# ECE 395A Lab2 Report

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# 1 Introduction

This time we are supposed to build the implementation of Chua's circuit discussed in class. Chua's circuit (also known as a Chua circuit) is a simple electronic circuit that exhibits classic chaotic behavior. This means roughly that it is a ”nonperiodic oscillator”; it produces an oscillating waveform that, unlike an ordinary electronic oscillator, never ”repeats”. It was invented in 1983 by Leon O. Chua.

In this report I will spread research process into Mathematical equation, simulation, and experiment, which can help me understand Chua circuit more comprehensive.

# 2 Body

## 2.1 Total Chua Circuit

Here is the total circuit we need to build during this lab. We use LT1058 instead of the op amps.

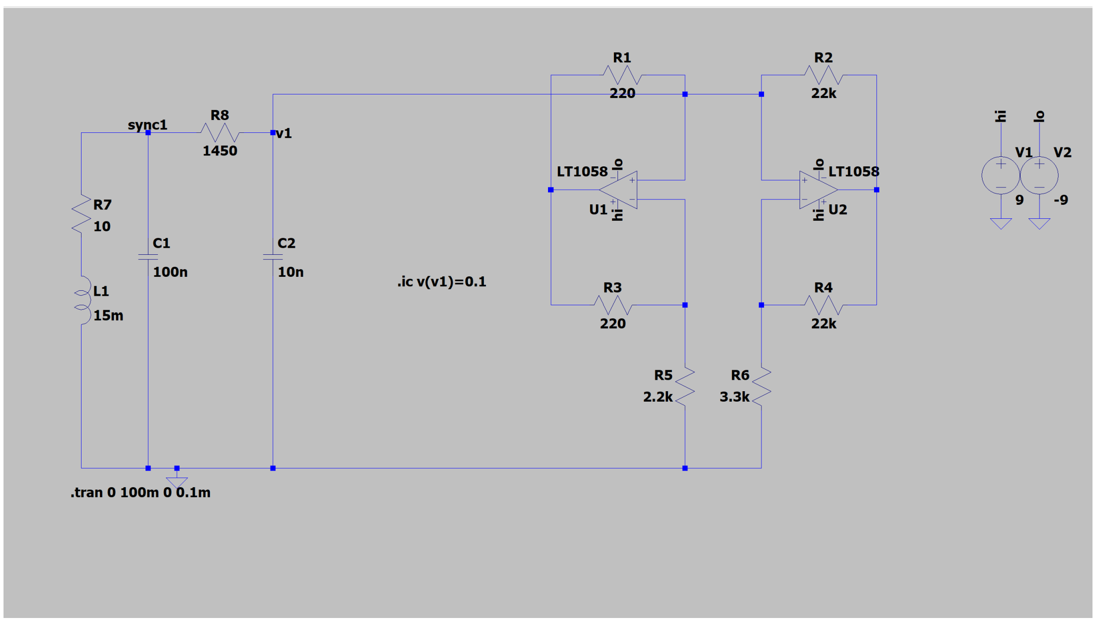


Figure 1: Chua Circuit

## 2.2 Chua diode

In order to verify if the Chua diode behaves as negative resistor, I connected it to an DC voltage source(Figure 2), and sweep it from -3V to 3V.

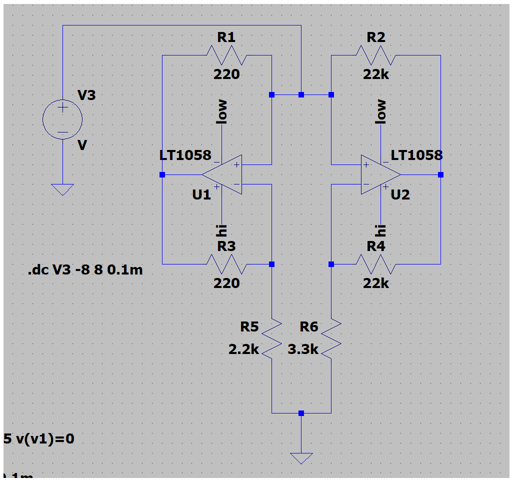


Figure 2: Chua Diode

Then I got the V-I curve of it.(Figure 3) We can see two points around +0.8V and -0.8V, that the slope of V-I curve changed. What's more the slope of that is negative, So we could said it works as a negative resistor.

