**OpAmp-Circuits**

|  |  |
| --- | --- |
| Amplifier/Adder | It is possible to add several inputs. |
| Integrator | It is possible to integrate the sum of several inputs. |
| Analog Multiplier | Functional Block Diagram of AD633  Division by (scaling) inhibits overflow.  Additional summing input Z is omitted.  Negative inputs of X- and Y-amplifiers are connected to ground.  Possible implementations:   * Gilbert cell |

**1\_Lotka-Volterra**

<https://en.wikipedia.org/wiki/Lotka%E2%80%93Volterra_equations>

<https://en.wikipedia.org/wiki/Competitive_Lotka%E2%80%93Volterra_equations>

<https://sprott.physics.wisc.edu/pubs/paper288.pdf>

As a 2-dimensional predator-prey-model no chaos is reported:

We might interpret as number of hares (prey) and as foxed (predator).  
 is the reproduction rate of hares, the deathrate of hares due to foxes.

is the efficiency in growing foxes from hares, the (natural) deathrate of foxes.

A n-dimensional Lotka-Volterra model is defined for ( designates the number of species):

The vector describes the reproduction rates of the species whereas the quadratic matrix describes the competition between species.

**2\_Lorenz System**

<http://en.wikipedia.org/wiki/Lorenz_attractor>

Developed 1963 by Edward Lorenz to model atmospheric convection.

is proportional to the rate of convection, to the horizontal temperature variation and to the vertical temperature variation. depicts the Prandtl number, the Rayleigh number and the physical dimensions.

The original parameters were:

leads to a periodic solution.

For an implementation as an electronic circuit, the equations have to be scaled to keep the variables within the desired range. This can be compared with calculating per-unit values by dividing by reference values:

We also have to take into account that the analog multiplier divides by to avoid overflow of the output.

After that, none of the computing block should encounter an overflow.  
This leads to the following set of equations:

These equations can easily get implemented as blocks or as an electronic circuit.

**3\_Roessler System**

<https://en.wikipedia.org/wiki/R%C3%B6ssler_attractor>

A simple system of 3 ordinary nonlinear differential equations to study chaos without physical background.

, and give periodic results. Changing reveals chaotic results.

For an implementation as an electronic circuit, the equations have to be scaled to keep the variables within the desired range. This can be compared with calculating per-unit values by dividing by reference values:

We also have to take into account that the analog multiplier divides by to avoid overflow of the output.

After that, none of the computing block should encounter an overflow.  
This leads to the following set of equations:

These equations can easily get implemented as blocks or as an electronic circuit.

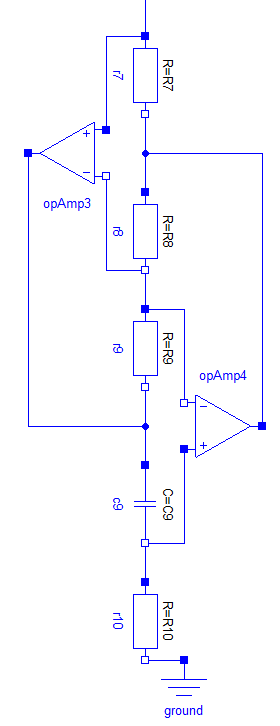
**4\_Chua’s Circuit**

<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>

|  |  |
| --- | --- |
|  | parameter SI.Resistance R=1.9e3 "Resistor";    parameter SI.Inductance L=18e-3 "Inductor";    parameter SI.Resistance RL=14 "Resistance of Inductor";    parameter SI.Capacitance C1=10.e-9 "Capacitor 1";    parameter SI.Capacitance C2=100e-9 "Capacitor 2";    //parameter of Chua's diode    parameter Real k0=15000.0 "No-load amplification ";    parameter SI.Voltage Vs=9 "Supply voltage of opAmps";    parameter SI.Resistance R12=220 "R1 and R2";    parameter SI.Resistance R3=2200 "R3";    parameter SI.Resistance R45=22e3 "R4 and R5";    parameter SI.Resistance R6=3300 "R6"; |

**Chua’s Circuit: Inductor Replacement**



**5\_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)

|  |  |
| --- | --- |
|  | 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"; |

**6\_Chaotic Oscillator**

[**https://www.researchgate.net/publication/230925506\_A\_simple\_chaotic\_oscillator\_for\_educational\_purposes**](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**](https://www.researchgate.net/publication/259216097_NUMERICAL_TREATMENT_OF_EDUCATIONAL_CHAOS_OSCILLATOR)

|  |  |
| --- | --- |
|  | //time constant and dimensionless parameters    parameter SI.Current I0=Vb/R0 "Estimated supply current";    parameter SI.Time Tau=sqrt(L\*C) "Time constant";    parameter SI.Impedance Z=sqrt(L/C) "Characteristic impedance (rho)";    parameter Real k=Z/R\*a + 1 + RL/R "Amplification";    parameter Real a=0.95;    parameter Real b=Z\*I0/nVt;    parameter Real c=Z\*Ids/nVt;    parameter Real e=Cs/C "epsilon";    //components    parameter SI.Resistance R =1.0e3 "Resistor r";    parameter SI.Resistance R1=10.e3 "Resistor r1";    parameter SI.Resistance R2=R1\*(k - 1) "Resistor r2 (tunable)";    parameter SI.Resistance R0=20.e3 "Resistor r0";    parameter SI.Voltage Vb=20 "Supply voltage";    parameter SI.Inductance L=100e-3 "Inductor";    parameter SI.Resistance RL=50 "Resistance of Inductor";    parameter SI.Capacitance C =100e-9 "Capacitor c";    parameter SI.Capacitance Cs=15.e-9 "Capacitor c\*";    //diode    parameter SI.Current Ids=1e-9 "Diode: saturation current";    parameter SI.Voltage nVt=2\*26e-3   "Diode: n \* voltage equivalent of temperature"; |

**7\_Colpitts Oscillator**

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

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

|  |  |
| --- | --- |
|  | parameter SI.Resistance RL=35. "Resistance of L";    parameter SI.Inductance L=98.5e-6 "Inductor";    parameter SI.Resistance R2=1000 "Resistor 2";    parameter SI.Capacitance C1=54.e-9 "Capacitor 1";    parameter SI.Capacitance C2=54.e-9 "Capacitor 2";    parameter SI.Voltage Vs=5 "Source Voltage”;  parameter SI.Voltage Vth=0.75 “Transistor threshold voltage”;  parameter SI.Resistance Ron=100   “Small-signal on-resistance of base-emitter junction”;  parameter Real beta=200 “Transistor forward current gain”; |

**8\_Shinriki Oscillator**

<https://pawn.physik.uni-wuerzburg.de/~slueck/PhyAmSa09/Home_files/Examensarbeit_Lueck.pdf>

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

|  |  |  |
| --- | --- | --- |
|  |  | |
| 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"; |