

## 1 Chaotic Diode Circuit

[https://www.researchgate.net/publication/309351711\\_A\\_simple\\_chaotic\\_circuit\\_with\\_a\\_light-emitting\\_diode](https://www.researchgate.net/publication/309351711_A_simple_chaotic_circuit_with_a_light-emitting_diode)

$$\begin{aligned}C \cdot \frac{dv_1}{dt} &= -\frac{v_2}{R} \\C \cdot \frac{dv_2}{dt} &= -\frac{v_3}{R} \\C \cdot \frac{dv_3}{dt} &= -\frac{v_1}{R} - \frac{v_3}{R_b} - \frac{v_4}{R} \\ \frac{v_4}{R_a} &= -I_{ds} \cdot \left( e^{\frac{v_2}{nV_t}} - 1 \right)\end{aligned}$$

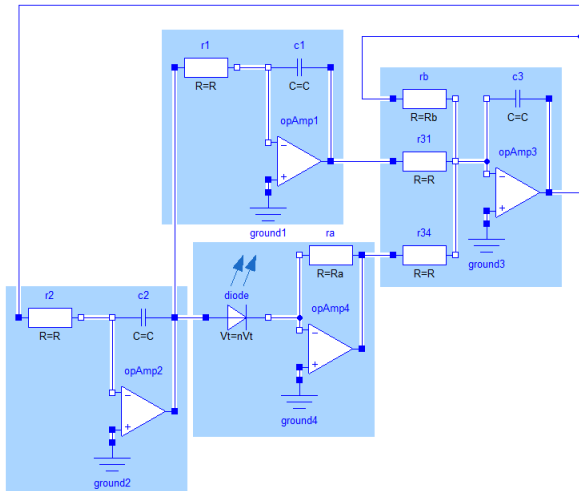
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$$\begin{aligned}\tau &= R \cdot C \\ \tau \cdot \frac{dv_1}{dt} &= -v_2 \\ \tau \cdot \frac{dv_2}{dt} &= -v_3 \\ \tau \cdot \frac{dv_3}{dt} &= -v_1 - \frac{R}{R_b} \cdot v_3 + R_a \cdot I_{ds} \cdot \left( e^{\frac{v_2}{nV_t}} - 1 \right)\end{aligned}$$


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$$\begin{aligned}a &= \frac{R_a \cdot I_{ds}}{nV_t} \\ b &= \frac{R}{R_b} \\ \tau \cdot \dot{x}_1 &= -x_2 \\ \tau \cdot \dot{x}_2 &= -x_3 \\ \tau \cdot \dot{x}_3 &= -x_1 + a \cdot (e^{x_2} - 1) - b \cdot x_3\end{aligned}$$


