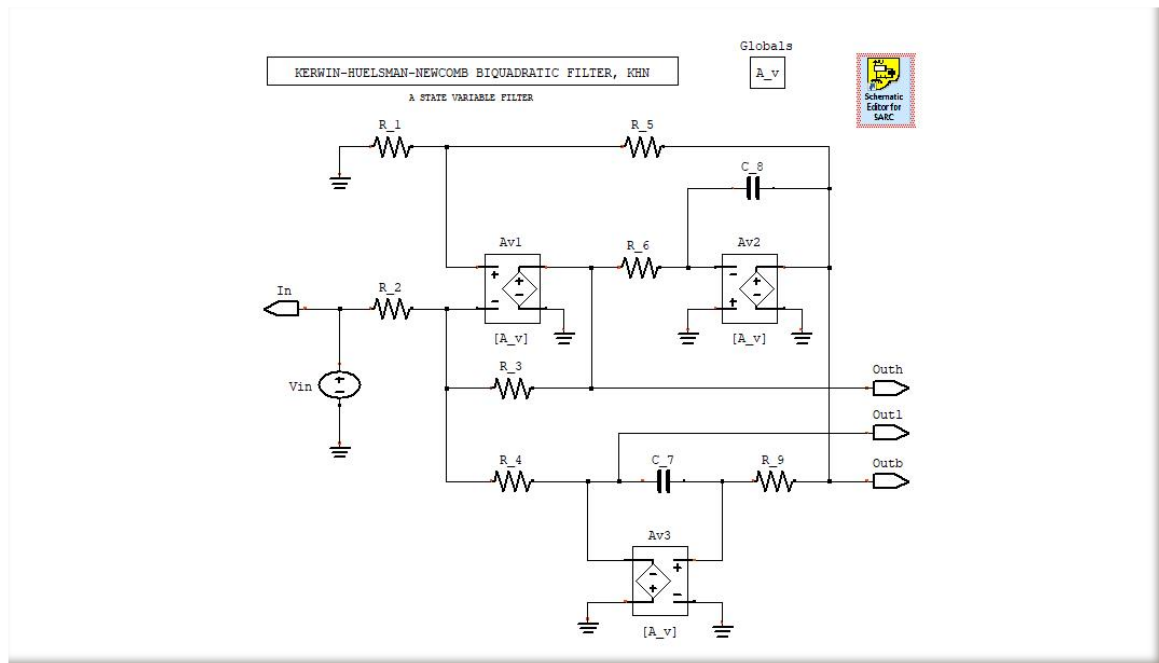




Transfer Functions, Modeling and Simulation using the SARC Schematic Editor

(Running on Windows OS, 64 bits)

Yves Leduc | July 2018

Introduction

The **SARC Schematic Editor**, the symbolic computation of the transfer functions and the SARC simulations are the work of *Jacques Mequin*.

The **Napa Compiler and Package** is the work of *Yves Leduc*.

http://www.borogoves.eu/NAPA_RELEASE_305e/

Maxima is a descendant of Macsyma, the legendary computer algebra system developed in the late 1960s at the **Massachusetts Institute of Technology**.

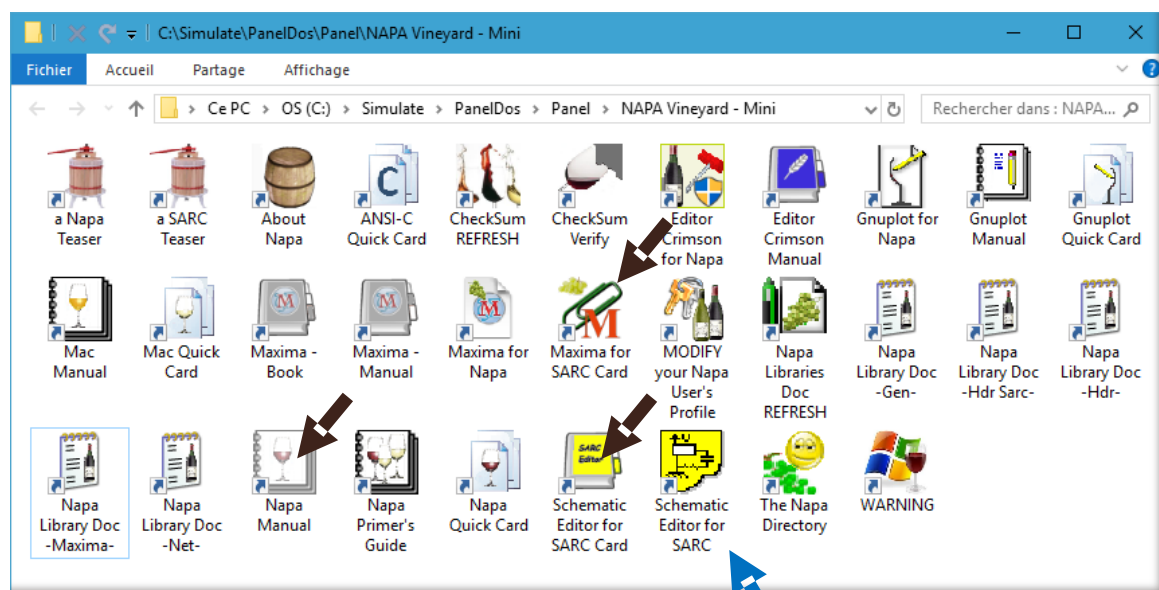
<http://maxima.sourceforge.net/>

The **SARC Schematic Editor** is the entry point to describe linear(ised) electrical circuits. It is closely linked to the symbolic programming tool Maxima which is used to compute, in the Laplace Domain, the transfer functions described by this editor and to mixed-signal simulations with the Napa package.

Maxima can be used to postprocess further the transfer functions. The functions produced by the pair SARC Schematic Editor/Maxima can be inserted in NAPA netlists.

The **Napa Compiler** is a compiler of netlists producing ad-hoc cycle-based ANSI-C simulators of mixed signal circuits. It can host continuous domain models described in the Laplace domain thanks to **SARC** (Semi Analytical Recursive Convolution).

The users' guides of these tools are not the object of this paper and can be found on the '**NAPA Vineyard**' Windows Panel created during the installation of the Napa package :



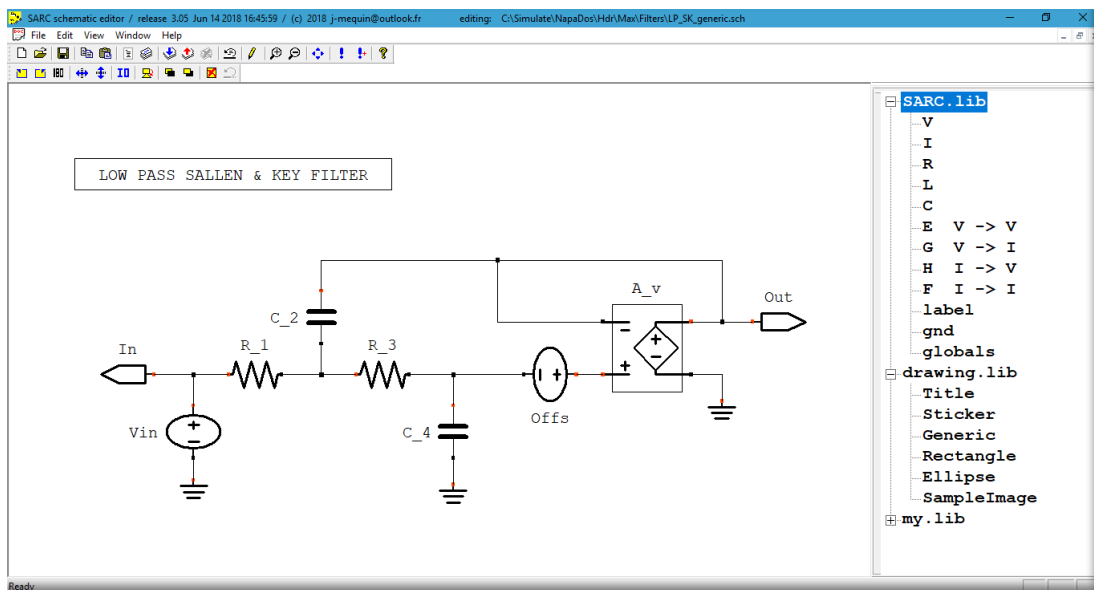
Open SARC Editor

1. AN EXAMPLE OF SCHEMATIC

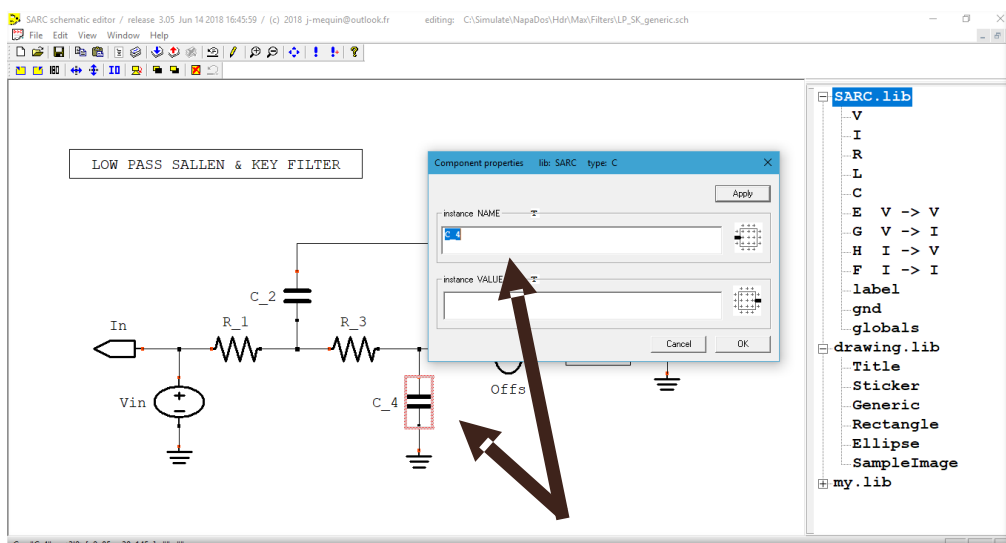
(These examples use netlists located in directory '*/Simulate/NapaDos/Sch*')

We will use a simple filter to illustrate how to build a schematic and use it to produce transfer functions. We will limit our ambition for the moment to the simplest process.

This is the schematic of a **Sallen & Key Filter**. We have chosen in this example to limit the description to the main elements: 2 resistors, 2 capacitors, 2 independent voltage sources and 1 voltage-controlled voltage source selected in the right menu in the '**SARC.lib**' as respectively '**R**', '**C**', '**V**' and '**E**'.

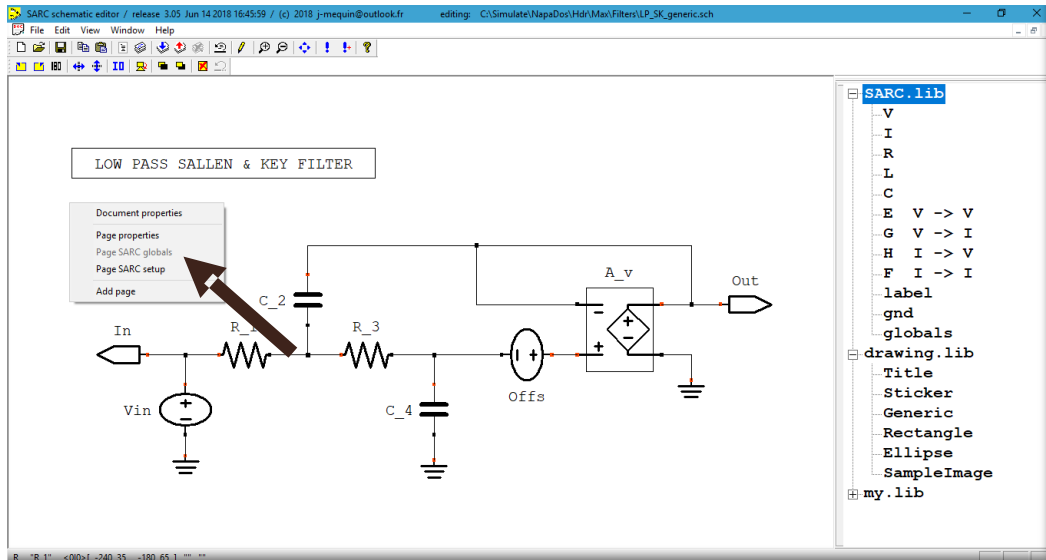


By a double click on an element, it is possible to enter its name and add some properties.



All constant sources ('V' or 'I') are by default the input of the circuits. We must indicate the output(s) we want to analyze: voltages or currents. (It is possible to output power and energy but only in a simulation context not for the transfer function)

By a single click on an empty zone of the schematic, a menu will appear, and we will select the item '**Page SARC setup**'



We then indicate the output(s) we want to compute, here the voltage of node 'Out'. We choose to consider the offset 'Offs' as a parameter by declaring it as an 'INTERN'. We select to produce a transfer function.

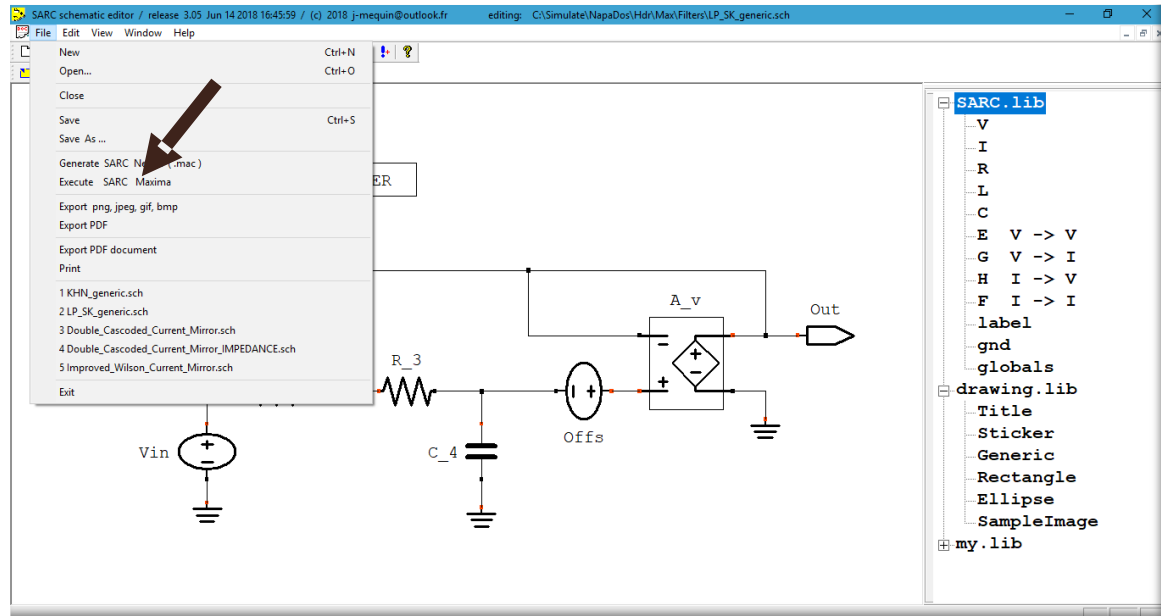
More details can be found in the '**Schematic Editor for SARC Card**' and '**Maxima for SARC Card**' documentations accessible from the '**NAPA Vineyard**' Windows panel (represented page 1).

