

Qucs

A Tutorial
Using Qucs in Textmode

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Introduction

Qucs consists of two parts: The simulator backend and a frontend, providing a GUI for drawing schematics, controlling simulation, and displaying the simulation results. The operation of the simulation backend is controlled via a text file (called *netlist* in the following) which describes the circuit to be simulated and the simulation(s) to perform in a textual manner. The simulation backend outputs simulation data. This document describes the syntax of netlist files, shows how the netlists are actually used to control Qucs, and finally demonstrates how the simulation data can be visualized via GNU Octave.

Controlling Qucs via netlists and using a separate program for visualizing simulation data may seem complex at first glance; this approach, however, poses the advantage of allowing more flexible usage scenarios: The potentially cpu-consuming circuit simulation could be executed on a powerful (even remote) server, while the result visualization can be done locally on a different computer. By creating netlists via other programs / scripts, it is easy to setup batch simulations.

Outline

After defining the prerequisites, Chapter presents a basic example netlist and shows how the simulation data can be visualized in Octave. Chapter describes the various devices and schematic elements provided by Qucs; Chapter 0.0.23 describes the simulation commands.

Basics

Prerequisites

Qucs installed `qucsator` command available
The m-files located under `qucs/qucs/octave`.

Type:Name [node list] [parameters]

Every schematic element has a type and is instantiated with a specific name.

Example

In this chapter we will start with a simple example of performing an AC simulation of the circuit shown in Fig. 1.

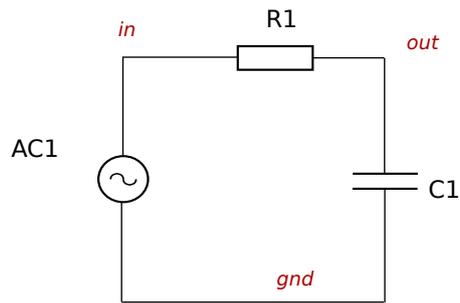


Figure 1: Circuit

The texts in red denote the node names and can be chosen freely. The netlist corresponding to the circuit is shown below.

```
Vac:V1 in gnd U="1 V" f="1 kHz"
R:R1 out in R="1 kOhm"
C:C1 out gnd C="10 nF"
```

It can be seen that the file is structured line-wise; every line instantiates one schematic element. The netlist instantiates

- a resistor R1 with resistance $R = 1\text{k}\Omega$,
- a capacitor C1 with capacity $C = 10\text{nF}$, and
- an AC source AC1 with "1"V peak-peak voltage(??) and a frequency of 1kHz.

Storing this netlist in a file `rc_ac.net` and feeding it into the simulator

```
qucsator < rc_ac.net
```

yields the following result:

```
parsing netlist...
checking netlist...
checker error, no actions defined: nothing to do
```

Qucs does not know what to do as we did not define any simulations to perform!

AC Sweep

Deciding to perform an AC sweep, we add the another line to the netlist, yielding:

```
Vac:V1 in gnd U="1 V" f="1 kHz"  
R:R1 out in R="1 kOhm"  
C:C1 out gnd C="10 nF"
```

```
.AC:AC1 Type="log" Start="1 Hz" Stop="10 MHz" Points="300" Noise="no"
```

Using this modified netlist with qucs starts an AC analysis of the circuit. The simulation data is written to stdout; for further processing we save the data in a file called `rc_ac.dat`.

```
qucsator < rc_ac.net > rc_ac.dat
```

The saved data from the simulation can be processed via Octave or Python; the next two subsections continue the example.