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```
parameter SI.Current Ids=1e-9 "Diode: saturation current";
parameter SI.Voltage nVt=2*26e-3
" n*voltage equ. of temperature";
//time constant and dimensionless parameters
parameter SI.Time Tau=0.1e-3 "Time constant";
parameter Real a=1/5200 "Parameter a = Ra*Ids/nVt";
parameter Real b=1.5 "Parameter b = R/Rb";
//configuration of the opAmps
parameter SI.Capacitance C=10e-9
"Capacitance of {c1, c2, c3}";
parameter SI.Resistance R=Tau/C "Resistance of {r1,r2,r3,r4}";
parameter SI.Resistance Ra=a*nVt/Ids "Resistance of ra";
parameter SI.Resistance Rb=R/b "Resistance of rb";
```

## 2 Chua's Circuit

<https://link.springer.com/book/10.1007/978-3-319-05900-6> (1.1)

<https://nonlinear.eecs.berkeley.edu/chaos/chaos.html#> Working With Chaos Simulation

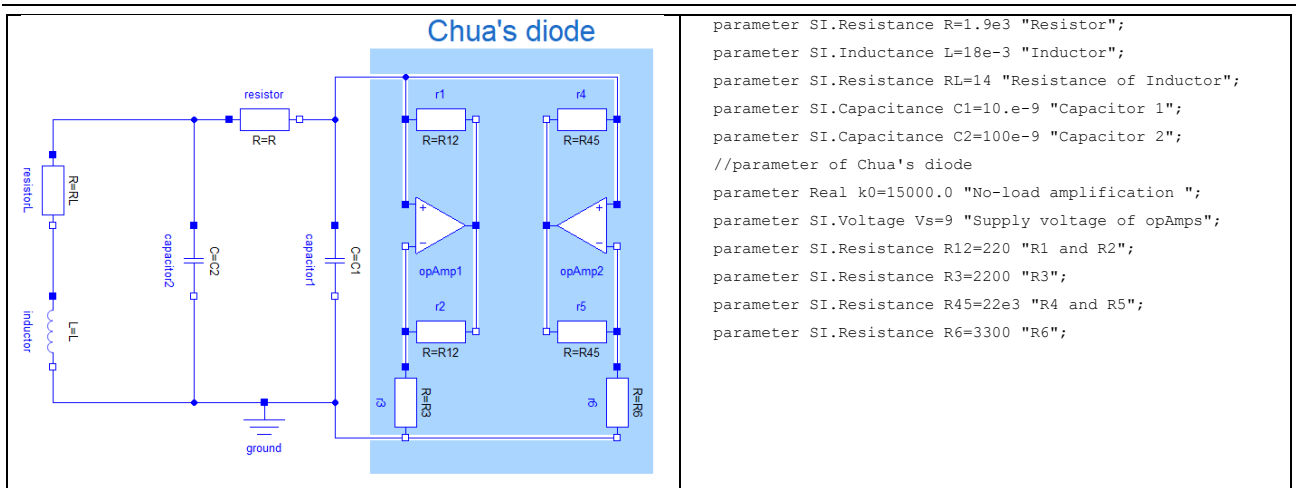
$$\begin{aligned}
 L \cdot \frac{di_L}{dt} &= v_2 - R_L \cdot i_L \\
 C_2 \cdot \frac{dv_2}{dt} &= -i_L - \frac{v_2 - v_1}{R} \\
 C_1 \cdot \frac{dv_1}{dt} &= -i_{NL} + \frac{v_2 - v_1}{R} \\
 -i_{NL}(v_1) &= \begin{cases} -\infty < v_1 < -V_e \rightarrow G_b \cdot (v_1 + V_e) - G_a \cdot V_e \\ -V_e < v_1 < +V_e \rightarrow G_a \cdot v_1 \\ +V_e < v_1 < +\infty \rightarrow G_b \cdot (v_1 - V_e) + G_a \cdot V_e \end{cases} \\