The screenshot shows the 'SARC setup' dialog box. The 'INTERN' field is set to 'Offs'. The 'OUTPUTS' field is set to 'v(Out)'. The 'next STEP' field is empty. The 'FEEDBACKS' field is empty. The 'C code' field is empty. The 'FEEDBACKS PARMS' field is empty. The 'execution order' is set to 1 for 'GENERATE_XFER' and 0 for 'GENERATE_MIMO'. The 'XWISH' field is empty. The 'PRINTPOLES' field is empty. The 'RUEMODE' checkbox is unchecked. The 'User code' field is empty. The 'Maxima' field is empty. The 'special control directives' field is empty. The 'Cancel' and 'OK' buttons are at the bottom right.

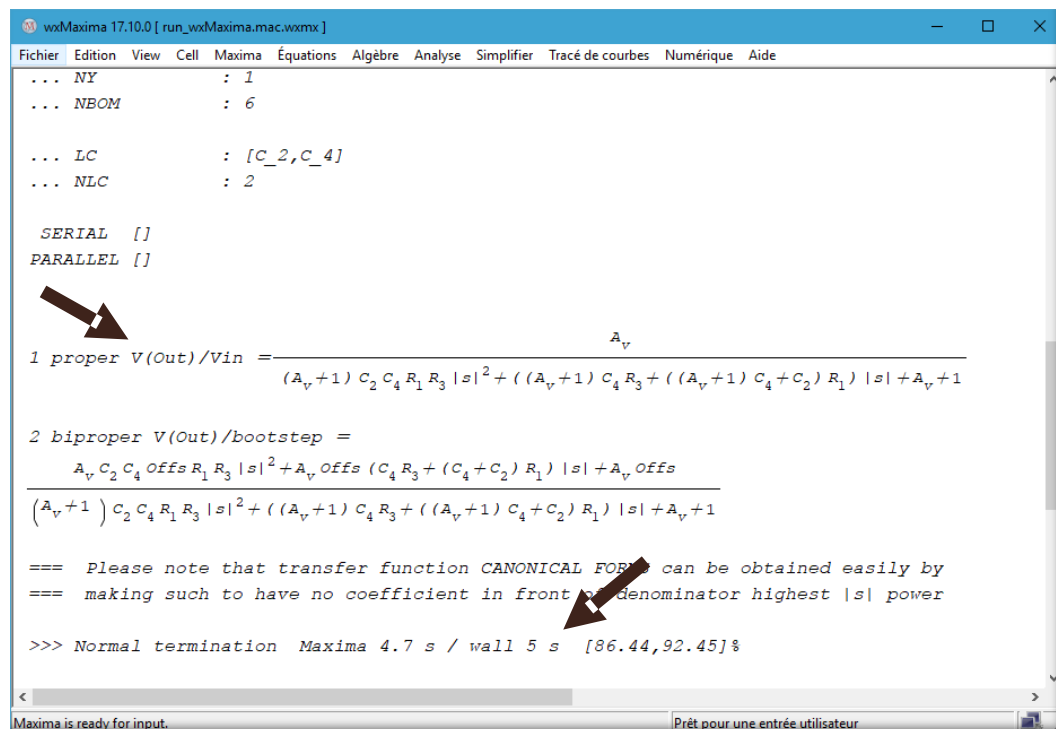
It is important to note that a simple 'Save' is automatically producing a textual netlist (.mac) and a document (.pdf). This is a guarantee that schematic, netlist and documentation are always synchronized.

It is now time to produce the transfer function!

In the menu 'File', we will select 'Execute SARC Maxima'.



After a few seconds, a Maxima session starts and the transfer function automatically computed. Wait for the message '>>> Normal termination'.



Here is the result:

$$1 \text{ proper } V(Out)/Vin = \frac{A_v}{(A_v + 1)C_2C_4R_1R_3|s|^2 + ((A_v + 1)C_4R_3 + ((A_v + 1)C_4 + C_2)R_1)|s| + A_v + 1}$$

The results are stored in Maxima variables **XFER[1]** where '1' is the number in front of the output. The 2nd transfer function represents the effect of the 'INTERN' input(s).

We can use Maxima to compute the transfer function for an ideal gain of the amplifier by applying a limit():

The screenshot shows the wxMaxima 17.10.0 interface. The main window displays the following content:

```

A_v C_2 C_4 Offs R_1 R_3 |s|^2 + A_v Offs (C_4 R_3 + (C_4 + C_2) R_1) |s| + A_v Offs
-----
(A_v + 1) C_2 C_4 R_1 R_3 |s|^2 + ((A_v + 1) C_4 R_3 + ((A_v + 1) C_4 + C_2) R_1) |s| + A_v + 1

=== Please note that transfer function CANONICAL FORMS can be obtained easily by
=== making such to have no coefficient in front of denominator highest |s| power

>>> Normal termination Maxima 0.72 s / wall 0.8 s [90.56,92.4]%

(%i2)  Tfinf : limit(XFER[1], A_v, inf);
(Tfinf)
      1
-----
C_2 C_4 R_1 R_3 |s|^2 + (C_4 R_3 + C_4 R_1) |s| + 1

```

The status bar at the bottom indicates "Maxima is ready for input." and "Prêt pour une entrée utilisateur".

We can also use Maxima to postprocess the results to get the sensitivity of the transfer function to the value of an element, here the sensitivity to R₁:

The screenshot shows the wxMaxima 17.10.0 interface. The main window displays the following content:

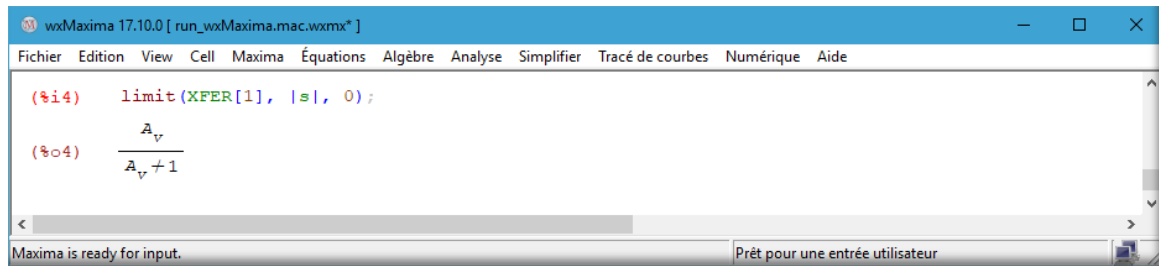
```

(%i3)  diff(XFER[1], R_1);
(%o3)
      A_v ((A_v + 1) C_2 C_4 R_3 |s|^2 + ((A_v + 1) C_4 + C_2) |s|)
-----
      ((A_v + 1) C_2 C_4 R_1 R_3 |s|^2 + ((A_v + 1) C_4 R_3 + ((A_v + 1) C_4 + C_2) R_1) |s| + A_v + 1)^2

```

The status bar at the bottom indicates "Maxima is ready for input." and "Prêt pour une entrée utilisateur".

We can also obtain the DC transfer function by applying a limit. The Laplace variable is $|s|$.

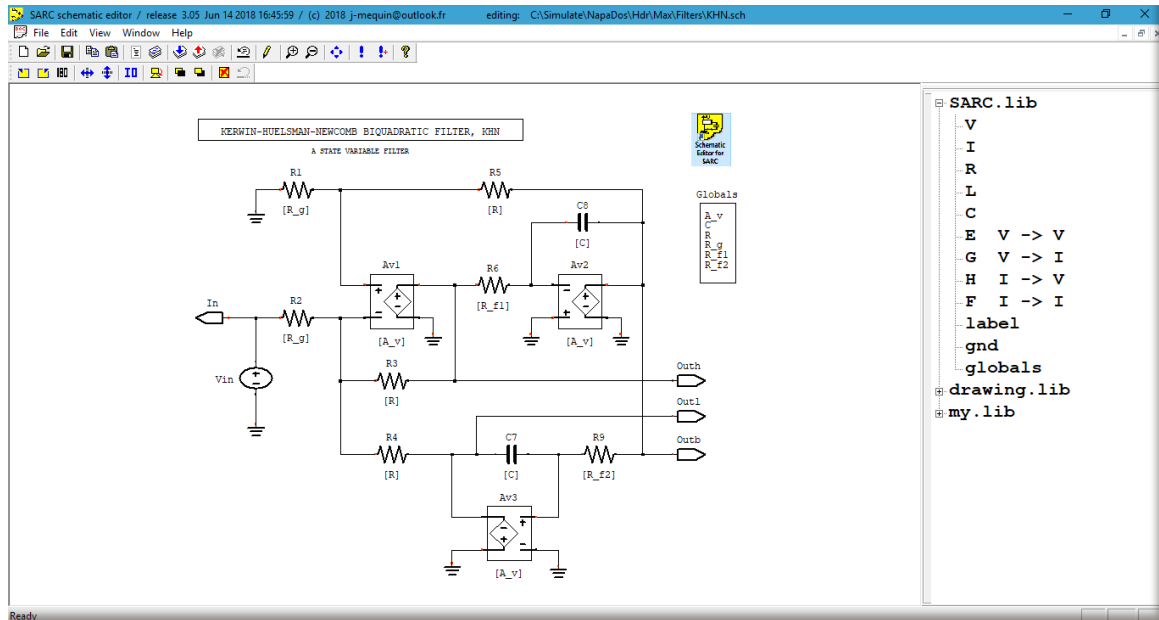


As expected, we can see that the DC gain of a Sallen & Key filter is about 1.

As it could be tedious to perform the same postprocesses again and again, we will add a few properties directly in the schematic.

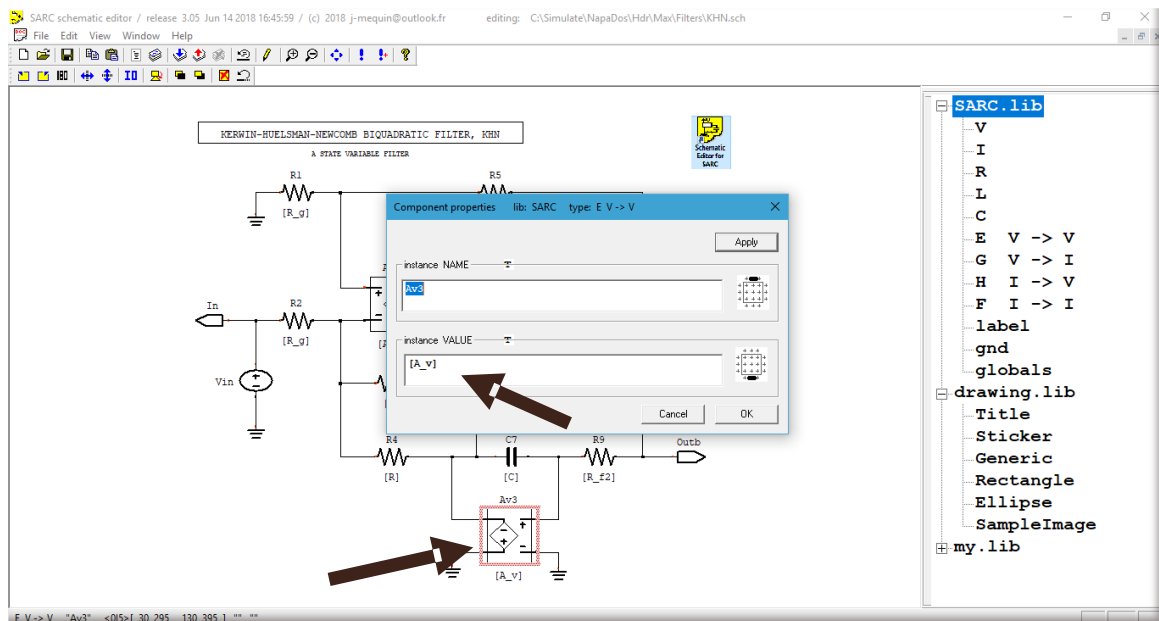
2. AN EXAMPLE OF SCHEMATIC, USING PROPERTIES

We use here the component properties to assign specific values to the elements.

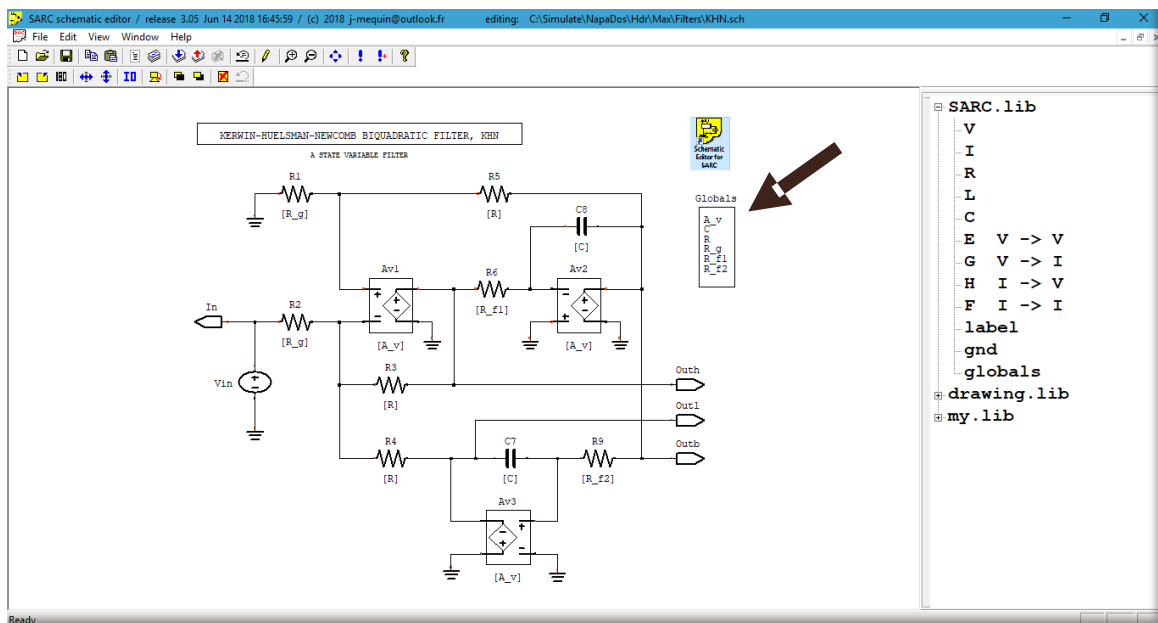
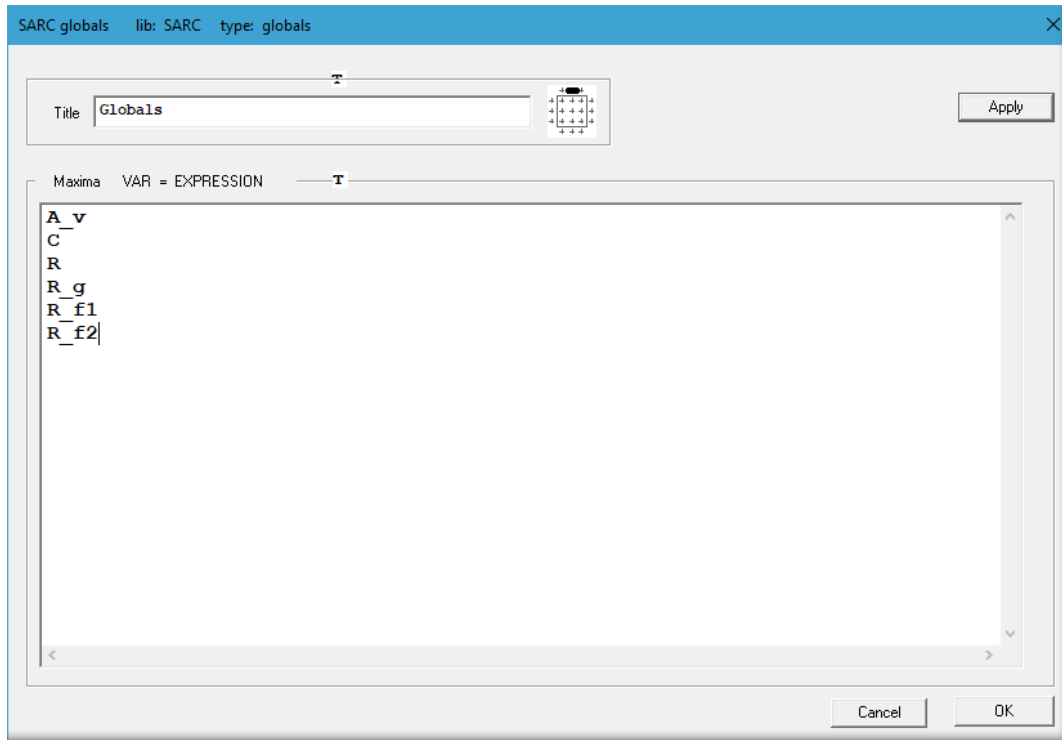


By double clicking on a component, we can fill its properties. The syntax uses brackets [].