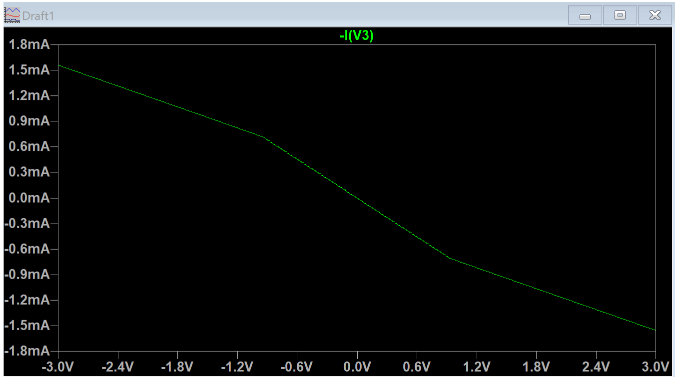


Figure 3: Chua Diode

After that, I increase the sweeping range to -8V to 8V, and get the figure below. The slope back to positive when voltage bigger than 6.5V or smaller than -6.5V, like an ordinary resistor.


Figure 4: Chua Diode with Big Voltage

### 2.3 Math Model

Based on Kirchhoff's circuit laws and figure 1, we could write 3 equation for these circuit. Let's set the voltage of $C_1$ as $V_1$, voltage of $C_2$ as $V_2$, and current go up through inductor as $I_L$. $G(V_1)$ is a piecewise-linear function representing the change in resistance vs. current across the Chua Diode.

$$C_1\frac{dV_1}{dt} = \frac{(V_2-V_1)}{R_8} \text{ - G}(V_1)$$

$$C_2\frac{dV_2}{dt} = \frac{(V_1-V_2)}{R_8} + I_L$$

$$L\frac{dI_L}{dt} = -(V_2 + R_7 * I_L)$$

As for function G[$V_1$], it V-I curve like Figure 3, and we can write down the equation of that.

$$G(x) = \begin{cases} m_1 * E + E * (m_0 - m_1) & V_1 < -E \\ m_0 * V_1 & -E \leq V_1 < E \\ m_1 * E + E * (m_1 - m_0) & E \leq V_1 \end{cases}$$

While E $= \frac{R_6}{R_4+R_6} = \frac{3.3k}{3.3k+22k} = \frac{3}{23}$V, $m_1 = -\frac{1}{R_5} - \frac{1}{R_6} =$ -$\frac{1}{1320}$, $m_0 = -\frac{1}{R_5} + \frac{1}{R_2} =$ -$\frac{9}{22000}$

### 2.4 Simulation

We are asked to simulate this circuit on LTspice, but the output of simulation results is too slow,so I modified the Chua Circuit simulation Matlab code from `http://www.chuacircuits.com/matlabsim.php`. And the edited code is published below.

```matlab
function out = RealChua(t,in)

x = in(1); %v_1
y = in(2); %v_2
z = in(3); %i_L

C1  = 10*10^(-9);    %10nF
C2  = 100*10^(-9);   %100nF
R = 1450;
G = 1/R;

R1 = 220;
R2 = 220;
R3 = 2200;
R4 = 22000;
R5 = 22000;
R6 = 3300;

Esat = 9; %9V batteries
E1 = R3/(R2+R3)*Esat;
E2 = R6/(R5+R6)*Esat;

m12 = -1/R6;
m02 = 1/R4;
m01 = 1/R1;
m11 = -1/R3;

m1 = m12+m11;

m0 = m11 + m02;

mm1 = m01 + m02;
Emax = max([E1 E2]);
Emin = min([E1 E2]);


if abs(x) < Emin
   g = x*m1;
elseif abs(x) < Emax
    g = x*m0;
    if x > 0
    g = g + Emin*(m1-m0);
    else
    g = g + Emin*(m0-m1);
    end
end
L = 15*10^-3

xdot = (1/C1)*(G*(y-x)-g);
ydot = (1/C2)*(G*(x-y)+z);
zdot  = -(1/L)*(y+10*z) ;
out = [xdot ydot zdot]';
```

```matlab
[t,y] = ode45(@RealChua,[0 0.05],[0 0.1 0]);
a = length(y(:,1))
c = 1:a
subplot(1,2,1)
plot(y(:,1),y(:,2))
subplot(1,2,2)
plot(c,y(:,1))
%plot3(y(:,1),y(:,2),y(:,3))
grid
```