 -\frac{i_{NL}}{v_1} &= \begin{cases} -\infty < v_1 < -V_e \rightarrow G_b - (G_a - G_b) \cdot \frac{V_e}{v_1} \\ -V_e < v_1 < +V_e \rightarrow G_a \\ +V_e < v_1 < +\infty \rightarrow G_b + (G_a - G_b) \cdot \frac{V_e}{v_1} \end{cases} \\
 -\frac{di_{NL}}{dv_1} &= \begin{cases} -\infty < v_1 < -V_e \rightarrow G_b \\ -V_e < v_1 < +V_e \rightarrow G_a \\ +V_e < v_1 < +\infty \rightarrow G_b \end{cases}
 \end{aligned}$$

$$\tau_L \cdot \dot{v}_{RL} = v_2 - v_{RL}$$

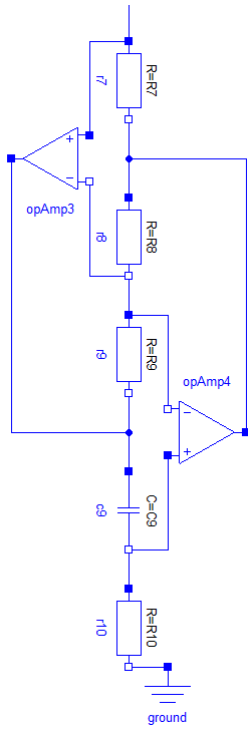
$$\tau_2 \cdot \dot{v}_2 = +v_1 - v_2 - \frac{R}{R_L} \cdot v_{RL}$$

$$\tau_1 \cdot \dot{v}_1 = -v_1 + v_2 + R \cdot g \cdot v_1$$

$$g(v_1) = \begin{cases} |v_1| > V_e \rightarrow G_b + (G_a - G_b) \cdot \frac{V_e}{|v_1|} \\ |v_1| < V_e \rightarrow G_a \end{cases}$$



## Chua's Circuit: Inductor Replacement



$$R_7 = 100 \, \Omega$$

$$R_8 = 1 \, k\Omega$$

$$R_9 = 1 \, k\Omega$$

$$R_{10} = 1,8 \, k\Omega$$

$$C_9 = 100 \, nF$$

$$R_7 \cdot i + R_8 \cdot (i + i_{OA4}) = 0$$

$$R_9 \cdot (i + i_{OA4}) + v_{C9} = 0$$

$$i + i_{OA4} + i_{OA3} = i_{C9}$$