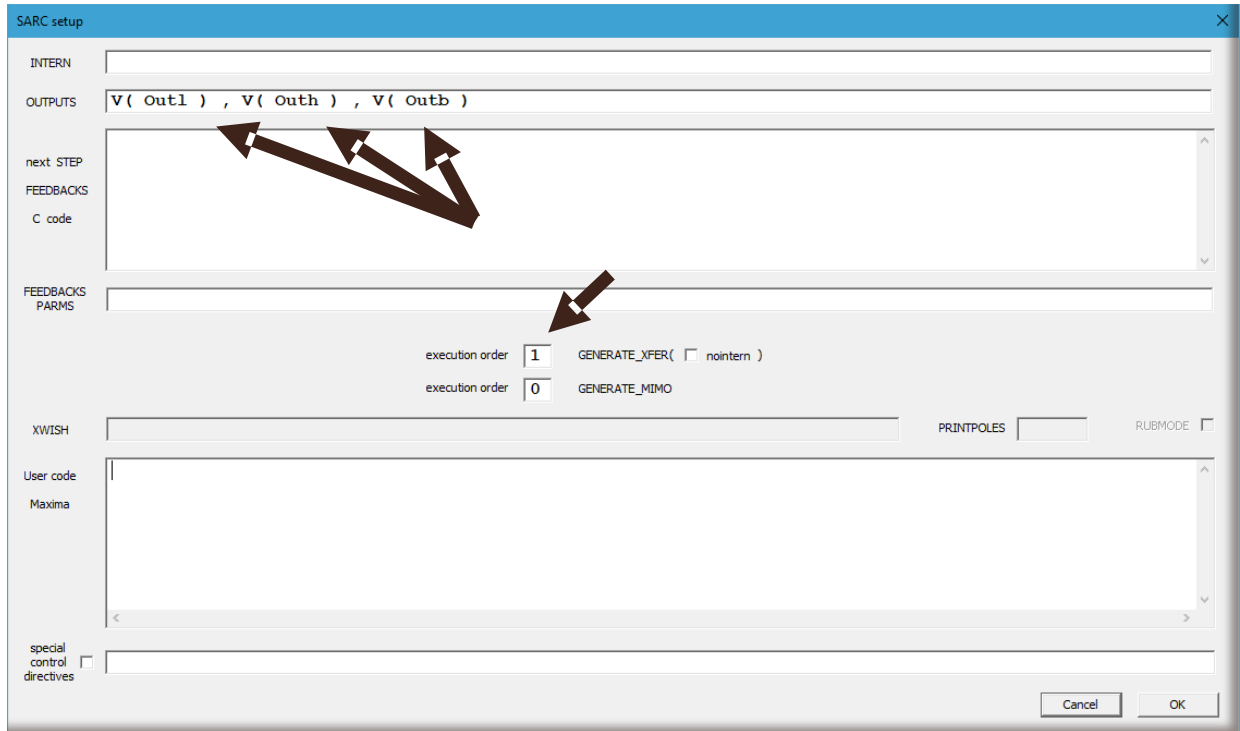
We assign, for example, the same symbolic value for the gain of each amplifiers 'A_v'.



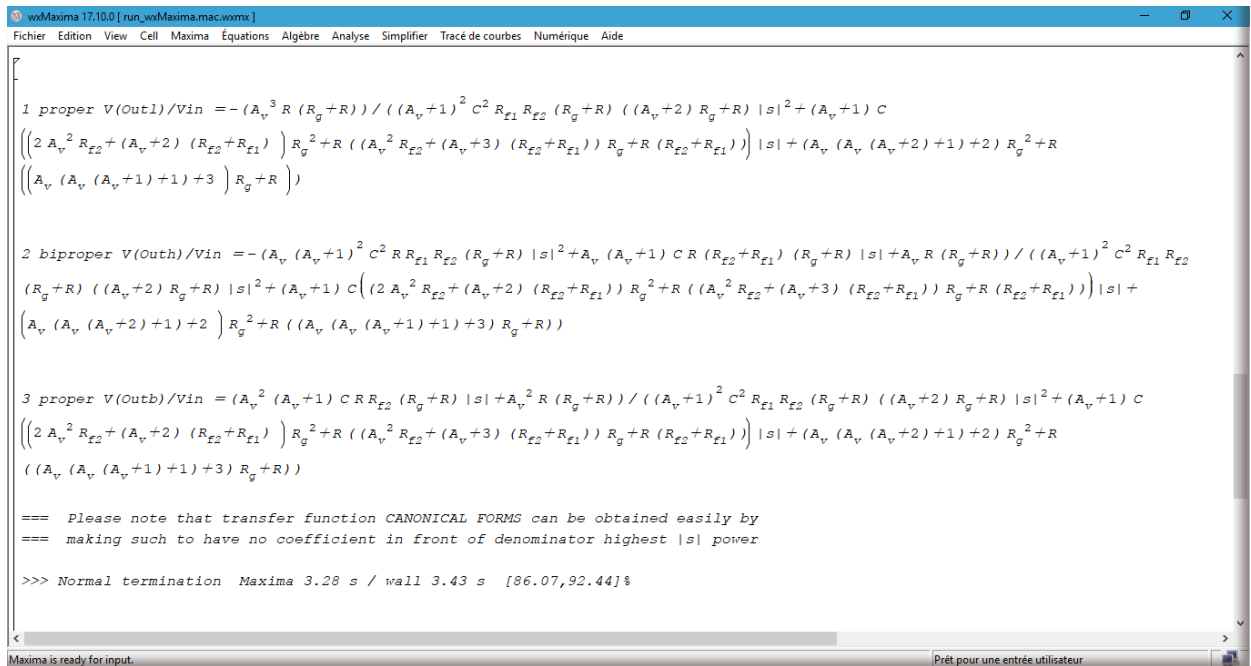
We need now to declare these new variables by selecting the component 'globals' in the 'SARC.lib' of menu on the right, instantiate it in the schematic, it is an empty rectangle, double click on it to access to the menu, and fill.



The 3 outputs are declared in the ‘Page SARC setup’ and the transfer function is selected.



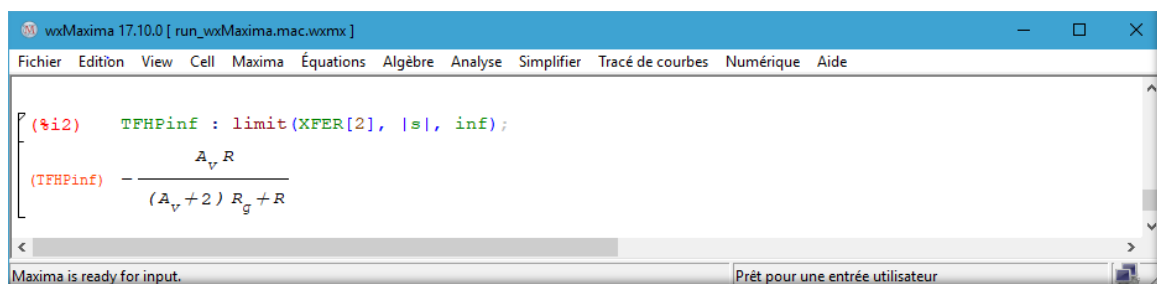
In the ‘File’ menu, on the top, click on the ‘Execute SARC Maxima’ to start the Maxima process.



The 3 transfer functions are produced. There is no need a postprocess to assign the values to the components. It is important to note that the complexity of the denominator is related to the complexity of the circuit.

The Maxima variables are respectively XFER[1], XFER[2], and XFER[3].

Again, we can use Maxima, to process more. Here we compute the gain at infinity of the high pass output (transfer function number 2 of the Maxima output):



It is possible to specify the postprocessing in the schematics.

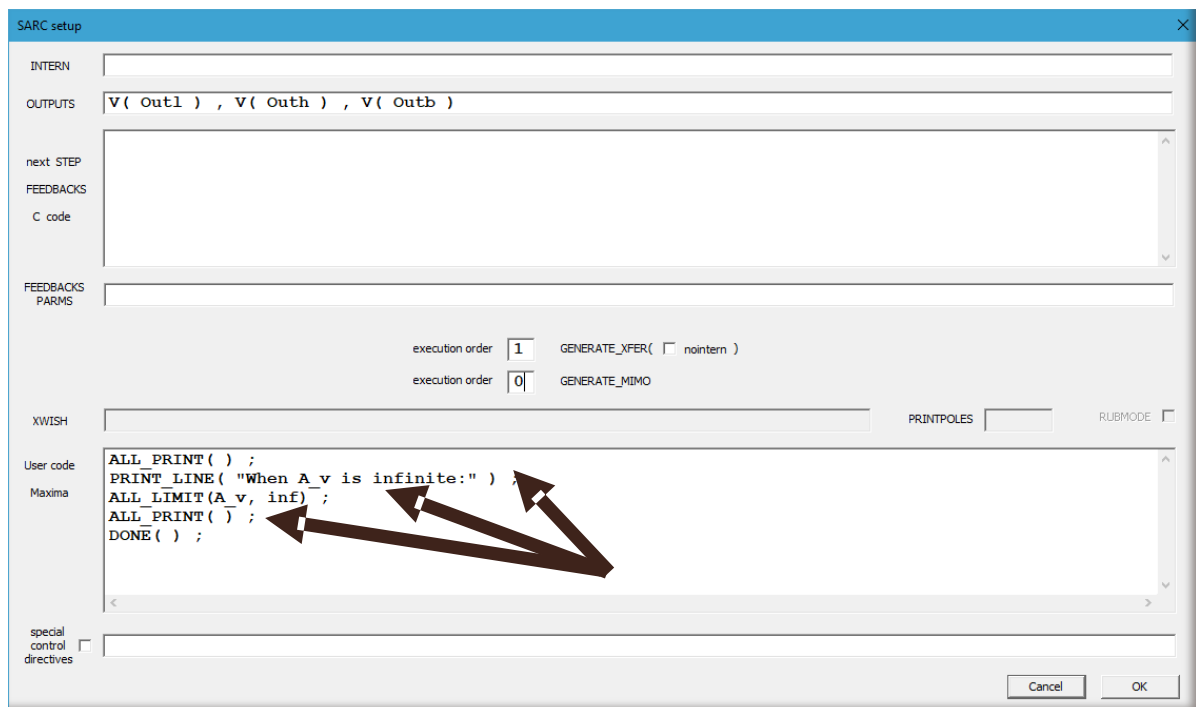
3. AN EXAMPLE OF SCHEMATIC, USING PROPERTIES AND POSTPROCESSING

In the previous schematics, we insert post processing in the schematics. Clicking in an empty space of the schematics, we access the ‘SARC setup page’. In the ‘User code Maxima’ field, we can insert Maxima code.

In addition to the standard Maxima functions, a few functions are currently available.
(located in “/Simulate/MaximaDos/Functions” directory)

Useful MAXIMA User's Functions		(used to process the transfer functions produced by the schematic editor)
PRINT_LINE(msg)	PRINT_LINE("line of text")	print the line
ALL_PRINT()	ALL_PRINT()	all transfer functions are printed
PRINT(id,xfer)	PRINT(IMPEDANCE,XFER[1])	return and print the transfer function "id = xfer"
Applied to all transfer functions (modify the array of transfer functions XFER[]) :		
ALL_NUMERIC()	ALL_NUMERIC()	insert numerical values in all transfer functions
ALL_SUBSTITUTE(parm,val)	ALL_SUBSTITUTE(gm01,10e-3)	substitute in all transfer functions
ALL_LIMIT(parm,lim)	ALL_LIMIT(gm01,inf)	apply limit in all transfer functions
Applied on a single transfer function (does not modify the array of transfer functions XFER[]) :		
NUMERIC(xfer)	NUMERIC(XFER[2])	return a transfer function after inserting numerical values
SUBSTITUTE(xfer,parm,val)	SUBSTITUTE(XFER[1],gds1,gn)	return a transfer function after substitution
LIMIT(xfer,parm,lim)	LIMIT(XFER[1],gm01,inf)	return a transfer function after applying the limit
NUMERATOR(xfr)	NUMERATOR(XFER[1])	return the numerator of a transfer function
DENOMINATOR(xfr)	DENOMINATOR(XFER[3])	return the denominator of a transfer function
NCOEFF(xfer,n)	NCOEFF(XFER[2],2)	return the nth coefficient of the numerator of a transfer function
DCOEFF(xfer,n)	DCOEFF(XFER[1],3)	return the nth coefficient of the denominator of a transfer function
DC(xfer)	DC(XFER[1])	return the DC transfer function
INF(xfer)	INF(XFER[1])	return the transfer function at infinite frequency
Useful to signal the end of the processing which could be in some cases (very) long		
DONE()		print a line "end of the processing"

Here is the postprocessing code we have chosen; the syntax is the syntax of Maxima.



