6. Experimental Contents

1) Use RLC series resonance circuit to measure the inductance of a ferrite material at different currents;
2) Observe the waveforms generated by a LC oscillator on an oscilloscope before and after RC phase-shift, respectively (oscilloscope in X-T mode);
3) Observe the phase figure of the above two waveforms (i.e. Lissajous figure, oscilloscope in X-Y mode));
4) Observe the periodic variations of the phase figure by adjusting the resistors of the RC phase shifter; Record phase figures of bifurcations, intermittency chaos, triple times period, attractor, and double attractors;
5) Measure the V-I characteristics of a nonlinear negative resistance device made of a LF353 dual operational amplifier; Explain the cause of the chaos generation using the dynamics equation of a nonlinear circuit.

7. Experiments
A. Observation of period-doubling bifurcation and chaos in nonlinear circuits

![Figure 5 Wiring schematic of experiment A](image-url)

Figure 5 Wiring schematic of experiment A
a) Connect wires on the panel per Figure 5 and connect CH1 and CH2 to X and Y of the oscilloscope, respectively;

b) $R_0$ consists of two variable resistors in serial, $W_1$ and $W_2$. $W_1$ is for coarse adjustment while $W_2$ for fine adjustment. Adjust $W_1$ and $W_2$ ($R_0 = W_1 + W_2$) while observing Lissajous figure (phase figure) on oscilloscope;

c) Adjust $R_0$ from large to small while depicting period bifurcation and chaos of the phase figure; (Note: turn in count-clockwise direction to decrease resistance.)

d) Using $P$ as the period of a ring phase figure, observe and record phase figures: $2P$, $4P$, intermittent chaos, $3P$, single-attractor (chaos), and double attractors (chaos).

**B. Measurement of V-I characteristic of active nonlinear negative resistance element**

a) Connect circuit per Figure 6;

b) Gradually increase resistance of the resistance box from small (e.g. 500 Ω) to large (e.g. 500K Ω), record voltage readings from the voltmeter at various resistances (note: $V<0$);

c) Acquire current-voltage characteristics of the nonlinear circuit using the recorded data;

d) Plot $I-V$ graph with least square curve fitting;

e) Understand the concept of negative resistance from the $I-V$ curve.

![Figure 6 Wiring schematic of experiment B](image-url)
C. Measurement of the inductance of a Ferrite inductor

1) There are two options for selecting inductor $L$: i) use the built-in ferrite inductor or ii) user makes the inductor using included ferrite core and frame by winding 70-75 turns of copper wire, and scrape off paints of the two leads for good contact.

2) Measure the inductance of the inductor using series resonance method (see Fig. 8). Connect the inductor and resistance box (set at 30 $\Omega$) in series, then connect a low frequency signal generator. Measure the voltage between the two ends of the resistance box using the oscilloscope and adjust the frequency of the sine wave signal to achieve the maximum voltage value on the resistance box, while measuring the current, $I$, flowing through the resistance box. Measure the inductance of the inductor when the current reaches 5 mA (effective value).