Figure 5: Matlab Code

With the help of Matlab Code, we could quickly find when R = 1450Ω, ”double scroll attractor” is showed in my monitor.(Figure 6)

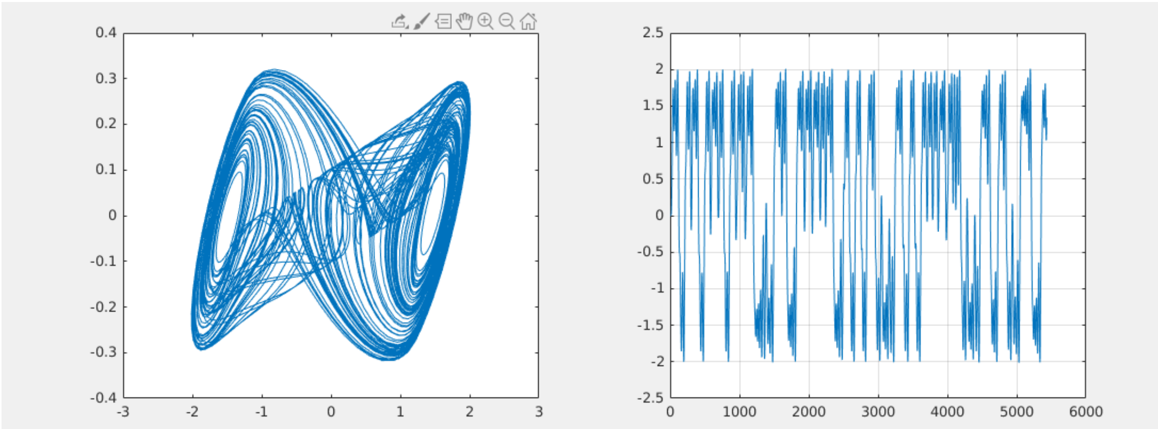


Figure 6: Matlab Result

Now here is four target of simulation.