$$i_{C9} = C_9 \cdot \frac{dv_{C9}}{dt}$$

$$v = R_{10} \cdot i_{C9}$$

$$(i + i_{OA4}) = -\frac{R_7}{R_8} \cdot i$$

$$v_{C9} = \frac{R_7 \cdot R_9}{R_8} \cdot i$$

$$i_{C9} = C_9 \cdot \frac{R_7 \cdot R_9}{R_8} \cdot \frac{di}{dt}$$

$$v = C_9 \cdot \frac{R_7 \cdot R_9 \cdot R_{10}}{R_8} \cdot \frac{di}{dt}$$

$$L = C_9 \cdot \frac{R_7 \cdot R_9 \cdot R_{10}}{R_8} = 18 \, mH$$

### 3 Chaotic Oscillator

<https://www.researchgate.net/publication/230925506> A simple chaotic oscillator for educational purposes

<https://www.researchgate.net/publication/259216097> NUMERICAL TREATMENT OF EDUCATIONAL CHAOS OSCILLATOR

$$i_L = C \cdot \frac{dv_C}{dt}$$

$$L \cdot \frac{di_L}{dt} = \left(k - 1 - \frac{R_L}{R}\right) \cdot R \cdot i_L - v_C - v_{C^*}$$

$$k = 1 + \frac{R_2}{R_1}$$

$$C^* \cdot \frac{dv_{C^*}}{dt} = I_0 + i_L - I_{DS} \cdot \left(e^{\frac{v_{C^*}}{nV_t}} - 1\right)$$

$$I_0 \approx \frac{V_b}{R_0}$$

$$\tau = \sqrt{L \cdot C}$$

$$Z = \sqrt{\frac{L}{C}}$$

$$a = \left(k - 1 - \frac{R_L}{R}\right) \cdot \frac{R}{Z}$$

$$b = \frac{Z \cdot I_0}{nV_t}$$

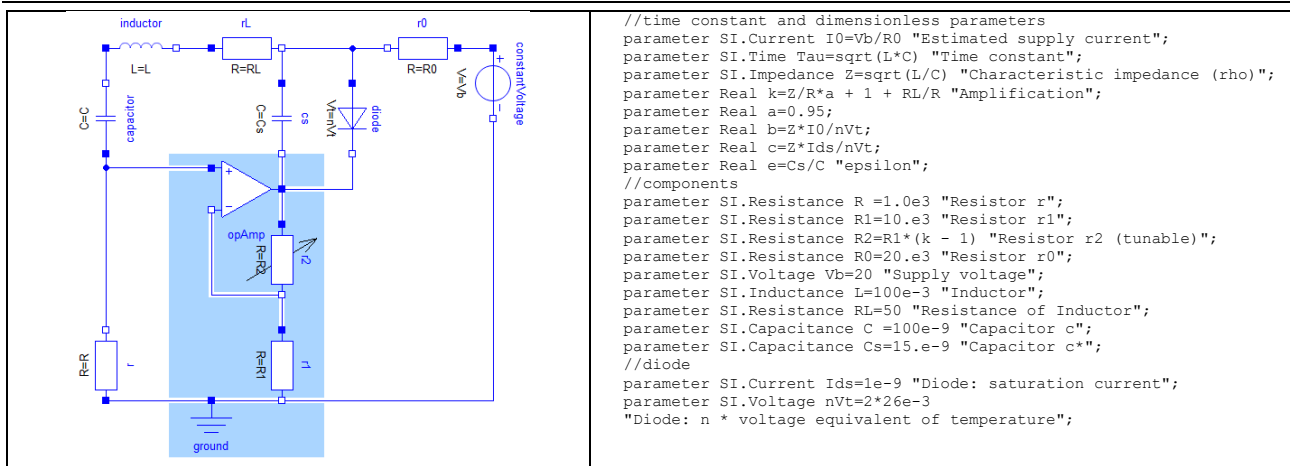
$$c = \frac{Z \cdot I_{DS}}{nV_t}$$

$$e = \frac{C^*}{C}$$