And the results are:

```

wxMaxima 17.10.0 [run_wxMaxima.mac*]
Fichier Edition View Cell Maxima Équations Algèbre Analyse Simplifier Tracé de courbes Numérique Aide

((R2 ((A_v + 1) R4 + R3) + R3 R4) R5 + R1 (R2 ((A_v + 1) R4 + R3) + R3 R4) R6) |s| + (R2 ((A_v + 1) R4 + (A_v^3 + 1) R3) + R3 R4) R5 + R1
(R2 ((A_v (A_v + 1) + 1) R4 + (A_v^2 (A_v + 1) + 1) R3) + (A_v^2 + 1) R3 R4)

XFER[ 3 ] = (A_v^2 (A_v + 1) C7 R3 R4 (R5 + R1) R9 |s| + A_v^2 R3 R4 (R5 + R1)) / ((A_v + 1)^2 C7 C8 (R3 R4 + R2 ((A_v + 1) R4 + R3)) (R5 + R1) R6 R9 |s|^2 +
(A_v + 1) (C7 ((R2 ((A_v + 1) R4 + R3) + R3 R4) R5 + R1 (R2 ((A_v (A_v + 1) + 1) R4 + (A_v^2 + 1) R3) + (A_v^2 + 1) R3 R4)) R9 + C8
((R2 ((A_v + 1) R4 + R3) + R3 R4) R5 + R1 (R2 ((A_v + 1) R4 + R3) + R3 R4) R6) |s| + (R2 ((A_v + 1) R4 + (A_v^3 + 1) R3) + R3 R4) R5 + R1
(R2 ((A_v (A_v + 1) + 1) R4 + (A_v^2 (A_v + 1) + 1) R3) + (A_v^2 + 1) R3 R4)

When A_v is infinite:

XFER[ 1 ] = - (R3 R4 (R5 + R1)) / (C7 C8 R2 R4 (R5 + R1) R6 R9 |s|^2 + C7 R1 (R3 R4 + R2 (R4 + R3)) R9 |s| + R2 R3 (R5 + R1))
XFER[ 2 ] = - (C7 C8 R3 R4 (R5 + R1) R6 R9 |s|^2) / (C7 C8 R2 R4 (R5 + R1) R6 R9 |s|^2 + C7 R1 (R3 R4 + R2 (R4 + R3)) R9 |s| + R2 R3 (R5 + R1))
XFER[ 3 ] = (C7 R3 R4 (R5 + R1) R9 |s|) / (C7 C8 R2 R4 (R5 + R1) R6 R9 |s|^2 + C7 R1 (R3 R4 + R2 (R4 + R3)) R9 |s| + R2 R3 (R5 + R1))

>>> end of postprocessing
Maxima is ready for input.
Prêt pour une entrée utilisateur

```

Again, we can ‘play’ with the solutions and use the plain symbolic capability of Maxima.

```

wxMaxima 17.10.0 [run_wxMaxima.mac.wxmx]
Fichier Edition View Cell Maxima Équations Algèbre Analyse Simplifier Tracé de courbes Numérique Aide

>>> end of postprocessing

(%i2) diff(XFER[3], C_8);

(%o2) - (C7^2 R2 R3 R4^2 (R5 + R1)^2 R6 R9^2 |s|^3) / ((C7 C8 R2 R4 (R5 + R1) R6 R9 |s|^2 + C7 R1 (R3 R4 + R2 (R4 + R3)) R9 |s| + R2 R3 (R5 + R1))^2)

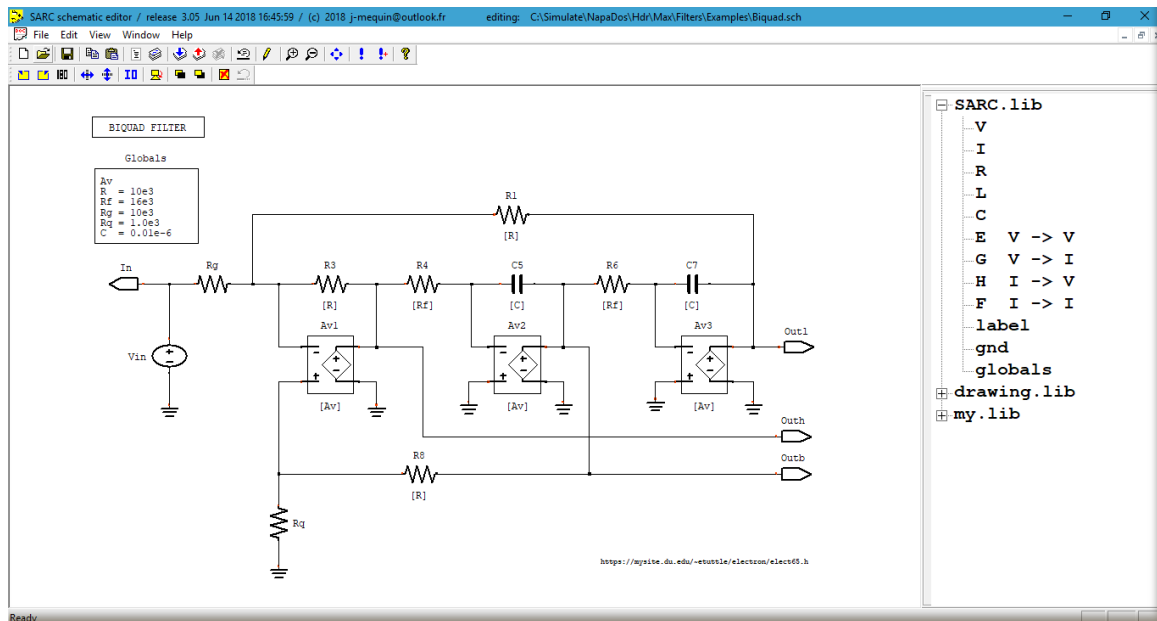
Maxima is ready for input.
Prêt pour une entrée utilisateur

```

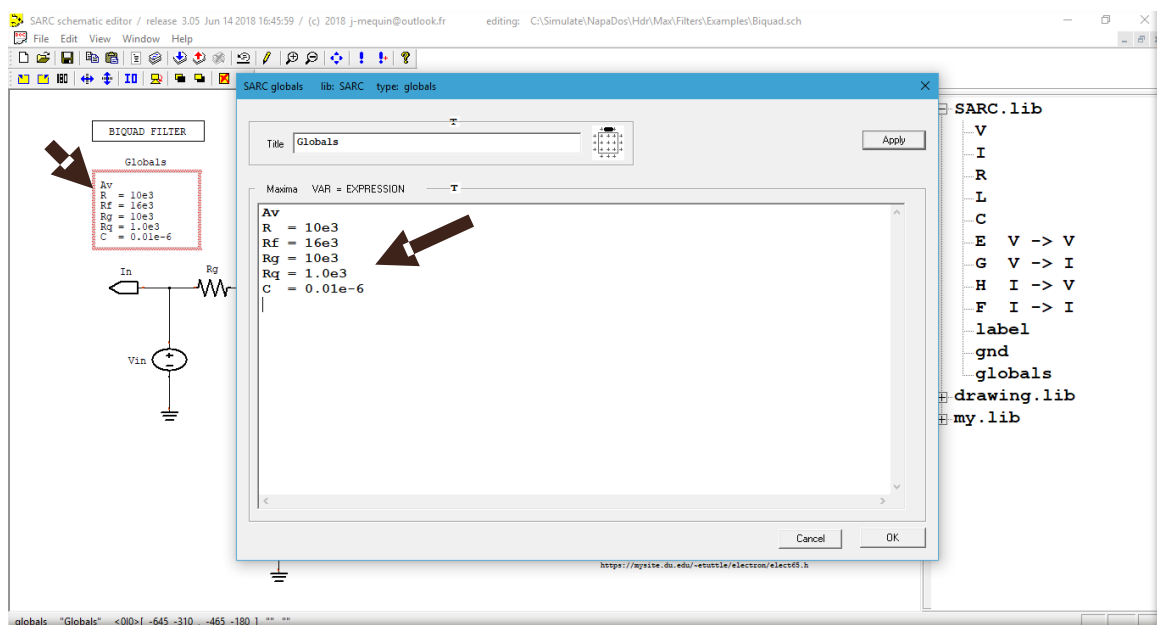
4. FROM SYMBOLIC RESULTS TO NUMBERS AND BODE PLOTS

After the symbolic analysis of transfer functions, it could be interesting to apply numerical values to evaluate the solutions.

In this example, we apply symbolic values for parameters and add numerical values to the 'globals' parameters and ask for bode plots.



To modify the 'globals' parameters, a double click on its instantiation and edit.



We edit the 'SARC page setup' and add a few Maxima code to apply the numerical values and produce the Bode plot of the first transfer function.

SARC setup

INTERM:

OUTPUTS:

next STEP:

FEEDBACKS:

C code:

FEEDBACKS PARS:

execution order: GENERATE_XFER(☐ nonterm)

execution order: GENERATE_MIMO

XWISH:

PRINTPOLES: ☒

RUBMODE: ☐

User code:

special control directives: ☐

Cancel OK

Here are the results of Maxima, the 3 transfer functions are now numerical.

wxMaxima 17.10.0 [run_wdMaxima.mac.wxmx]

Fichier Edition View Cell Maxima Équations Algèbre Analyse Simplifier Tracé de courbes Numérique Aide

```

XFER[ 1 ] = - 
$$\frac{R (Rq + R)}{C^2 Rf^2 Rg (Rq + R) |s|^2 + C Rf (2 Rg + R) Rq |s| + Rg (Rq + R)}$$

XFER[ 2 ] = - 
$$\frac{C R Rf (Rq + R) |s|}{C^2 Rf^2 Rg (Rq + R) |s|^2 + C Rf (2 Rg + R) Rq |s| + Rg (Rq + R)}$$

XFER[ 3 ] = - 
$$\frac{C^2 R Rf^2 (Rq + R) |s|^2}{C^2 Rf^2 Rg (Rq + R) |s|^2 + C Rf (2 Rg + R) Rq |s| + Rg (Rq + R)}$$


Applying numerical values:

XFER[ 1 ] = - 
$$\frac{1.110^8}{2.816 |s|^2 + 4800.0 |s| + 1.110^8}$$

XFER[ 2 ] = - 
$$\frac{17600.0 |s|}{2.816 |s|^2 + 4800.0 |s| + 1.110^8}$$

XFER[ 3 ] = - 
$$\frac{2.816 |s|^2}{2.816 |s|^2 + 4800.0 |s| + 1.110^8}$$

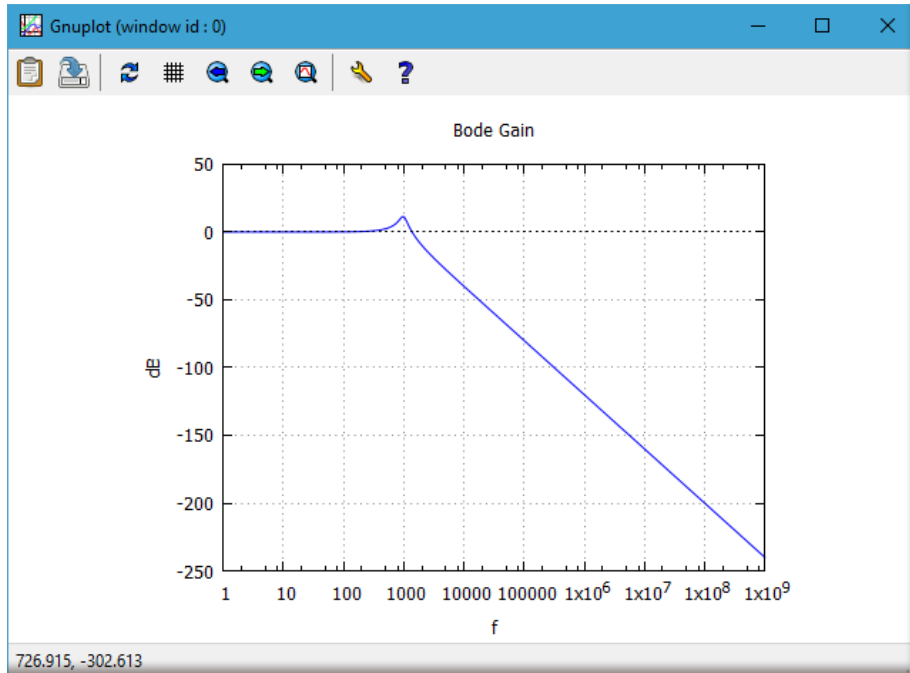

>>> loading file '\Simulate\MaximaDos\Functions\bode.mac'

Plot Bode Diagram (gain)

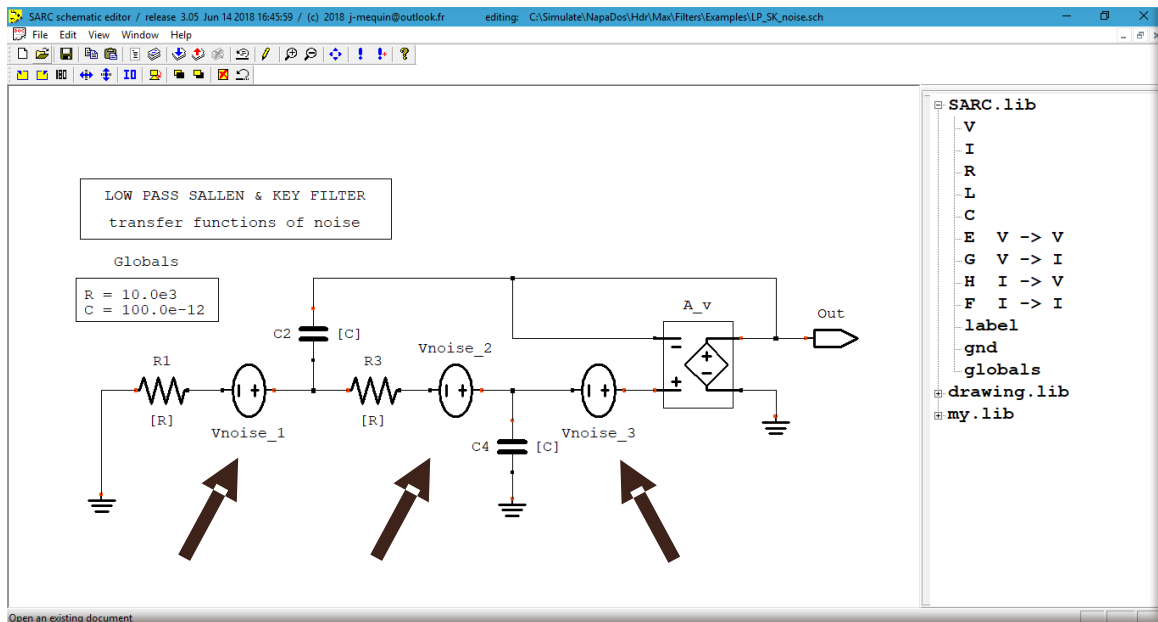
```