#### 2.4.1 R 2000 ohm (no oscillations)

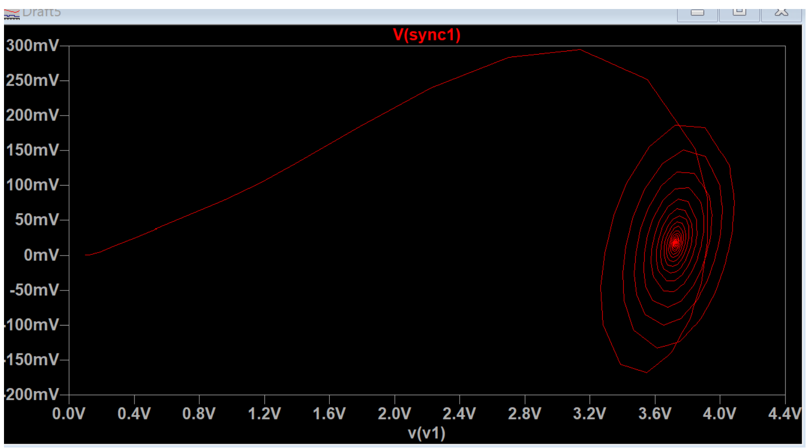


Figure 7: Vsync, Vc vs time

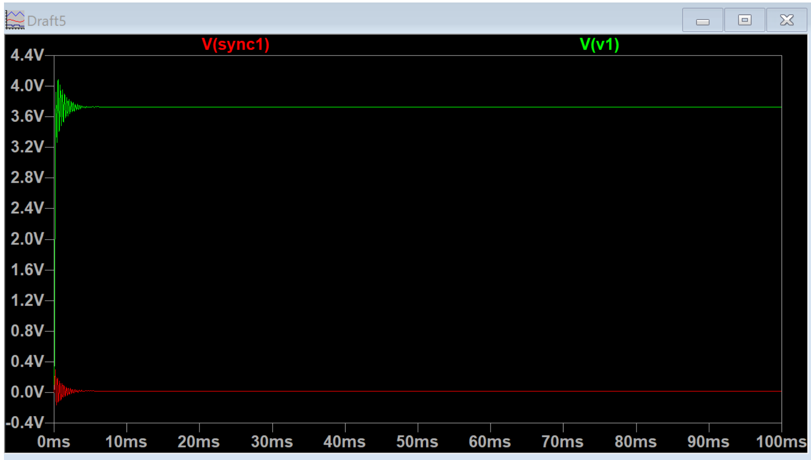


Figure 8: Vsync vs Vc

### 2.4.2 Quasi-linear oscillato

I get this result when R = 1100Ω, V1 curve have a little distortion.

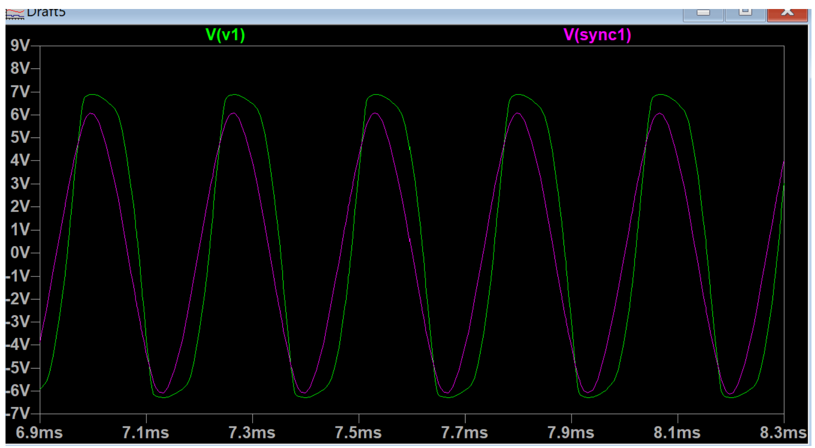


Figure 9: Vsync, Vc vs time

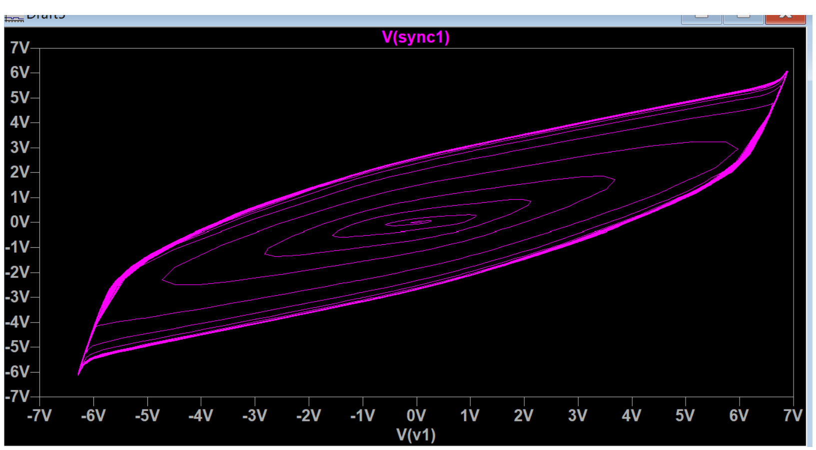


Figure 10: Vsync vs Vc

### 2.4.3 Period Doubling

I get this result when R = 1375Ω.


