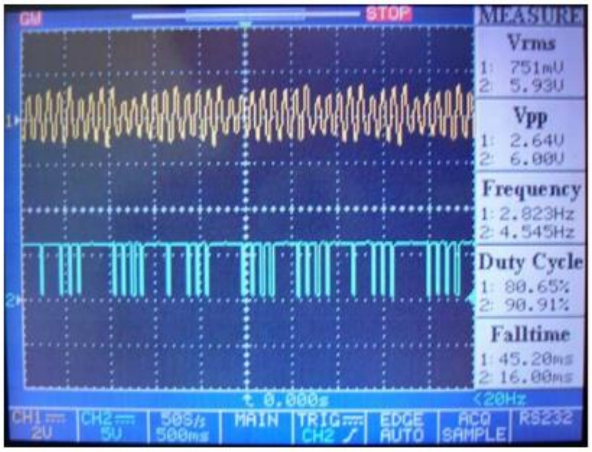

Figure 11. Single scroll C1 = 4.7 $\mu F$, C2 = 47 $\mu F$, $L_{eq}$ = 8.46 $H$

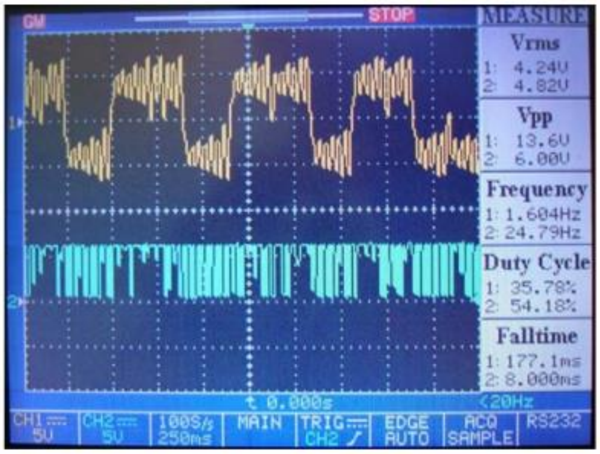

Figure 12. Double scroll C1 = 1 $\mu F$, C2 = 10 $\mu F$, $L_{eq}$ = 1.80 $H$

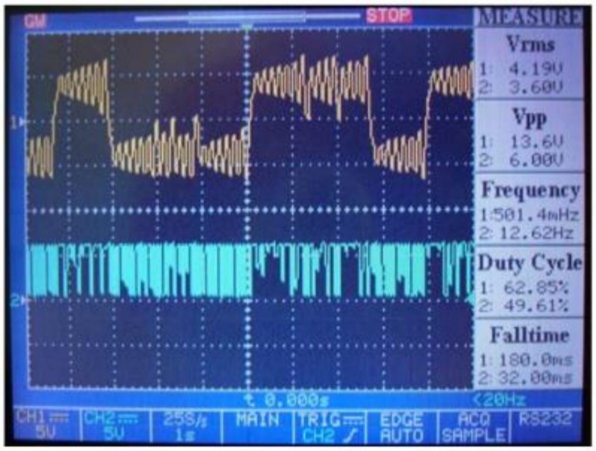

Figure 13. Double scroll C1 = 3.3 $\mu F$, C2 = 33 $\mu F$, $L_{eq}$ = 5.94 $H$

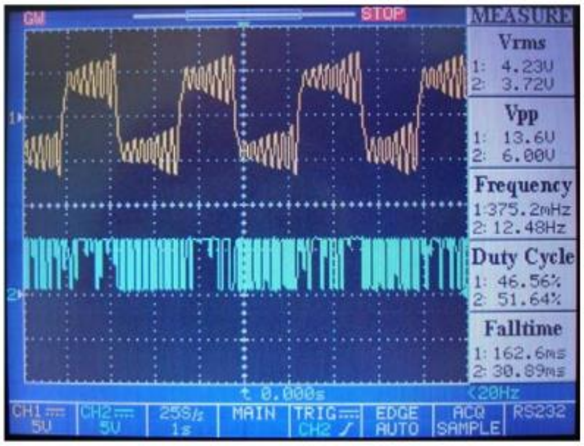

Figure 14. Double scroll C1 = 4.7 $\mu F$, C2 = 47 $\mu F$, $L_{eq}$ = 8.46 $H$

Table I: Experimental coverage mixing results

| | | | |
|---|---|---|---|
| **DC** | ***2VDC*** | ***3VDC*** | ***4VDC*** |
| | 67.8% | 71.9% | 71.2% |
| **Sine Wave** | ***1Hz*** | ***5Hz*** | ***10Hz*** |
| | 75.5% | 74.8% | 73.8% |
| **Chua's Single** | ***Leq 1.80H*** | ***Leq 5.94H*** | ***Leq 8.46H*** |
| | 79.0% | 86.0% | 86.6% |
| **Chua's Double** | ***Leq 1.80H*** | ***Leq 5.94H*** | ***Leq 8.46H*** |
| | 84.5% | 89.7% | <u>90.8%</u> |