Maxima is ready for input. Analyse du résultat

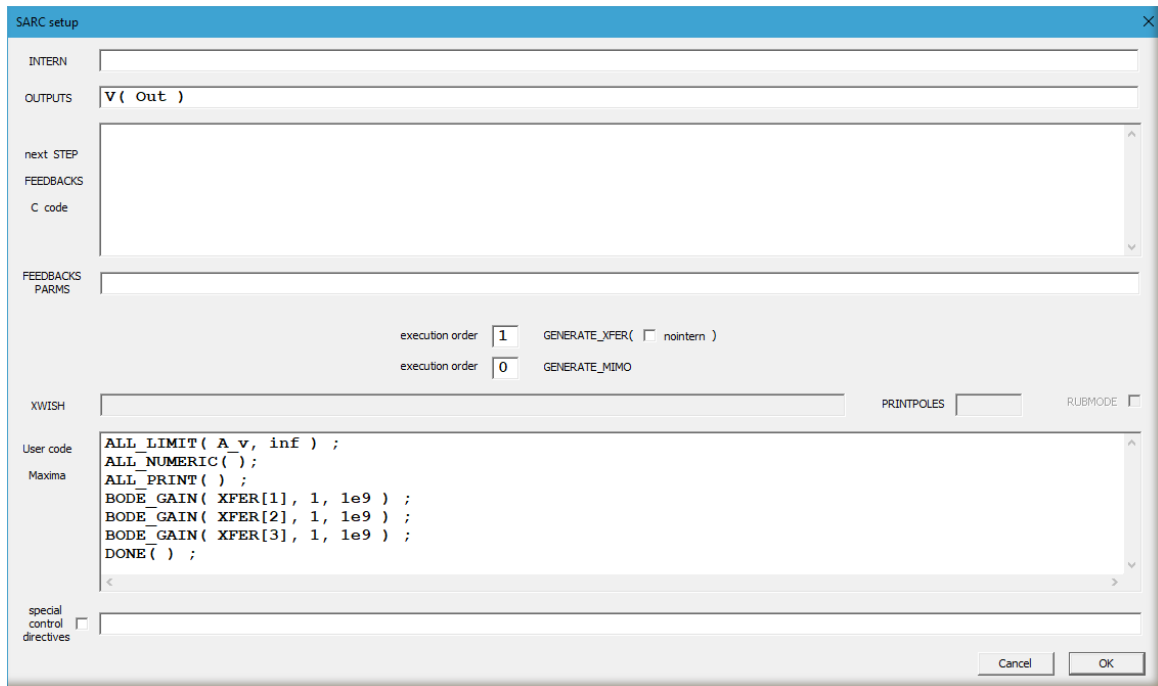
A Bode plot is then produced by Maxima:



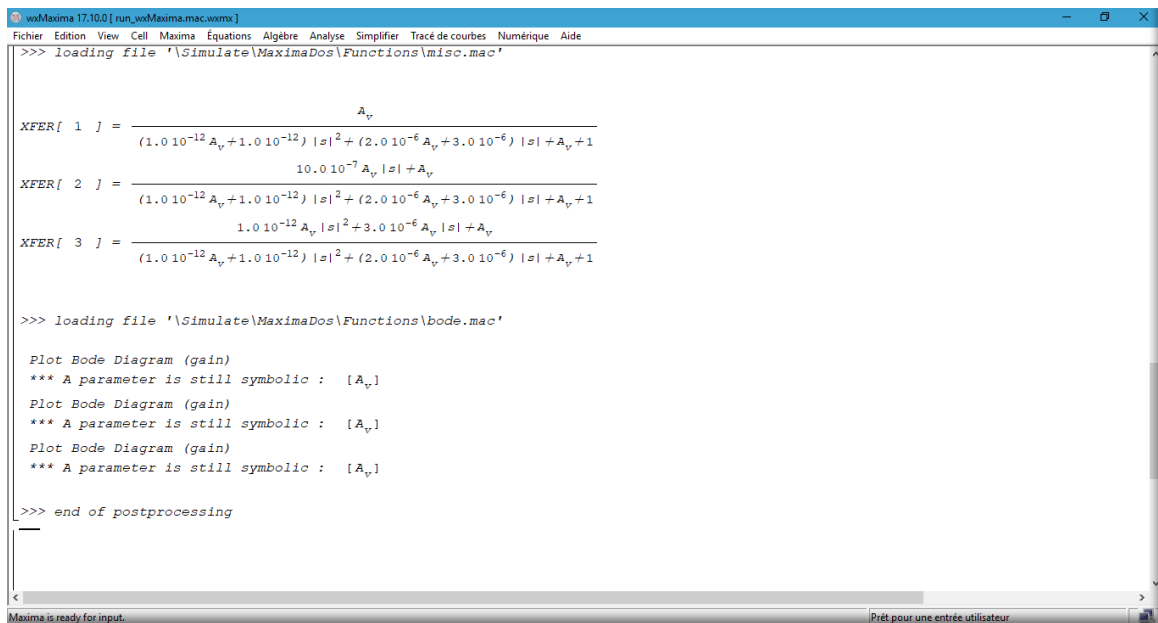
Another example produces the transfer function of noise sources, resistors and amplifier.



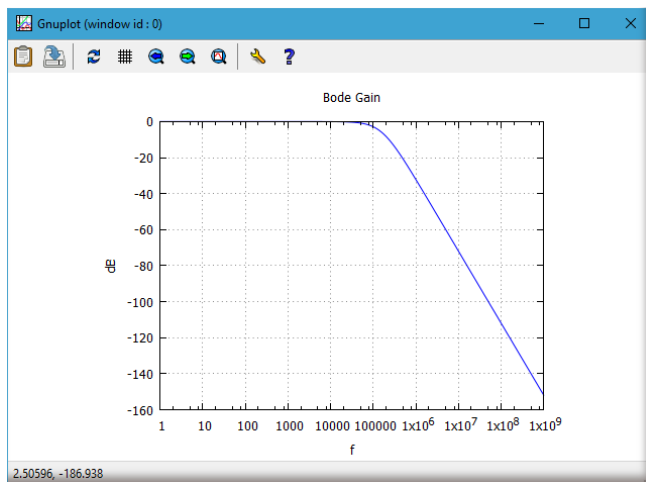
The setup for transfer functions and Bode plots when the gain of the amplifier is infinite.



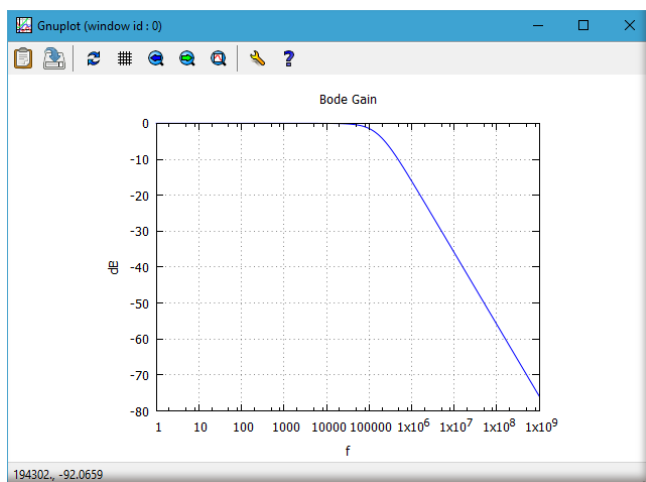
And the results:



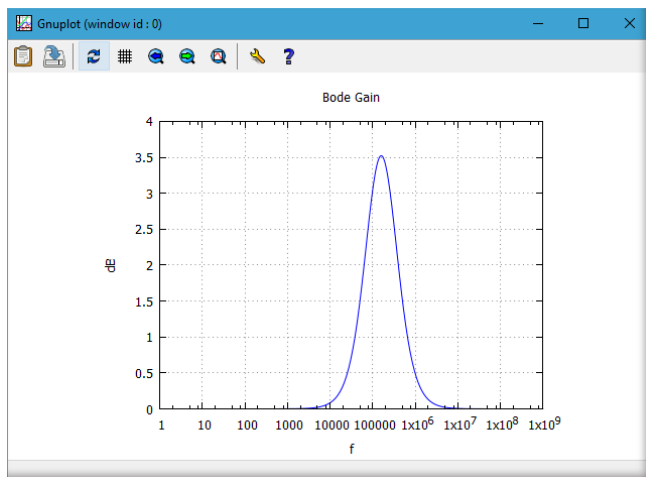
The Bode plot (noise 1 $\rightarrow$ output) :



The Bode plot (noise 2 $\rightarrow$ output) :



The Bode plot (noise 3 $\rightarrow$ output) :



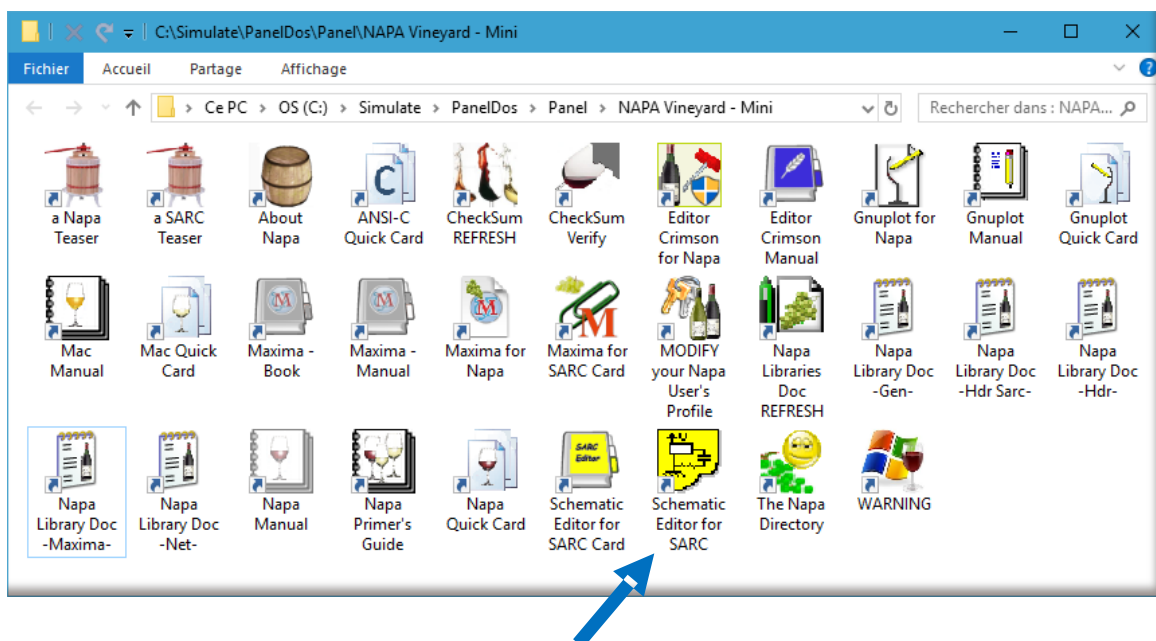
5. DO NOT BE TOO AMBITIOUS

Symbolic analysis plays with (smart) manipulations of equations of Kirchhoff.

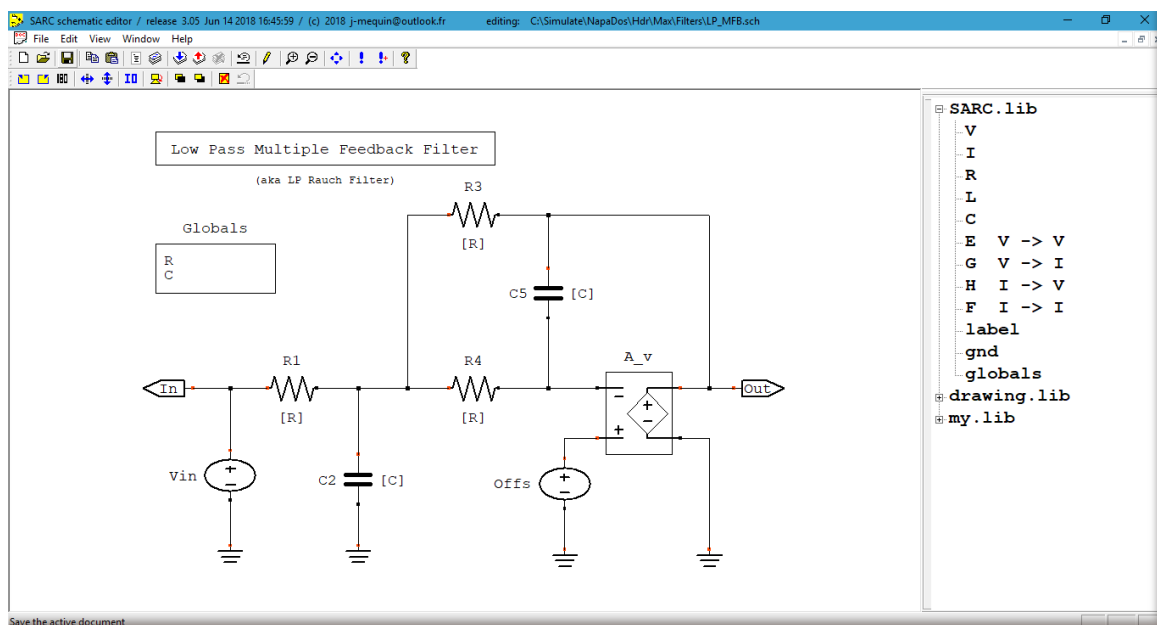
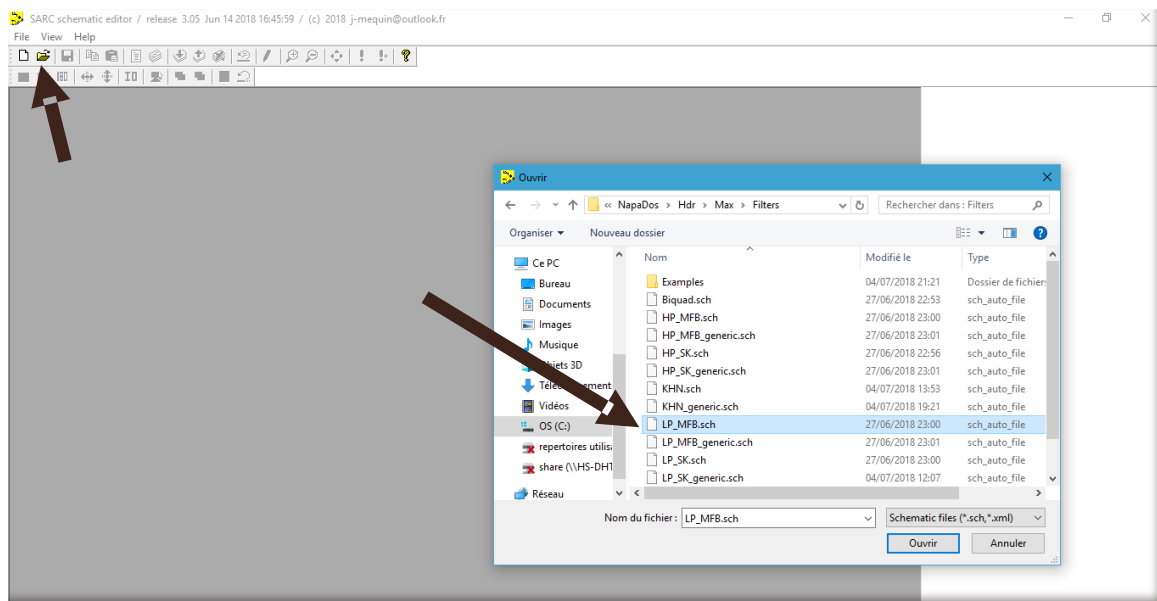
Examples are in directory `'/Simulate/Napados/Hdr/Max'`. You will notice that this software handles impressive problems. But this is a real challenge to handle too complex schematics, there is a limit in the complexity.

It is time to compute your first transfer function.

Open the **'Sarc Schematic Editor'** from the **'NAPA Vineyard'** panel



Open (or create) a schematic...