Figure 11: Vsync, Vc vs time

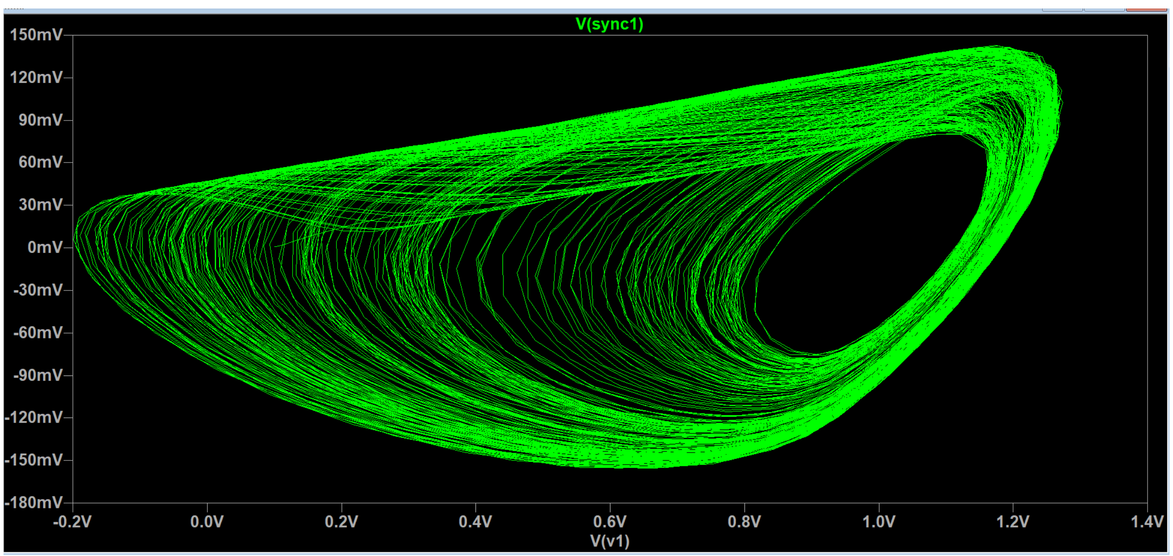


Figure 12: Vsync vs Vc

### 2.4.4 Double Scroll Attractor

I get this result when R = 1450Ω

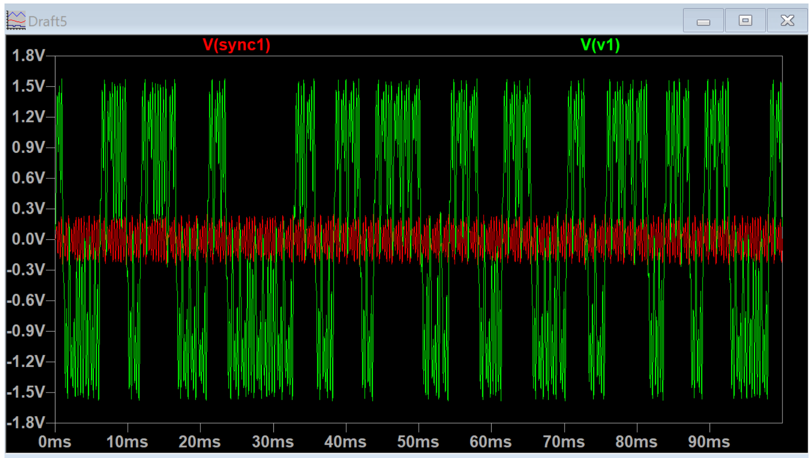


Figure 13: Vsync, Vc vs time

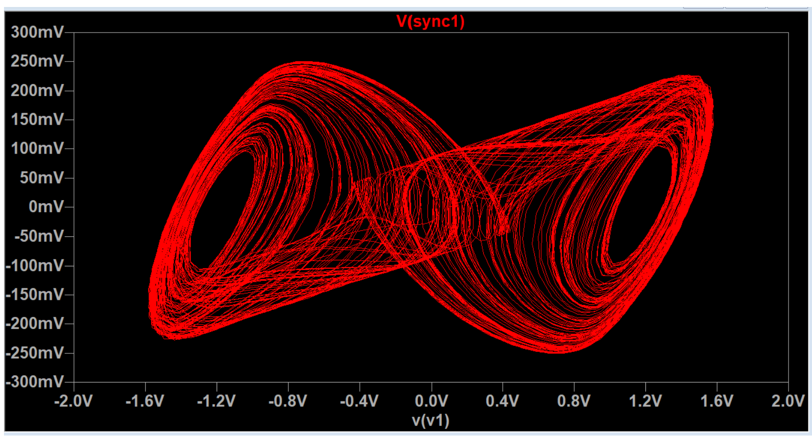


Figure 14: Vsync vs Vc

## 2.5 Experiment

We are also asked to detect the circuit in practical. However, because some components out of stock, my Digi-Key order still did not send. Thus, I use following circu.it to in place of an actual inductor, while L = $\frac{R_7 R_9 R_{10} C}{R_8}$