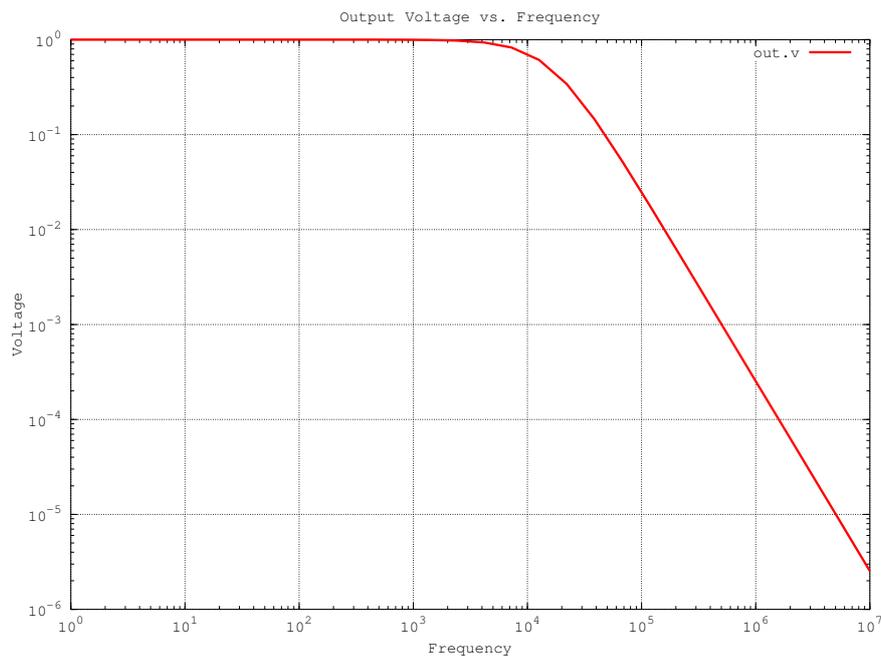


Figure 2: Simulation Result

Analysis with Octave

Starting GNU Octave and issuing the following commands

```
data=loadQucsDataSet('temp.dat')
loglog(data(1).data, data(3).data)
```

produces a log-log plot of the output voltage versus the frequency. A slightly more polished plot is shown in Fig. 2.

Analysis with Python

Similar to the octave scripts, Qucs provides a Python script which allows parsing of the generated simulation data file. The code example below shows how to load and parse the data file with Python. The plot using Matplotlib is shown in Fig. 4.

```
import numpy as np
import matplotlib.pyplot as plt
import parse_result as pr

data = pr.parse_file('rc_ac.dat')

x = data['acfrequency']
y = np.abs(data['out.v'])

plt.loglog(x, y, '-r')
plt.grid()
plt.xlabel('Frequency')
plt.ylabel('Voltage')
plt.legend(['out.v'])
plt.show()
plt.savefig('rc_ac_python.eps') # save plot as eps file
```