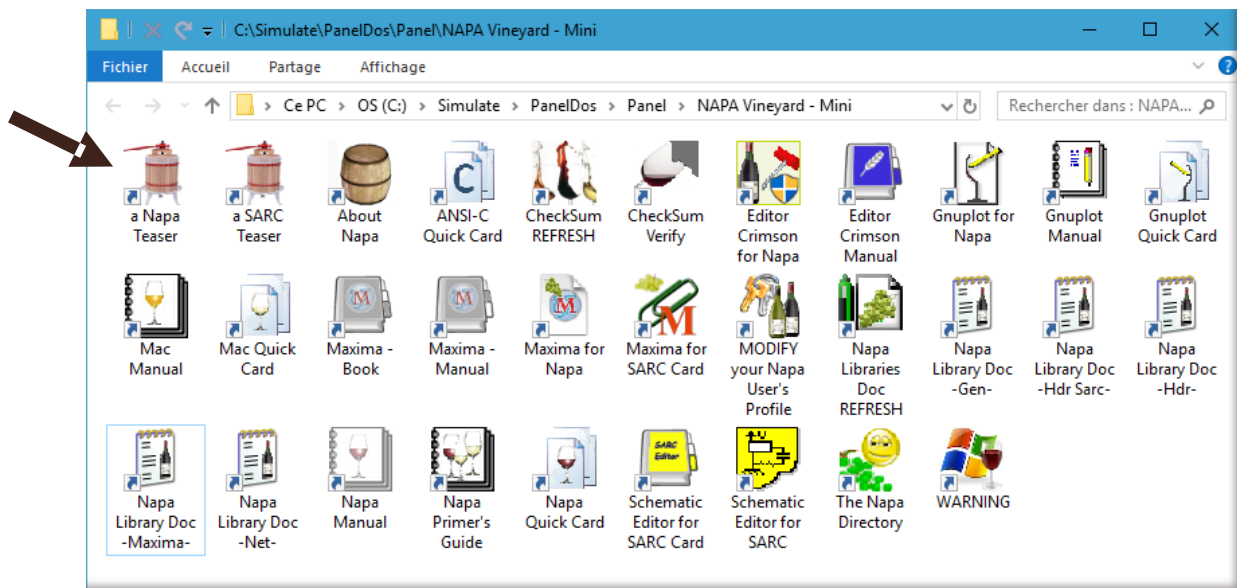
And enjoy !

6. MIXED-SIGNAL SIMULATIONS IN TIME-DOMAIN

This SARC Schematic Editor is also the entry point to insert continuous time modules in the Napa mixed-signal simulator netlist. The same schematics can produce the C code compatible to this simulator. The simulations are running in the time-domain together with sampled domain sub-circuits like switched capacitor network and/or digital circuitry.

The technology behind the simulation is SARC (Semi-Analytical Recursive Convolution) allowing to simulate linear and piece-wise linear circuits. A piece-wise linear circuit is a linear circuit with a few percussions which change on the fly the value of some elements while preserving strictly the flux of inductances and the charges of capacitances.

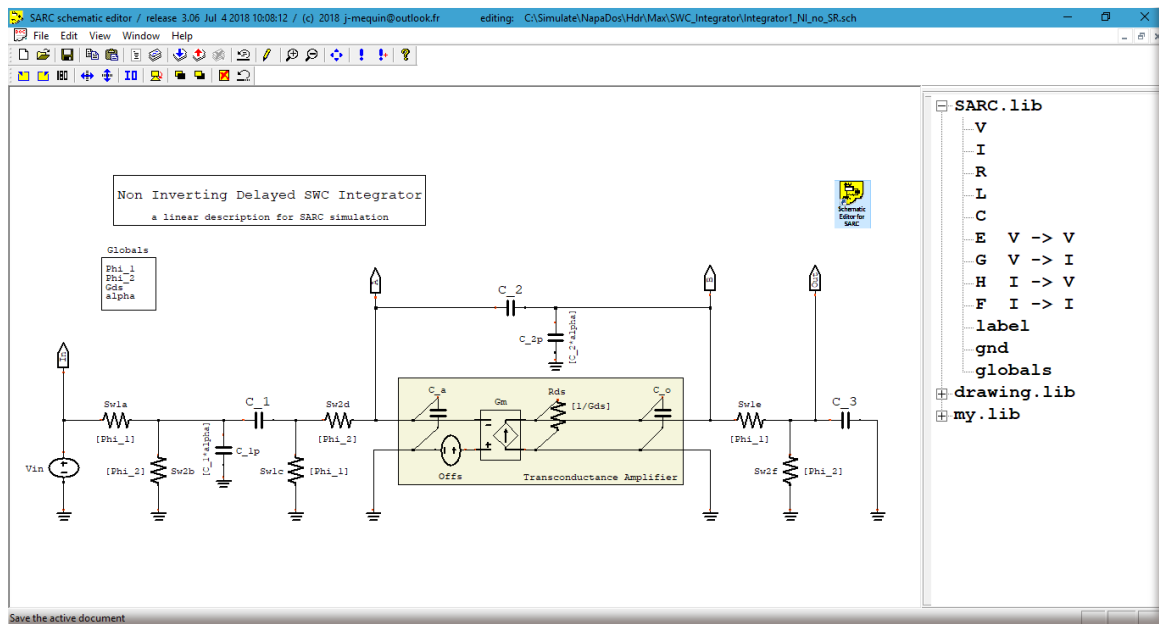
Napa is a mixed-signal simulator, a teaser is available in the 'NAPA Vineyard' panel :



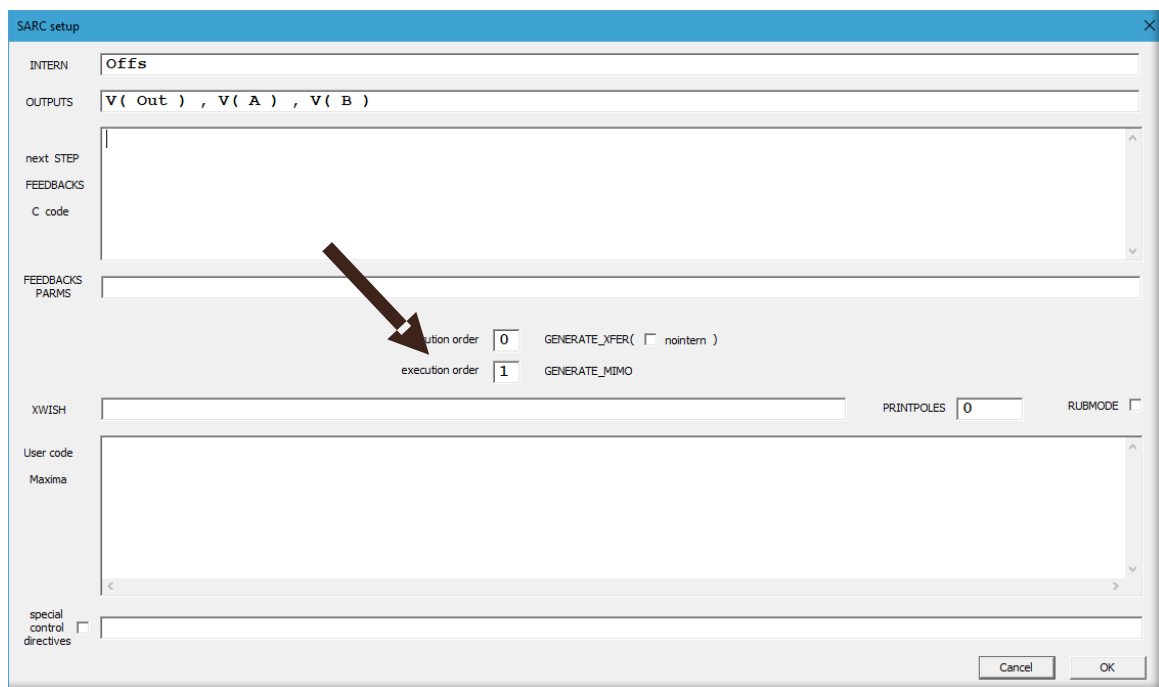
First, we will describe a non-inverting switched-capacitor integrator using the SARC Schematic Editor. All switches are described as resistors with a symbolic value 'phi1' or 'phi2'. During the simulations the value of these resistors will set to large or small. This change of value is a percussion which will be handled properly by the SARC algorithm.

Symbolic values of components and '**globals**' variables are set. The model includes parasitic capacitances ad offset. We will add slew rate later.

The schematic is in “/Simulate/Napados/Hdr/Max/SWC_Integrator/Integrator_NI.sch”



This schematic described a piece-wise linear circuit and there is no meaning to compute a transfer function as it has no utility at this point. We will prefer to output a C code for the SARC algorithm. We select a ‘GENERATE_MIMO’ instead of a ‘GENERATE_XFER’.



And we start Maxima from the ‘File’ menu on the top of the SARC Editor. Maxima outputs the matrices A, B, C, and D for the SARC editor.

The screenshot shows the wxMaxima 17.10.0 interface. The main window displays a complex algebraic expression for A and a matrix B .

$A =$

$$\begin{aligned} & \frac{\phi_2 + \phi_1}{c_1 \phi_1 \phi_2} \quad \frac{\phi_2 + \phi_1}{c_1 \phi_1 \phi_2} \quad \frac{1}{c_1 \phi_2} \quad \frac{1}{c_1 \phi_2} \quad 0 \\ & \frac{\phi_2 + \phi_1}{c_1 \phi_1 \phi_2 \alpha} \quad \frac{2(\phi_2 + \phi_1)}{c_1 \phi_1 \phi_2 \alpha} \quad \frac{1}{c_1 \phi_2 \alpha} \quad \frac{1}{c_1 \phi_2 \alpha} \quad 0 \\ & \frac{c_2 \alpha + c_0}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_2 \alpha + c_0}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_2 \alpha - c_a \alpha \phi_2 + c_0}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_2 \phi_1 \alpha - c_a ((\alpha \phi_1 + \alpha \phi_2) \phi_1 + 1) \phi_2 + c_0 \phi_1}{\phi_1 \phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_a}{\phi_1 (c_2 (c_a + c_2) \alpha + c_a)} \\ & \frac{c_2}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_2}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_a \alpha \phi_2 + c_2 (\alpha \phi_2 + 1)}{\phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{((c_2 \alpha \phi_1 + c_a + c_2) \alpha \phi_1 + c_a (\alpha \phi_1 + 1) \phi_2 + c_2 (\phi_2 + \phi_1))}{\phi_1 \phi_2 (c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a))} \quad \frac{c_a + c_2}{\phi_1 (c_2 (c_a + c_2) \alpha + c_a)} \\ & 0 \quad 0 \quad 0 \quad \frac{1}{c_3 \phi_1} \quad -\frac{\phi_2 + \phi_1}{c_3 \phi_1} \end{aligned}$$

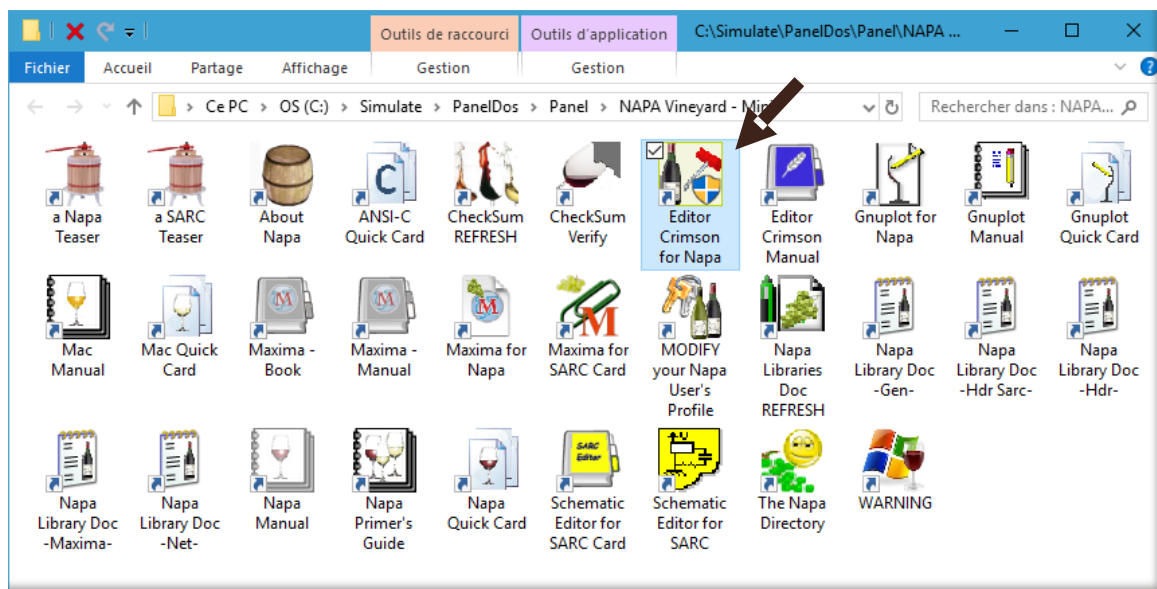
$B =$

$$\begin{bmatrix} 0 & 0 \\ \frac{1}{c_1 \phi_1 \alpha} & 0 \\ 0 & \frac{c_a \alpha \phi_2}{c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a)} \\ 0 & \frac{(c_a + c_2) \alpha \phi_2}{c_2 (c_a + c_2) \alpha + c_a c_0 + c_2 (c_0 + c_a)} \\ 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Maxima is ready for input.

Maxima produces also a text file, an ANSI-C header file ('.hdr') compatible with the Napa simulator. The list of inputs, outputs and parameters of this model will be used to create a Napa cell.

Open the Crimson Editor from ten 'Napa Vineyard' panel:



We use here files contained in the package. The explanations concerning the Napa simulator can be found in the corresponding teaser. We will explain briefly and focus to start quickly a Napa simulation.

The header produced by Maxima ‘/Simulate/Napados/Hdr/Max/SWC_Integrator/Integrator_NI.hdr’

```

1 #ifndef MIMO_Integrator1_NI_no_SR_
2 #define MIMO_Integrator1_NI_no_SR_
3
4
5 /* **** Created at 2018-07-06 12:34:46+02:00 from C:\Simulate\Napados\Hdr\Max\SWC_Integrator\Integrator1_NI_no_SR.mac **** */
6
7 #define MIMO_Integrator1_NI_no_SR_xmldocument "Integrator1_NI_no_SR"
8 #define MIMO_Integrator1_NI_no_SR_xmldpage "Page 1"
9 #define MIMO_Integrator1_NI_no_SR_xmldate "Fri Jul 6 12:34:16 2018 generated with release 3.06"
10
11 #define MIMO_Integrator1_NI_no_SR_SCHEMA "\
12 Non Inverting Delayed SWC Integrator
13 a linear description for SARC simulation
14 with slew-rate modeling
15 "
16 #define MIMO_Integrator1_NI_no_SR_schema 42
17
18 #define MIMO_Integrator1_NI_no_SR_SARCV "SARC 10.12 (c) 2018 \SARCV"
19
20 #define MIMO_Integrator1_NI_no_SR_ipmode "fasl"
21 #define MIMO_Integrator1_NI_no_SR_rubmode 0
22 #define MIMO_Integrator1_NI_no_SR_printpoles 0
23 #define MIMO_Integrator1_NI_no_SR_nintern 1
24 #define MIMO_Integrator1_NI_no_SR_nfeedcalc 0
25
26 #define MIMO_Integrator1_NI_no_SR_INPUTS { "Vin" }
27
28 #define MIMO_Integrator1_NI_no_SR_OUTPUTS { "V(Out)", "V(A)", "V(B)" }
29
30 #define MIMO_Integrator1_NI_no_SR_BOM { "C_1", "C_2", "C_3", "C_a", "C_o", "alpha", "Gds", "Phi_1", "Phi_2", "Gm", "Offs" }
31

```

This model has 1 input, 3 outputs and 11 parameters. This file is in the directory containing the corresponding schematic (‘.sch’), netlist (‘.mac’) and pdf files.