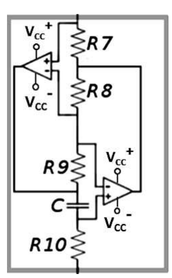


Figure 15: Inductor Circuit

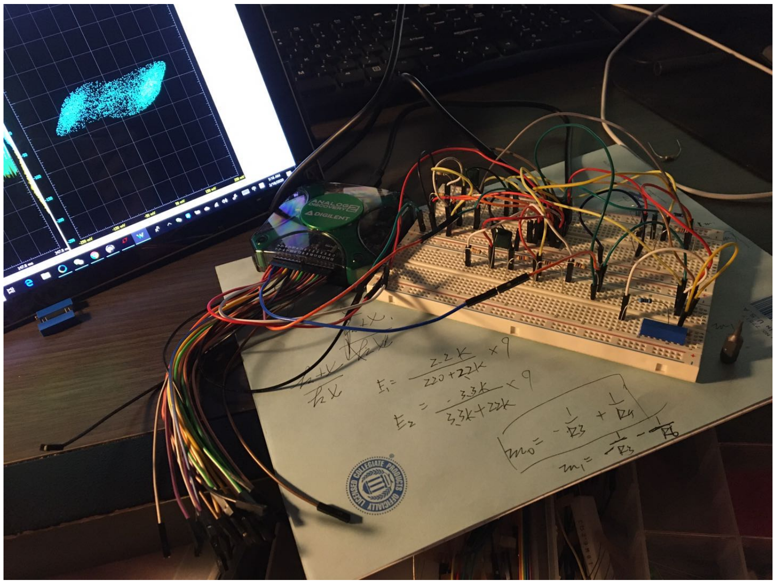

Figure 16: Experiment Circuit

### 2.5.1 R 2000 ohm (no oscillations)

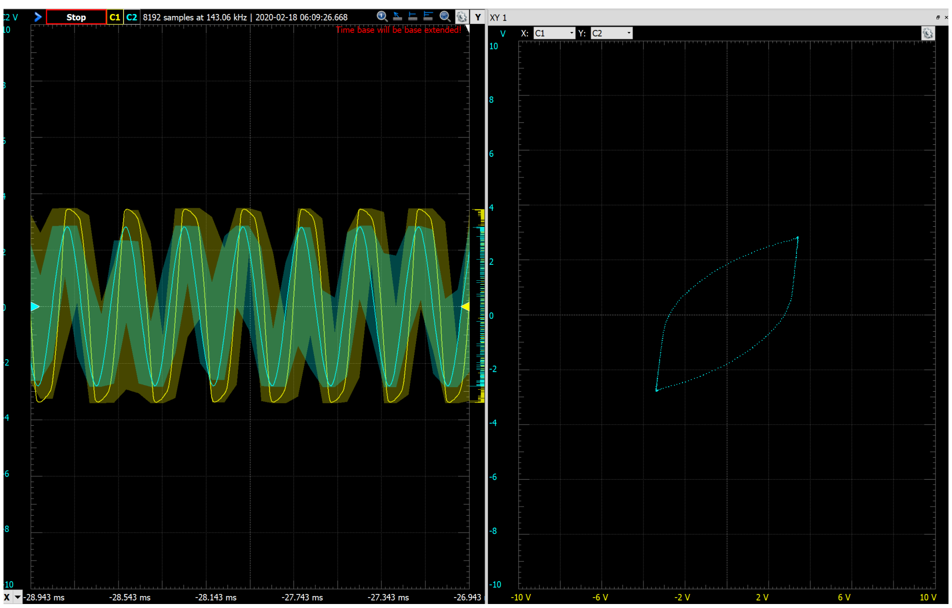


Figure 17: WaveForms

### 2.5.2 Quasi-linear oscillator

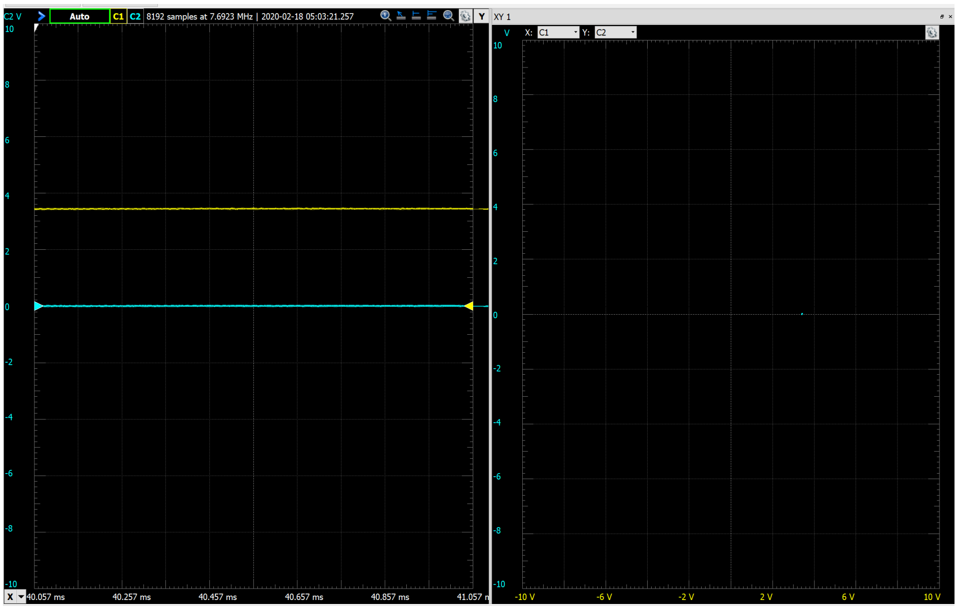


Figure 18: WaveForms

### 2.5.3 Period Doubling

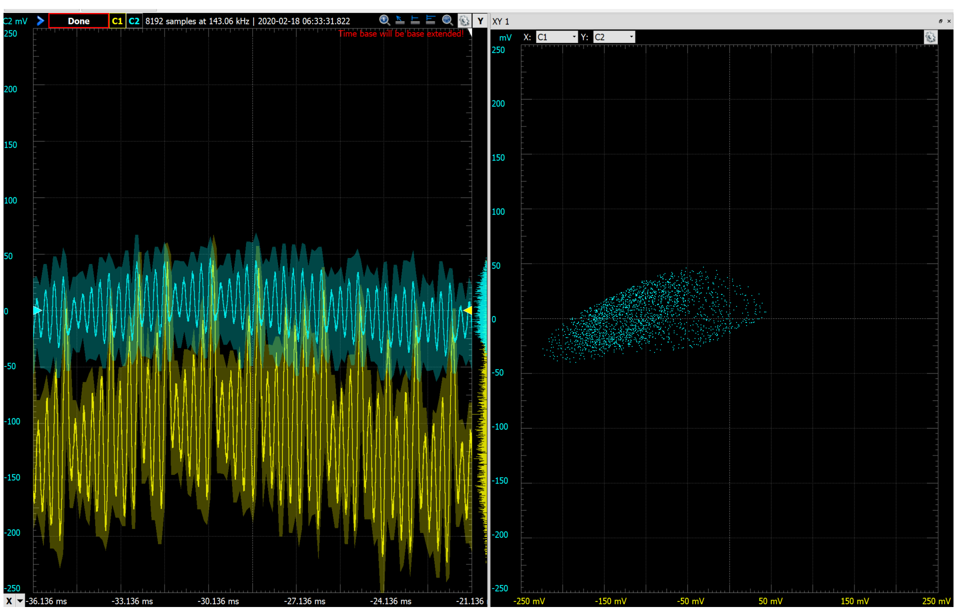


Figure 19: WaveForms