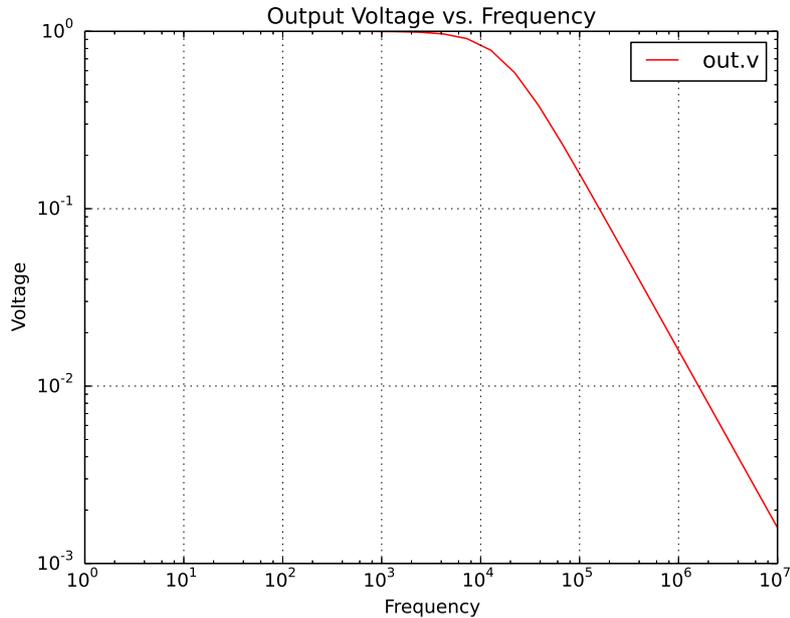


Figure 3: Simulation Result

Nested Simulations. Qucs allows for nested simulations; as an example we consider an AC analysis together with a parameter sweep. The AC analysis is set up as before, but in addition the value of the capacitor C1 is increased in 5 steps from 10nF to 100nF. The netlist for this simulation is as follows.

```
Vac:V1 in gnd U="1 V" f="1 kHz"
R:R1 out in R="1 kOhm"
C:C1 out gnd C="Cx"

.SW:SW1 Sim="AC1" Type="lin" Param="Cx" Start="10 nF" Stop="100 nF" Points="5"

.AC:AC1 Start="1 Hz" Stop="10 MHz" Points="100" Type="log" Noise="no"
```

The provided Python script can parse data files produced by such a nested simulation as well; in case of two nested simulations it returns not vectors, but matrices. The Python script below parses the simulation data file and plots the output voltage versus the frequency for two different capacitor values (10nF and 100nF, respectively). The corresponding plot is shown in Fig. ??.

```
import numpy as np
import matplotlib.pyplot as plt
import parse_result as pr

data = pr.parse_file('rc_ac_sweep.dat')

x = data['acfrequency']
y = np.abs(data['out.v'])
c = data['Cx']

plt.loglog(x,y[0,:],'-r')
plt.loglog(x,y[4,:],'-g')
plt.legend(['Cx=' + str(c[0]), 'Cx=' + str(c[4])])
plt.xlabel('Frequency')
plt.ylabel('Voltage')
plt.title('Output Voltage vs. Frequency')
plt.grid()
plt.savefig('rc_ac_sweep_python.eps')
plt.show()
```

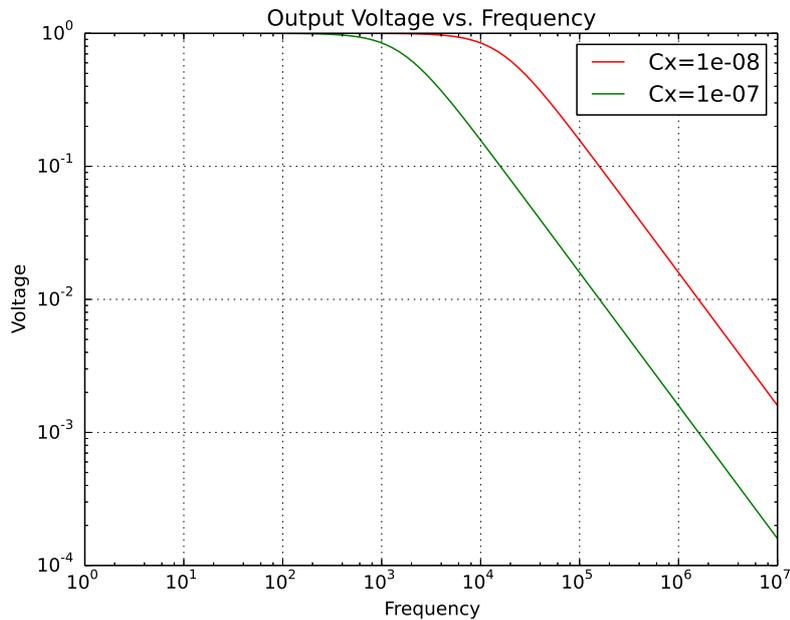


Figure 4: Simulation Result

Transient Simulation

We can use almost the same circuit to perform a transient analysis

```
Vpulse:V1 in gnd U1=0 U2=1 T1="1 ns" T2="1 ms"
```

```
R:R1 out in R="1 kOhm"
```

```
C:C1 out gnd C="100 nF"
```

```
.TR:TR Type=lin Start="0" Stop="1.5 ms" Points="51"
```

Here we have replaced the AC source with a voltage source generating pulses and told qucs to perform a transient analysis from 0 to 1.5ms. Storing the simulation results in a file and using octave to plot the results (analogous to the previous Subsection) yields the plot shown in Fig. 5-