$$\tau \cdot \frac{\dot{v}_C}{nV_t} = \frac{Z \cdot i_L}{nV_t}$$

$$\tau \cdot \frac{Z \cdot i_L}{nV_t} = \left(k - 1 - \frac{R_L}{R}\right) \cdot \frac{R}{Z} \cdot \frac{Z \cdot i_L}{nV_t} - \frac{v_C}{nV_t} - \frac{v_{C^*}}{nV_t}$$

$$\tau \cdot e \cdot \frac{\dot{v}_{C^*}}{nV_t} = \frac{Z \cdot I_0}{nV_t} + \frac{Z \cdot i_L}{nV_t} - \frac{Z \cdot I_{DS}}{nV_t} \cdot \left(e^{\frac{v_{C^*}}{nV_t}} - 1\right)$$



#### 4 Colpitts Oscillator

<https://link.springer.com/book/10.1007/978-3-319-05900-6> (1.3)

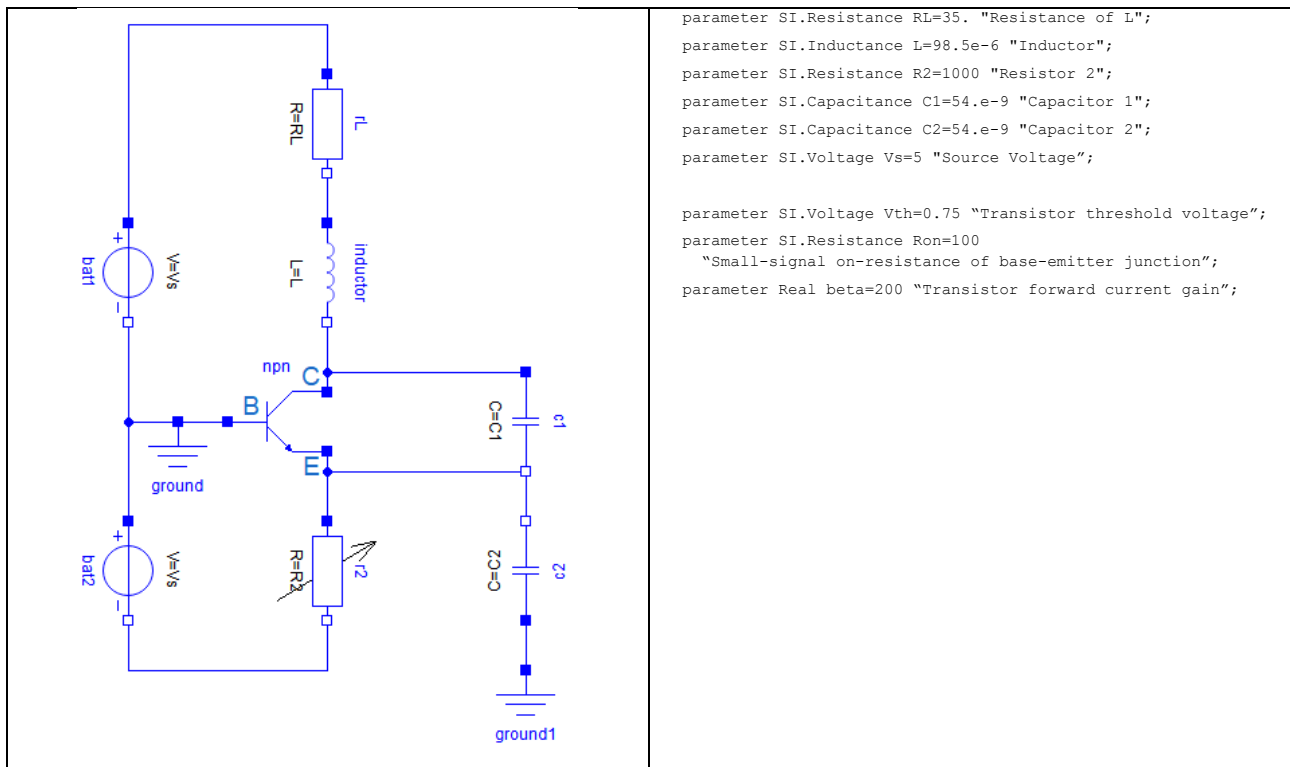
<https://ieeexplore.ieee.org/document/331536>

$$C_1 \cdot \frac{dv_1}{dt} = i_L - \beta \cdot i_B$$

$$C_2 \cdot \frac{dv_2}{dt} = -\frac{V_{s-} + v_2}{R_2} - i_L - i_B$$

$$L \cdot \frac{di_L}{dt} = V_{s+} - v_1 + v_2 - R_L \cdot i_L$$

$$i_B = \begin{cases} v_2 = v_{BE} \leq V_{th} \rightarrow 0 \\ v_2 = v_{BE} > V_{th} \rightarrow \frac{v_2 - V_{th}}{R_{on}} \end{cases}$$



## 5 Shinriki Oscillator

[https://paw.n.physik.uni-wuerzburg.de/~slueck/PhyAmSa09/Home\\_files/Examensarbeit\\_Lueck.pdf](https://paw.n.physik.uni-wuerzburg.de/~slueck/PhyAmSa09/Home_files/Examensarbeit_Lueck.pdf)

<https://ieeexplore.ieee.org/abstract/document/1456241>