We prepare now a cell containing the call of the code produced by Maxima (‘.net’), a data file containing the numerical values of the components (‘.dat’) and finally the file containing the simulation (‘.nap’).

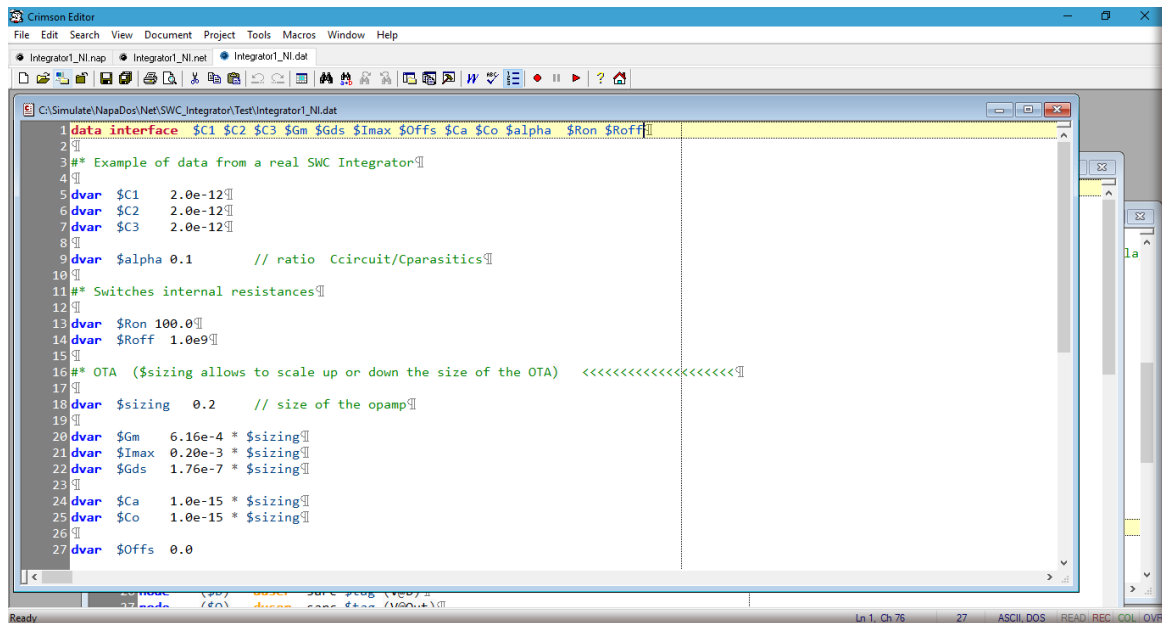
The cell file ‘/Simulate/Napados/Net/SWC_Integrator/Integrator_NI.net’

```

1 cell interface $dummy $I $A $B $O $Clk1 $Clk2 $fildat
2
3 *** 1 Input Non Inverting Delayed Switched Capacitor Integrator
4 ***
5 *** USAGE: node void cell plsnam "Integrator1_NI.net" I A B O Clk1 Clk2 fildat
6 ***
7
8 declare (analog) $I
9 declare (analog) $C1 $C2 $C3 $CA $CO
10 declare (analog) $alpha
11 declare (analog) $GM $GDS $IMAX
12 declare (digital) $Clk1 $Clk2
13 declare (string) $fildat
14
15 header <Max/SWC_Integrator/Integrator1_NI.hdr>
16
17 data $fildat $C1 $C2 $C3 $GM $GDS $IMAX $OFFS $CA $CO $alpha $Ron $Roff
18
19 dvar $rsw1 switch_d($Clk1, $Roff, $Ron) &update
20 dvar $rsw2 switch_d($Clk2, $Roff, $Ron) &update
21
22 ganging $param[] $C1 $C2 $C3 $CA $CO $alpha $GDS $rsw1 $rsw2 $GM $OFFS $IMAX
23
24 node $tag duser sarc Integrator1_NI() $param $I
25 node ($A) duser sarc $tag (V(A))
26 node ($B) duser sarc $tag (V(B))
27 node ($O) duser sarc $tag (V(Out))

```


A second file is used to assign values to the components and is instantiated inside the cell. This data cell file is '/Simulate/Napados/Net/SWC_Integrator/Test/Integrator_NI.dat'



```

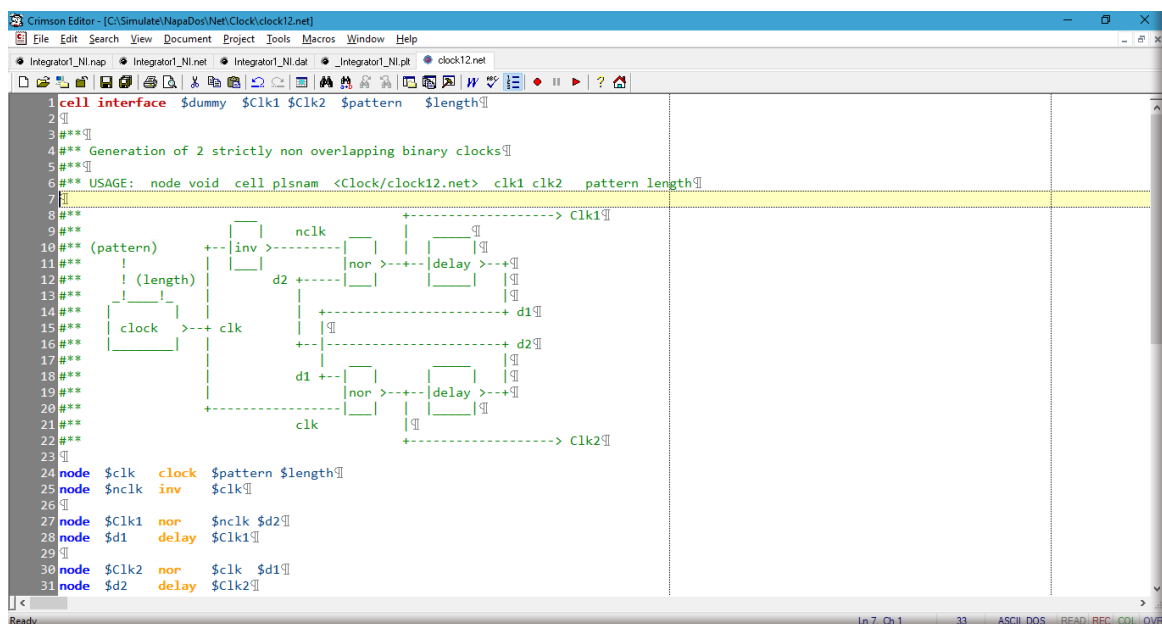
1 data interface $C1 $C2 $C3 $Gm $Gds $Imax $Offs $Ca $Co $alpha $Ron $Roff
2
3 ** Example of data from a real SWC Integrator
4
5 dvar $C1 2.0e-12
6 dvar $C2 2.0e-12
7 dvar $C3 2.0e-12
8
9 dvar $alpha 0.1 // ratio Ccircuit/Cparasitics
10
11 ** Switches internal resistances
12
13 dvar $Ron 100.0
14 dvar $Roff 1.0e9
15
16 ** OTA ($sizing allows to scale up or down the size of the OTA) <----->
17
18 dvar $sizing 0.2 // size of the opamp
19
20 dvar $Gm 6.16e-4 * $sizing
21 dvar $Imax 0.20e-3 * $sizing
22 dvar $Gds 1.76e-7 * $sizing
23
24 dvar $Ca 1.0e-15 * $sizing
25 dvar $Co 1.0e-15 * $sizing
26
27 dvar $Offs 0.0
  
```

The last file is the netlist of the simulation.

The simulation file is '/Simulate/Napados/Net/SWC_Integrator/Test/Integrator_NI.nap'

The file contains the instantiation of a non-overlapped clock generator, the cell describing the integrator, a 'pwl' cell describing the input, and the location of the data file containing the parameters. A change in clocks percutes the value of the switches resistances.

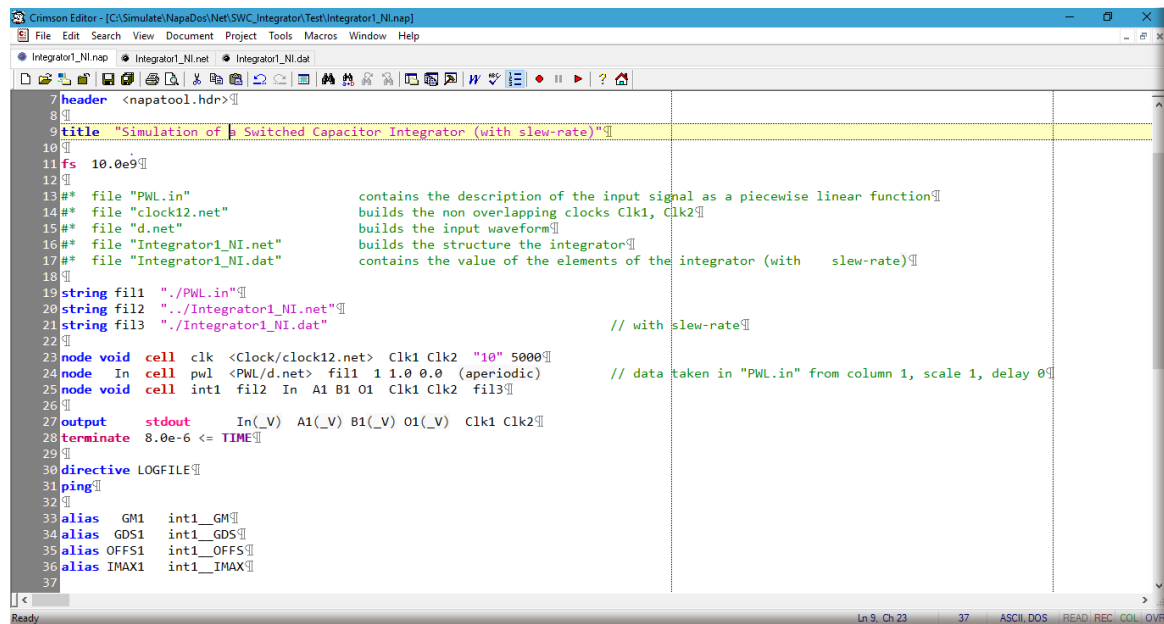
The instantiated pwl cell is '/Simulate/Napados/Net/Clock/clock12.net'



```

1 cell interface $dummy $Clk1 $Clk2 $pattern $length
2
3 ***
4 ** Generation of 2 strictly non overlapping binary clocks
5 ***
6 ** USAGE: node void cell plsnam <Clock/clock12.net> clk1 clk2 pattern length
7 **
8 ***
9 ***
10 *** (pattern)
11 *** |
12 *** | (length)
13 *** |
14 *** |
15 *** |
16 *** |
17 *** |
18 *** |
19 *** |
20 *** |
21 *** |
22 *** |
23 ***
24 node $clk clock $pattern $length
25 node $nclk inv $clk
26
27 node $Clk1 nor $nclk $d2
28 node $d1 delay $Clk1
29
30 node $Clk2 nor $clk $d1
31 node $d2 delay $Clk2
  
```

The simulation file:



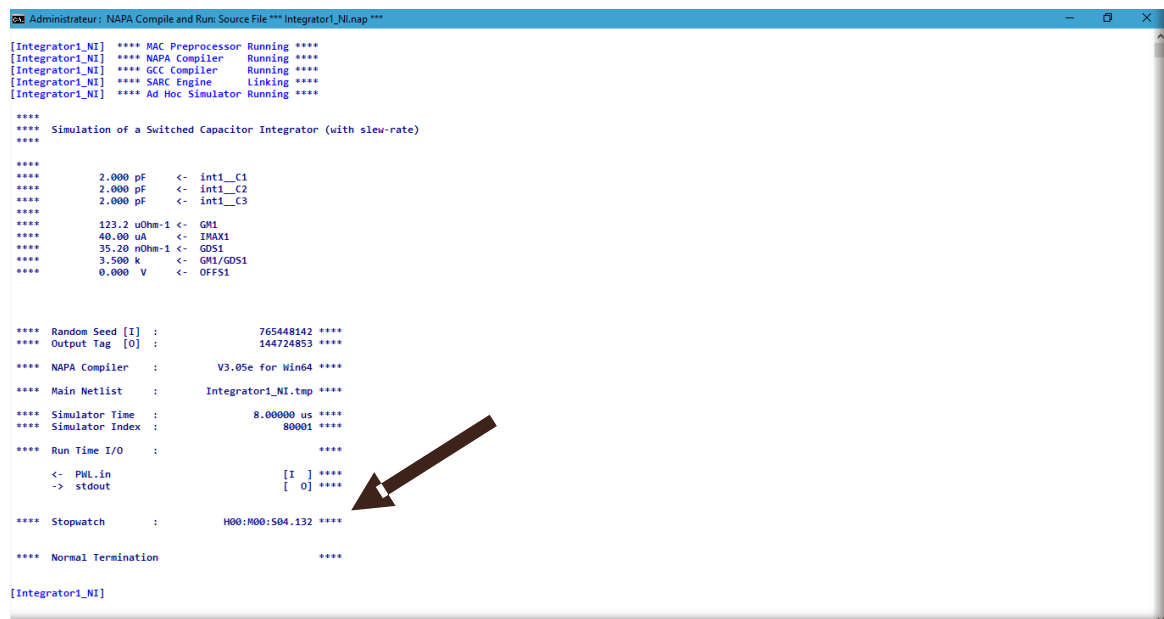
```
7 header <napatool.hdr>
8
9 title "Simulation of a Switched Capacitor Integrator (with slew-rate)"
10
11 fs 10.0e9
12
13 /* file "PWL.in"           contains the description of the input signal as a piecewise linear function
14 /* file "clock12.net"      builds the non overlapping clocks Clk1, Clk2
15 /* file "d.net"           builds the input waveform
16 /* file "Integrator1_NI.net" builds the structure the integrator
17 /* file "Integrator1_NI.dat" contains the value of the elements of the integrator (with    slew-rate)
18
19 string fil1  "./PWL.in"
20 string fil2  "../Integrator1_NI.net"
21 string fil3  "../Integrator1_NI.dat"
22
23 // with slew-rate
24 node void cell clk <Clock/clock12.net> Clk1 Clk2 "10" 5000
25 node In cell pwl <PWL/d.net> fil1 1 1.0 0.0 (aperiodic) // data taken in "PWL.in" from column 1, scale 1, delay 0
26 node void cell int1 fil2 In A1 B1 O1 Clk1 Clk2 fil3
27
28 output stdout In(_V) A1(_V) B1(_V) O1(_V) Clk1 Clk2
29
30 terminate 8.0e-6 <= TIME
31
32 directive LOGFILE
33 ping
34
35 alias GM1 int1_GM
36 alias GDS1 int1_GDS
37 alias OFFS1 int1_OFFS
38 alias IMAX1 int1_IMAX
```

To start the simulation, from the file in the editor, press <left alt> <R>. The simulation flow is then automatic.