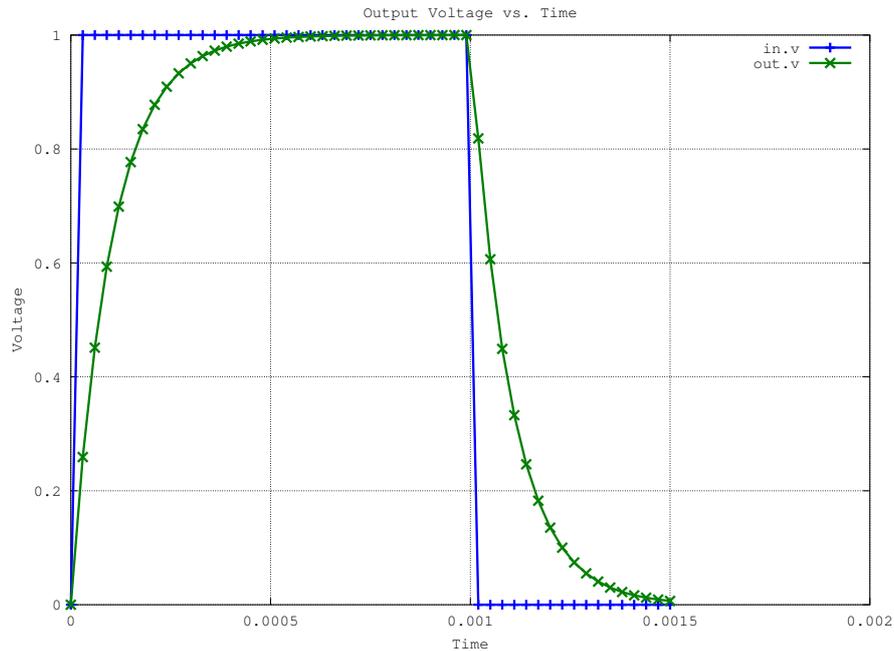


Figure 5: Simulation Result

Qucs Devices

Passive Devices

0.0.1 Resistor

R:Name Node1 Node2 [Parameters]

Parameter	Name	Default	Value Mandatory
R	ohmic resistance in Ohms	n/a	yes
Temp	simulation temperature in degree Celsius	26.85	no
Tc1	first order temperature coefficient	0.0	no
Tc2	second order temperature coefficient	0.0	no
Tnom	temperature at which parameters were extracted	26.85	no

0.0.2 Capacitor

C:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
C	capacitance in Farad	n/a	yes
V	initial voltage for transient simulation	n/a	no

0.0.3 Inductor

L:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
L	inductance in Henry	n/a	yes
I	initial current for transient simulation	n/a	no

Nonlinear Components

0.0.4 Diode

Diode:Name Cathode-Node Anode-Node [Parameters]

Parameter	Name	Default Value	Mandatory
Is	saturation current	1e-15 A	yes
N	emission coefficient	1	yes
Cj0	zero-bias junction capacitance	10 fF	yes
M	grading coefficient	0.5	yes
Vj	junction potential	0.7 V	yes
Fc	forward-bias depletion capacitance coefficient	0.5	no
Cp	linear capacitance	0.0 fF	no
Isr	recombination current parameter	0.0	no
Nr	emission coefficient for Isr	2.0	no
Rs	ohmic series resistance	0.0 Ohm	no
Tt	transit time	0.0 ps	no
Ikf	high-injection knee current (0=infinity)	0	no
Kf	flicker noise coefficient	0.0	no
Af	flicker noise exponent	1.0	no
Ffe	flicker noise frequency exponent	1.0	no
Bv	reverse breakdown voltage	0	no
Ibv	current at reverse breakdown voltage	1 mA	no
Temp	simulation temperature in degree Celsius	26.85	no
Xti	saturation current temperature exponent	3.0	no
Eg	energy bandgap in eV	1.11	no
Tbv	Bv linear temperature coefficient	0.0	no
Trs	Rs linear temperature coefficient	0.0	no
Ttt1	Tt linear temperature coefficient	0.0	no
Ttt2	Tt quadratic temperature coefficient	0.0	no
Tm1	M linear temperature coefficient	0.0	no
Tm2	M quadratic temperature coefficient	0.0	no
Tnom	temperature at which parameters were extracted	26.85	no
Area	default area for diode	1.0	no