#### 2.5.4 Double Scroll Attractor

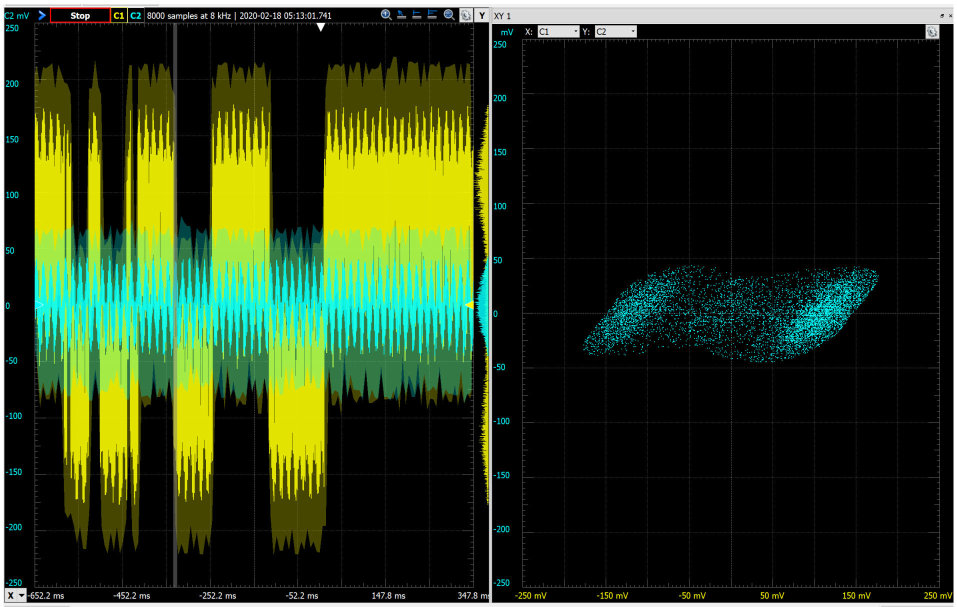


Figure 20: WaveForms

### 2.6 Compare between Simulations and Experiments

After finish the case "Double Scroll Attractor", I detect the resistor value of rheostat, it is 1592Ω, bigger than the value we got from simulation 1450Ω. All the resistor and capacitor value are extremely same as simulation, but as for inductor, it is not real inductor, so there must be some error.

When we change the value of rheostat, it is not as accurate as in simulation. Also, all components are not ideal, which may cause some difference between simulation and experiments.

## 3 Conclusion

Chua's circuits are some of the simplest kinds of chaotic circuits, but it helps me a lot to understand oscillator, this lab was a meaningful experience.

## 4 REFERENCE

`http://www.chuacircuits.com/`

`https://en.wikipedia.org/wiki/Chua%27s_circuit`