- The '**Mac preprocessor**' processes the simulation file and creates '`/Simulate/Napados/Net/SWC_Integrator/Test/Integrator_NI.temp`'.
- From this file, the '**Napa Compiler**' produces an ANSI-C file representing the simulator to run.
The ANSI-C file is '`/Simulate/Napados/Net/SWC_Integrator/Test/Integrator_NI.c`'.
- This file is compiled by the '**mingw gcc Compiler**'.

The executable is '`/Simulate/Napados/Net/SWC_Integrator/Test/Integrator_NI.exe`'.

Output on screen:



```
Administrator: NAPA Compile and Run: Source File *** Integrator1_NI.nap ***

[Integrator1_NI] **** MAC Preprocessor Running ****
[Integrator1_NI] **** NAPA Compiler Running ****
[Integrator1_NI] **** GCC Compiler Running ****
[Integrator1_NI] **** SARC Engine Linking ****
[Integrator1_NI] **** Ad Hoc Simulator Running ****

****
**** Simulation of a Switched Capacitor Integrator (with slew-rate)
****

****
****      2.000 pF  <-  int1_C1
****      2.000 pF  <-  int1_C2
****      2.000 pF  <-  int1_C3
****
****      123.2 uOhm-1 <-  GM1
****      40.00 uA      <-  IMAX1
****      35.20 nOhm-1 <-  GDS1
****      3.500 k       <-  GM1/GDS1
****      0.000 V      <-  OFFS1
****

**** Random Seed [I] :      765448142 ****
**** Output Tag [O] :      144724853 ****

**** NAPA Compiler :      V3.05e for Win64 ****
**** Main Netlist :      Integrator1_NI.tmp ****

**** Simulator Time :      8.00000 us ****
**** Simulator Index :      80001 ****

**** Run Time I/O :      ****

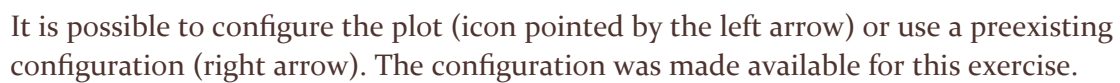
<- PWL.in      [I] ****
-> stdout      [O] ****

**** Stopwatch :      H00:M00:S04.132 ****

**** Normal Termination ****

[Integrator1_NI]
```

Now, from the file in the editor, press **<left alt> <G>** to call **'gnuplot'**.

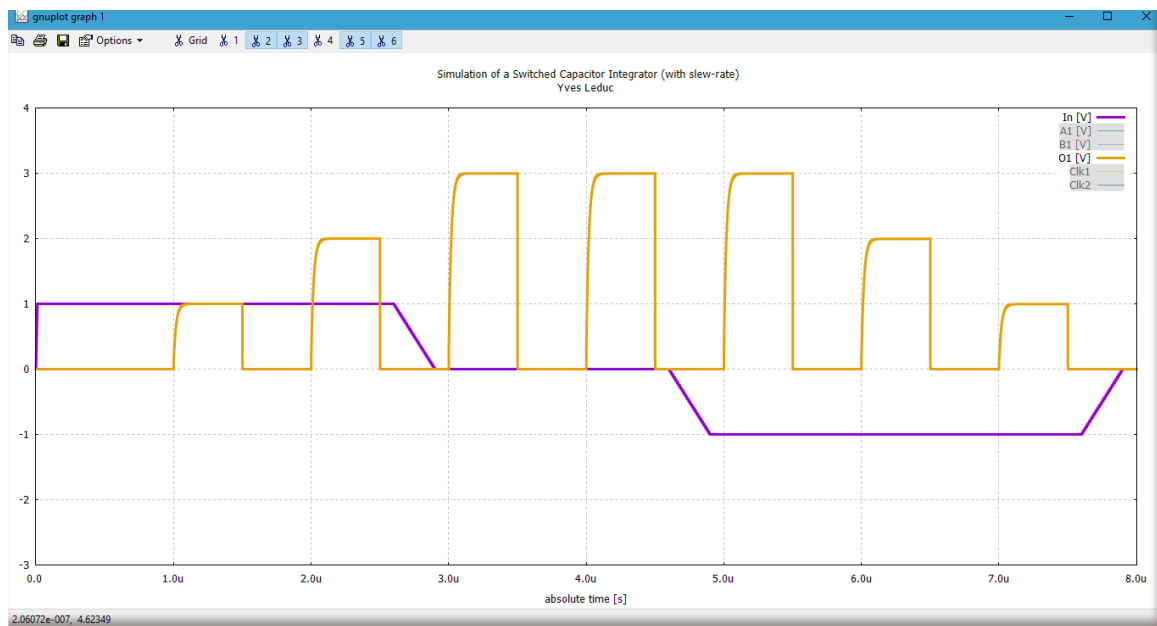
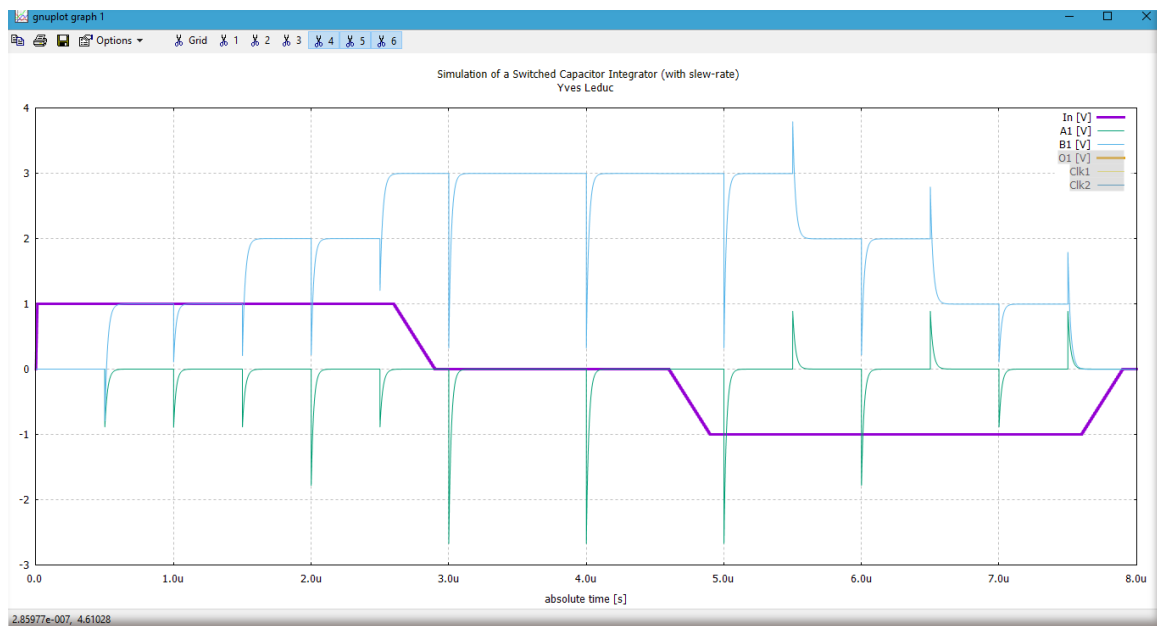


The screenshot shows the 'Choose Plot' dialog box. The file explorer on the left shows the 'Test' directory. The file list on the right contains the following files:

Nom	Modifié le	Type
_Integrator1_NI.plt	25/06/2018 14:54	Fichier PLT
_Integrator2_NI.plt	15/05/2018 19:18	Fichier PLT
_Integrator3_NI.plt	15/05/2018 19:17	Fichier PLT
_Nagaraj_Integrator1_NI.plt	16/05/2018 13:45	Fichier PLT
_Nagaraj_Integrator2_NI.plt	16/05/2018 13:45	Fichier PLT
_Nagaraj_Integrator3_NI.plt	16/05/2018 13:45	Fichier PLT

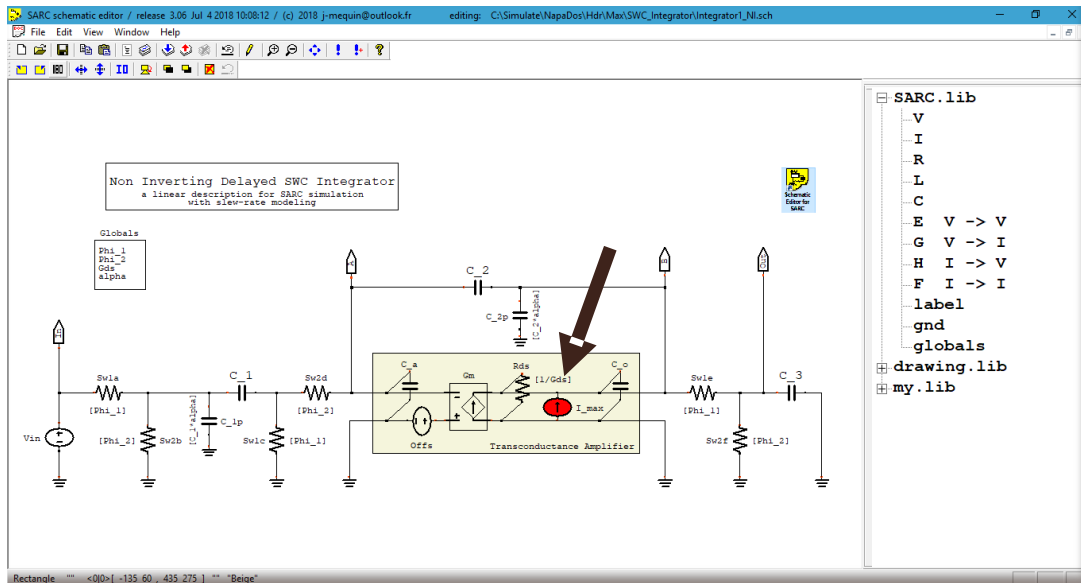
The 'Nom du fichier' field at the bottom contains '_Integrator1_NI.plt'. The 'Ouvrir' button is highlighted.

And 'gnuplot' produces the graphic, 2 views of this output:



No slew-rate? We will add the appropriate model.

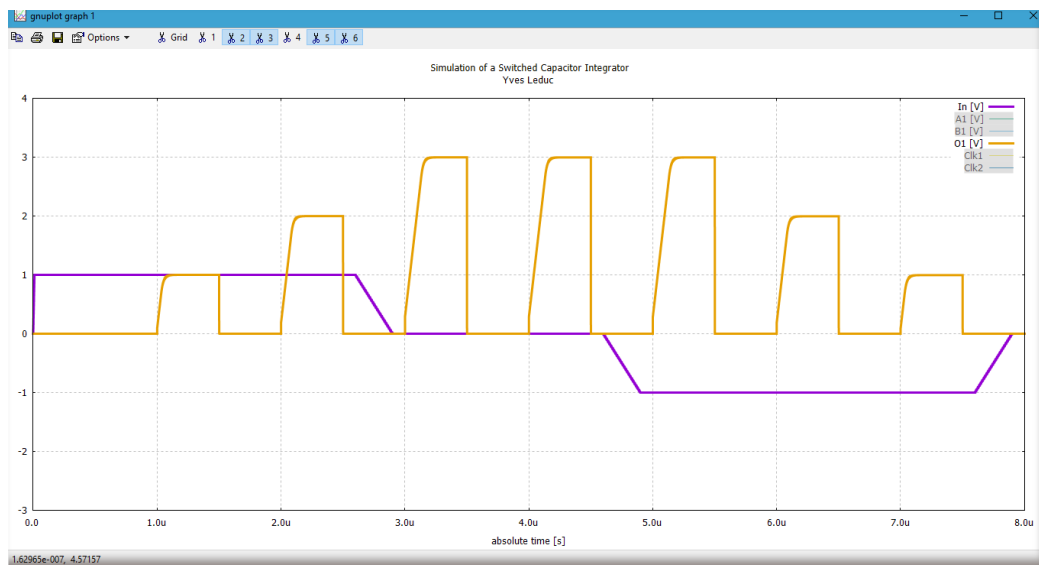
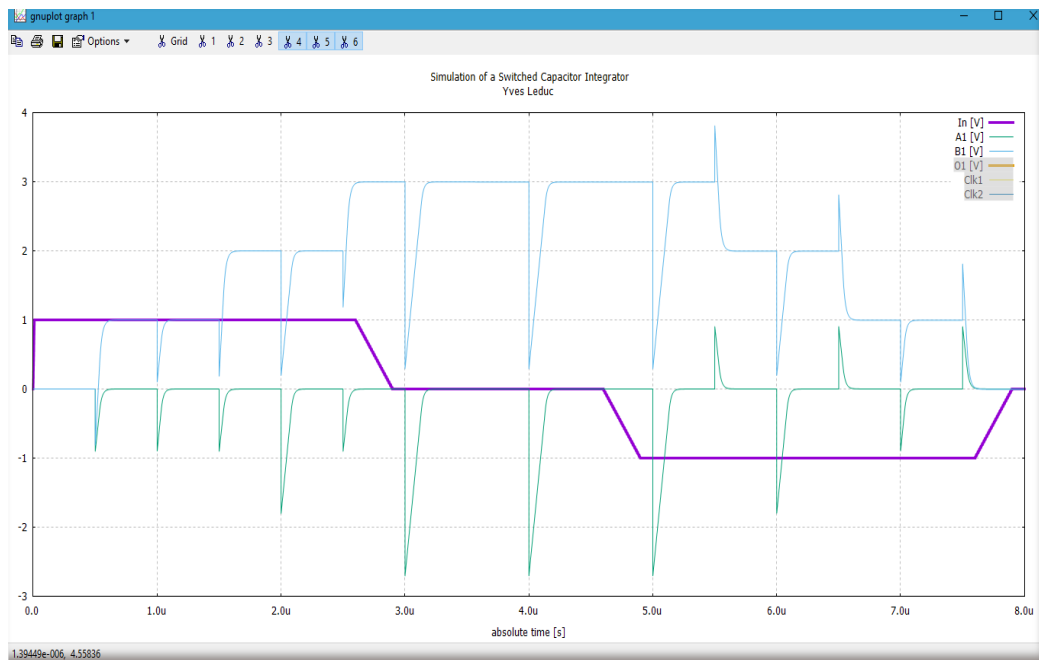
A current source is added in parallel to the transconductance.



A Maxima user's function 'APPLY_LIMIT()' is used to implement the slew-rate model. The value of the constant current source must be declared as 'INTERN', the current 'I(gm)' flowing in the transconductance and its voltage command 'cV(gm)' must be in 'OUTPUTS'.

The numerical value of 'I_max' is in the data file and transmitted to the SARC function.

Using the same procedure, the slew-rate limitation appears now in the graphic.



The Napa Simulator has many features to analyze the results. Please consult the related teaser.