0.0.5 Bipolar Junction Transistor with Substrate

BJT:Name Base-Node Collector-Node Emitter-Node Substrate-Node [Parameters]

Parameter	Name	Default	Value Mandatory
Type	Polarity [npn, pnp]	n/a	yes
Is	saturation current	1e-16	yes
Nf	forward emission coefficient	1	yes
Nr	reverse emission coefficient	1	yes
Ikf	high current corner for forward beta	0	yes
Ikr	high current corner for reverse beta	0	yes
Vaf	forward early voltage	0	yes
Var	reverse early voltage	0	yes
Ise	base-emitter leakage saturation current	0	yes
Ne	base-emitter leakage emission coefficient	1.5	yes
Isc	base-collector leakage saturation current	0	yes
Nc	base-collector leakage emission coefficient	2	yes
Bf	forward beta	100	yes
Br	reverse beta	1	yes
Rbm	minimum base resistance for high currents	0	yes
Irb	current for base resistance midpoint	0	yes
Rc	collector ohmic resistance	0	yes
Re	emitter ohmic resistance	0	yes
Rb	zero-bias base resistance (may be high-current dependent)	0	yes
Cje	base-emitter zero-bias depletion capacitance	0	yes
Vje	base-emitter junction built-in potential	0.75	yes
Mje	base-emitter junction exponential factor	0.33	yes
Cjc	base-collector zero-bias depletion capacitance	0	yes
Vjc	base-collector junction built-in potential	0.75	yes
Mjc	base-collector junction exponential factor	0.33	yes
Xcjc	fraction of Cjc that goes to internal base pin	1.0	yes
Cjs	zero-bias collector-substrate capacitance	0	yes
Vjs	substrate junction built-in potential	0.75	yes
Mjs	substrate junction exponential factor	0	yes
Fc	forward-bias depletion capacitance coefficient	0.5	yes
Tf	ideal forward transit time	0.0	yes
Xtf	coefficient of bias-dependence for Tf	0.0	yes
Vtf	voltage dependence of Tf on base-collector voltage	0.0	yes
Itf	high-current effect on Tf	0.0	yes
Tr	ideal reverse transit time τ_1	0.0	yes
Temp	simulation temperature in degree Celsius	26.85	no
Kf	flicker noise coefficient	0.0	no
Af	flicker noise exponent	1.0	no
Ffe	flicker noise frequency exponent	1.0	no
Kb	burst noise coefficient	0.0	no
Ab	burst noise exponent	1.0	no
Fb	burst noise corner frequency in Hertz	1.0	no
Ptf	excess phase in degrees	0.0	no

0.0.6 Diac

Diac:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
Vbo	(bidirectional) breakover voltage	30 V	yes
Ibo	(bidirectional) breakover current	50 uA	yes
Cj0	parasitic capacitance	10 pF	no
Is	saturation current	1e-10 A	no
N	emission coefficient	2	no
Ri	intrinsic junction resistance	10 Ohm	no
Temp	simulation temperature	26.85	no

0.0.7 Junction Field-effect Transistor

JFET:Name Gate-Node Drain-Node Source-Node [Parameters]