## VI. CONCLUSION

The chaotic signal from Chua's circuit for industrial mixing processes is designed and implemented using a basic of control engineering. The system is simple yet effective both in cost and performance. In our system, Chua's signal double scroll *Leq = 8.46H* is selected for chaotic mixing because the result of mean average is maximum (90.8%) as shown in Table I. Figure 15-16 shows conventional mixing on pure water and the figure 17-28 shows coverage area of the plastic ball effect with different signal.

## REFERENCES

[1] E.L. Paul, V.A. Atiemo-Obeng, and S.M. Kresta, Handbook of Industrial Mixing : Science and Practice, Hoboken, NJ : Wiley-Interscience, 2004.

[2] G.B. Tatterson, Scaleup and design of industrial mixing processes, New York : McGraw-Hill, Inc., 1994.

[3] Z. Zhong, "Chaotic liquid shaker : Design, Implementation and application," Master of Philosophy, City University of Hong Kong, 2006.

[4] T. Shinbrot, A. Alexander, M. Moakher, and F.J. Muzzio, "Chaotic Granular Mixing," Amarican Institule of Physics : Chaos, Vol.9, No. 3, September 1999, pp. 611-620.

[5] E.T Cuautle, M.A. Villasenor, and J.M. Ortega, "Modeling and Simulation of a Chaotic Oscillator by MATLAB," Electronics, Robotics and Automotive Mechanics Conference, Vol.1, September 2006, pp. 239-242.

[6] M.P. Kennedy, "Experimental Chaos via Chua's Circuit," Electronic Research Laboratory, University of California, Berkeley, 1992, pp. 340-351.

[7] R.N. Madan, Chua's circuit: A paradigm for chaos, World scientific publishing Co. Pte. Ltd., Singapore, 1993.

[8] T. Matsumoto, "A Chaotic Attractor from Chua's Circuit," IEEE Transactions on Circuits & Systems, Vol.31, No.12, December 1984, pp.1055-1058.

[9] R.N. Madan "Chua's circuit: a paradigm for chaos", River Edge, N.J.: World Scientific Publishing Company, 1993

[10] G.Q. Zhong, and F. Ayrom, "Experimental Confirmation of Chaos from Chua's Circuit," International Journal of Circuit Theory & Applications, Vol.13, No.1, 1985, pp. 93-98.

[11] F. Ayrom, and G.Q. Zhong, "Chaos in Chua's circuit," IEEE Proceedings-D Control Theory & Applications, Vol.133, No.6, November 1986, pp. 307-312.


File Name : DC.mpg
File Size : 23.34 MB
Average FPS : 25.00
Resolution : 640x480
Duration : 00:01:07

Figure 15. DC signal @4VDC. (Pure water)


File Name : Sine.mpg
File Size : 23.22 MB
Average FPS : 25.00
Resolution : 640x480
Duration : 00:01:06

Figure 16. Sine Wave 5Vp-p @1Hz (Pure water)


File Name : 2V.mpg
File Size : 10.71 MB
Average FPS : 25.00
Resolution : 640x480
Duration : 00:00:30

Figure 17. DC signal @2VDC.

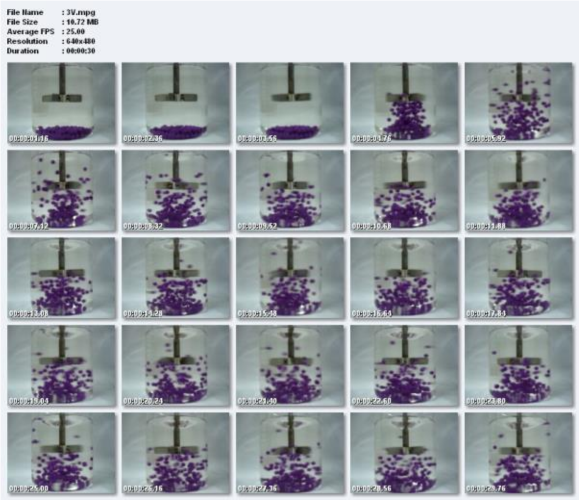
File Name : 3V.mpg
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Figure 18. DC signal @3VDC.


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Figure 19. DC signal @4VDC.