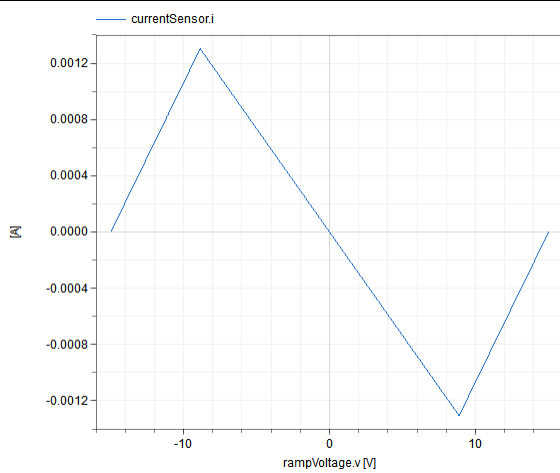
$$i_z = \begin{cases} 0 & |v_z| < V_{bt} \\ \text{sign}(v_z) \cdot [a \cdot (|v_z| - V_{bt}) + b \cdot (|v_z| - V_{bt})^3 + c \cdot (|v_z| - V_{bt})^5] & |v_z| \geq V_{bt} \end{cases}$$

$$C_1 \cdot \frac{dv_1}{dt} = -i_{NIC} - \frac{v_1}{R_1} - i_z$$

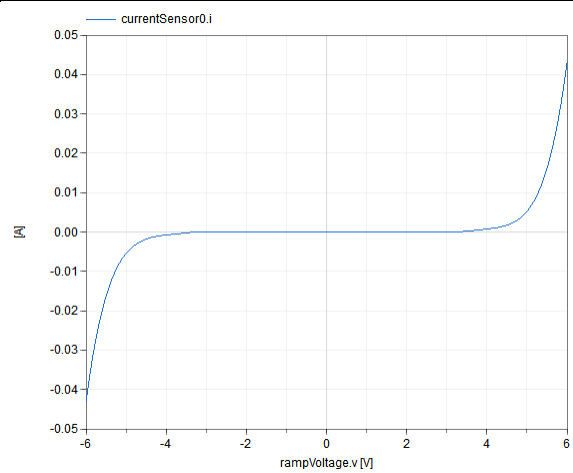
$$C_2 \cdot \frac{dv_2}{dt} = i_z - i_L$$

$$v_2 = L \cdot \frac{di_L}{dt} + R_L \cdot i_L$$

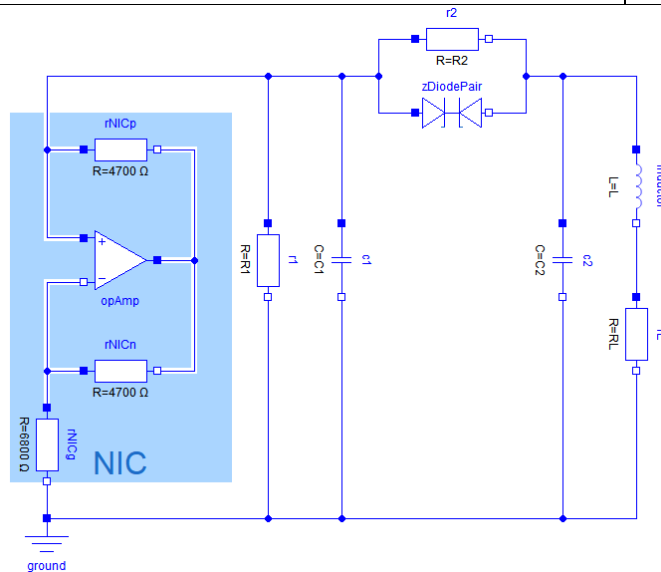
$$g_{NIC} = \frac{di_{NIC}}{dv_{NIC}} = \begin{cases} G_+ & |v_{NIC}| > V_{Lim} \\ G_- & |v_{NIC}| \leq V_{Lim} \end{cases}$$



Characteristic of negative impedance converter



Characteristic of Zener diode pair



```
parameter SI.Inductance L=320e-3 "Inductor";
parameter SI.Resistance RL=100. "Resistor of L";
parameter SI.Resistance R1=60e3 "Resistor 1";
parameter SI.Resistance R2=20e3 "Resistor 2";
parameter SI.Capacitance C1=10.e-9 "Capacitor 1";
parameter SI.Capacitance C2=100e-9 "Capacitor 2";
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$$a = 1,0862 \frac{mA}{V}$$

$$b = -0,1615 \frac{mA}{V^3}$$

$$c = 0,3021 \frac{mA}{V^5}$$

$$V_{Lim} = 8,870565 V$$

$$G_+ = 0,212766 mS$$

$$G_- = -0,147018 mS$$