Parameter	Name	Default Value	Mandatory
Type	polarity [nfet, pfet]	n/a	yes
Vt0	threshold voltage	-2.0 V	yes
Beta	transconductance parameter	1e-4	yes
Lambda	channel-length modulation parameter	0.0	yes
Rd	parasitic drain resistance	0.0	yes
Rs	parasitic source resistance	0.0	yes
Is	gate-junction saturation current	1e-14	yes
N	gate-junction emission coefficient	1.0	yes
Isr	gate-junction recombination current parameter	1e-14	yes
Nr	Isr emission coefficient	2.0	yes
Cgs	zero-bias gate-source junction capacitance	0.0	yes
Cgd	zero-bias gate-drain junction capacitance	0.0	yes
Pb	gate-junction potential	1.0	yes
Fc	forward-bias junction capacitance coefficient	0.5	yes
M	gate P-N grading coefficient	0.5	yes
Kf	flicker noise coefficient	0.0	no
Af	flicker noise exponent	1.0	no
Ffe	flicker noise frequency exponent	1.0	no
Temp	simulation temperature in degree Celsius	26.85	no
Xti	saturation current temperature exponent	3.0	no
Vt0tc	Vt0 temperature coefficient	0.0	no
Betatce	Beta exponential temperature coefficient	0.0	no
Tnom	temperature at which parameters were extracted	26.85	no
Area	default area for JFET	1.0	no

0.0.8 MOS field-effect transistor with substrate

MOSFET:Name Gate-Node Drain-Node Source-Node Bulk-Nod[Parameters]

Parameter	Name	Default Value	Mandatory
Type	polarity [nfet, pfet]	n/a	yes
Vt0	zero-bias threshold voltage	1.0 V	yes
Kp	transconductance coefficient in A/V ²	2e-5	yes
Gamma	bulk threshold in sqrt(V)	yes	
Phi	surface potential	0.6 V	yes
Lambda	channel-length modulation parameter in 1/V	0.0	yes
Rd	drain ohmic resistance	0.0 Ohm	no
Rs	source ohmic resistance	0.0 Ohm	no
Rg	gate ohmic resistance	0.0 Ohm	no
Is	bulk junction saturation current	1e-14 A	yes
N	bulk junction emission coefficient	1.0	yes
W	channel width	1 um	no
L	channel length	1 um	no
Ld	lateral diffusion length	0.0	no
Tox	oxide thickness	0.1 um	no
Cgso	gate-source overlap capacitance per meter of channel width in F/m	0.0	no
Cgdo	gate-drain overlap capacitance per meter of channel width in F/m	0.0	no
Cgbo	gate-bulk overlap capacitance per meter of channel length in F/m	0.0	no
Cbd	zero-bias bulk-drain junction capacitance	0.0 F	no
Cbs	zero-bias bulk-source junction capacitance	0.0 F	no
Pb	bulk junction potential	0.8 V	no
Mj	bulk junction bottom grading coefficient	0.5	no
Fc	bulk junction forward-bias depletion capacitance coefficient	0.5	no
Cjsw	zero-bias bulk junction periphery capacitance per meter of junction perimeter in F/m	0.0	no
Mjsw	bulk junction periphery grading coefficient	0.33	no
Tt	bulk transit time	0.0 ps	no
Nsub	substrate bulk doping density in 1/cm ³	0.0	no
Nss	surface state density in 1/cm ²	0.0	no
Tpg	gate material type: 0 = alumina; -1 = same as bulk; 1 = opposite to bulk	0	no
Uo	surface mobility in cm ² /Vs	600.0	no
Rsh	drain and source diffusion sheet resistance in Ohms/square	0.0	no
Nrd	number of equivalent drain squares	1	no
Nrs	number of equivalent source squares	1	no
Cj	zero-bias bulk junction bottom capacitance per square meter of junction area in F/m ²	0.0	no
Js	bulk junction saturation current per square meter of junction area in A/m ²	0.0	no
Ad	drain diffusion area in m ²	0.0	no

Sources

0.0.9 DC Voltage Source

V:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
U	voltage in Volts		yes

0.0.10 AC Voltage Source

Vac:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
U	peak voltage in Volts	n/a	yes
f	frequency in Hertz	n/a	no
Phase	initial phase in degrees	0	no
Theta	damping factor (transient simulation only)	0	no

0.0.11 Voltage Controlled Voltage Source

VCVS:Name Node1 Node2 Node3 Node4 [Parameters]

Node1 is the input , Node2 is the output, Node3 is the ground for the input, and Node4 is the ground for the output.