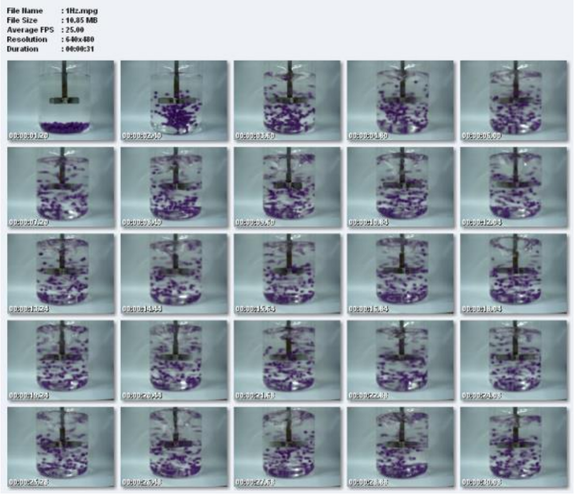
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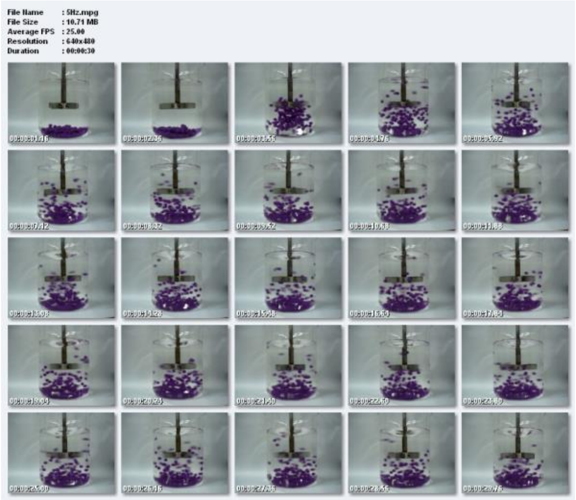
Figure 20. Sine Wave 5Vp-p @1Hz



File Name : 5Hz.mpg
File Size : 10.71 MB
Average FPS : 25.00
Resolution : 640x480
Duration : 00:00:30

Figure 21. Sine Wave 5Vp-p @5Hz

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Figure 22. Sine Wave 5Vp-p @10Hz

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Figure 23. Chua's Single Scroll @$L_{eq}$ 1.80$H$

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Average FPS : 25.00
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Duration : 00:00:32

Figure 24. Chua's Single Scroll @$L_{eq}$ 5.94$H$

File Name : Chua single scroll 8.46H.mpg
File Size : 11.98 MB
Average FPS : 25.00
Resolution : 640x480
Duration : 00:00:34

Figure 25. Chua's Single Scroll @$L_{eq}$ 8.46$H$

File Name : Chua double scroll 1.8H.mpg
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Figure 26. Chua's Double Scroll @ $L_{eq}$ 1.80$H$

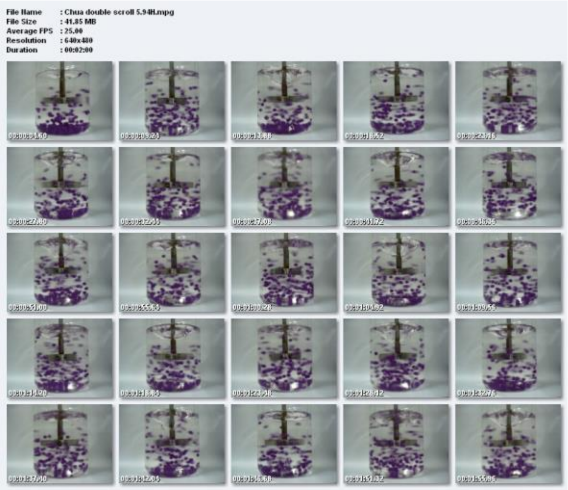

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Figure 27. Chua's Double Scroll @ $L_{eq}$ 5.94*H*

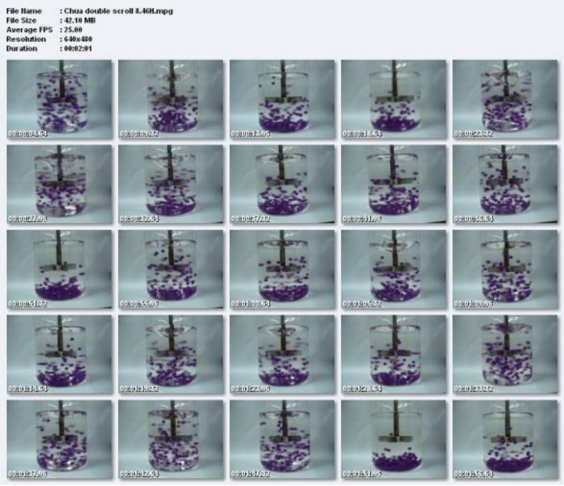

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Figure 28. Chua's Double Scroll @$L_{eq}$ 8.46*H*