Parameter	Name	Default Value	Mandatory
G	forward transfer factor	1.0	todo
T	delay time	0	todo

0.0.12 Voltage Controlled Current Source

VCVS:Name Node1 Node2 Node3 Node4 [Parameters]

Node1 is the input , Node2 is the output, Node3 is the ground for the input, and Node4 is the ground for the output.

Parameter	Name	Default Value	Mandatory
G	forward transconductance	1.0	todo
T	delay time	0	todo

0.0.13 Current Controlled Voltage Source

VCVS:Name Node1 Node2 Node3 Node4 [Parameters]

Node1 is the input , Node2 is the output, Node3 is the ground for the input, and Node4 is the ground for the output.

Parameter	Name	Default Value	Mandatory
G	forward transfer factor	1.0	todo
T	delay time	0	todo

0.0.14 Current Controlled Current Source

VCVS:Name Node1 Node2 Node3 Node4 [Parameters]

Node1 is the input , Node2 is the output, Node3 is the ground for the input, and Node4 is the ground for the output.

Parameter	Name	Default Value	Mandatory
G	forward transfer factor	1.0	todo
T	delay time	0	todo

0.0.15 Voltage Pulse

Vpulse:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
U1	voltage before and after the pulse	0 V	yes
U2	voltage of the pulse	1 V	yes
T1	start time of the pulse	0	yes
T2	ending time of the pulse	1 ms	yes
Tr	rise time of the leading edge	1 ns	no
Tf	fall time of the trailing edge	1 ns	no

0.0.16 Current Pulse

Ipulse:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
I1	current before and after the pulse	0 V	yes
I2	current of the pulse	1 V	yes
T1	start time of the pulse	0	yes
T2	ending time of the pulse	1 ms	yes
Tr	rise time of the leading edge	1 ns	no
Tf	fall time of the trailing edge	1 ns	no

0.0.17 Rectangle Voltage

Vrect:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
U	voltage of high signal	1 V	yes
TH	duration of high pulses	1 ms	yes
TL	duration of low pulses	1 ms	yes
Tr	rise time of the leading edge	1 ns	todo
Tf	fall time of the leading edge	1 ns	todo
Td	initial delay time	0 ns	todo

0.0.18 Rectangle Current

Irect:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
I	current at high pulse	1 mA	yes
TH	duration of high pulses	1 ms	yes
TL	duration of low pulses	1 ms	yes
Tr	rise time of the leading edge	1 ns	todo
Tf	fall time of the leading edge	1 ns	todo
Td	initial delay time	0 ns	todo

0.0.19 Exponential Voltage Source

Vexp:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
U1	voltage before rising edge	0 V	todo
U2	maximum voltage of the pulse	1 V	todo
T1	start time of the exponentially rising edge	0	todo
T2	start of exponential decay	1 ms	todo
Tr	rise time of the rising edge	1 ns	todo
Tf	fall time of the falling edge	1 ns	todo

0.0.20 Exponential Current Source

Vexp:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
I1	Current before rising edge	0 V	todo
I2	maximum current of the pulse	1 A	todo
T1	start time of the exponentially rising edge	0	todo
T2	start of exponential decay	1 ms	todo
Tr	rise time of the rising edge	1 ns	todo
Tf	fall time of the falling edge	1 ns	todo

0.0.21 AC Voltage Source with Amplitude Modulator

AM_Mod:Name Node1 Node2 Node3 [Parameters]

Node1 is the modulated output, Node2 is the common ground, and Node3 is the modulation input.

Parameter	Name	Default Value	Mandatory
U	peak voltage in Volts	1 V	todo
f	frequency in Hertz	1 GHz	todo
Phase	initial phase in degrees	0	todo
m	modulation level	1.0	todo

0.0.22 AC Voltage Source with Amplitude Modulator

AM_Mod:Name Node1 Node2 Node3 [Parameters]

Node1 is the modulated output, Node2 is the common ground, and Node3 is the modulation input.

Parameter	Name	Default Value	Mandatory
U	peak voltage in Volts	1 V	todo
f	frequency in Hertz	1 GHz	todo
Phase	initial phase in degrees	0	todo
m	modulation level	1.0	todo

0.0.23 AC Voltage Source with Phase Modulator

PM_Mod:Name Node1 Node2 Node3 [Parameters]

Node1 is the modulated output, Node2 is the common ground, and Node3 is the modulation input.

Parameter	Name	Default Value	Mandatory
U	peak voltage in Volts	1 V	todo
f	frequency in Hertz	1 GHz	todo
Phase	initial phase in degrees	0	todo
M	modulation index	1.0	todo

Simulation Commands

DC Simulation

.DC:Name [Parameters]

Parameter	Name	Default Value	Mandatory
Temp	simulation temperature in degree Celsius	26.85	no
reltol	relative tolerance for convergence	0.001	no
absol	absolute tolerance for currents	1 pA	no
vntol	absolute tolerance for voltages	1 uV	no
saveOPs	put operating points into dataset [yes,no]		no
MaxIter	maximum number of iterations until error	150	no
saveAll	save subcircuit nodes into dataset [yes,no]	no	no
convHelper	preferred convergence algorithm [none, gMinStepping, SteepestDescent, LineSearch, Attenuation, SourceStepping]	none	
Solver	method for solving the circuit matrix [CroutLU, DoolittleLU, HouseholderQR, HouseholderLQ, GolubSVD]	CroutLU	no

AC Simulation

.AC:Name [Parameters]

Parameter	Name	Default Value	Mandatory
Type	sweep type [lin,log,list,const]	n/a	yes
Start	start frequency in Hertz	n/a	yes
Stop	stop frequency in Hertz	n/a	yes
Points	number of simulation steps	n/a	yes
Noise	calculate noise voltages	no	no

Parameter Sweep

.SW:Name [Parameters]

Parameter	Name	Default Value	Mandatory
Sim	simulation to perform parameter sweep on	n/a	yes
Type	sweep type [lin,log,list,const]	n/a	yes
Param	parameter to sweep	n/a	yes
Stop	start value for sweep	n/a	yes
Start	stop value for sweep	n/a	yes

Transient Simulation

.TR:Name [Parameters]

Parameter	Name	Default Value	Mandatory
Type	sweep type [lin,log,list,const]	todo	todo
Start	start time in seconds	todo	todo
Stop	stop time in seconds	todo	todo
Points	number of simulation time steps	11(todo)	todo
IntegrationMethod	integration method [Euler, Trapezoidal, Gear, AdamsMoulton]	Trapezoidal	todo
Order	order of integration method	2	todo
InitialStep	initial step size in seconds	1 ns (todo)	todo
MinStep	minimum step size in seconds	1e-16	todo
MaxIter	maximum number of iterations until error	150	todo
reltol	relative tolerance for convergence	0.001	todo
abstol	absolute tolerance for currents	1 pA	todo
vntol	absolute tolerance for voltages	1 uV	todo
Temp	simulation temperature in degree Celsius	26.85	todo
LTEreltol	relative tolerance of local truncation error	1e-3	todo
LTEabstol	absolute tolerance of local truncation error	1e-6	todo
LTEfactor	overestimation of local truncation error	1	todo
Solver	method for solving the circuit matrix [CroutLU, DoolittleLU, HouseholderQR, HouseholderLQ, GolubSVD]	CroutLU	todo
relaxTSR	relax time step raster [no, yes]	yes	todo
initialDC	perform an initial DC analysis [yes, no]	yes	todo
MaxStep	maximum step size in seconds	0	todo

S Parameter Simulation

xxx:Name Node1 Node2 [Parameters]

Parameter	Name	Default Value	Mandatory
Type	sweep type [lin,log,list,const]	todo	todo
Start	start frequency in Hertz	1 GHz	todo
Stop	stop frequency in Hertz	10 GHz	todo
Points	number of simulation steps	19	todo
Noise	calculate noise parameters	no	todo
NoiseIP	input port for noise figure	1	todo
NoiseOP	output port for noise figure	2	todo
saveCVs	put characteristic values into dataset [yes,no]	no	todo
saveAll	save subcircuit characteristic values into dataset [yes,no]	no	todo