Comparing ODE Modelling and Electrical Network Modelling for ARGESIM Benchmark C3 'Class-E Amplifier' using SimulationX

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Simulator: SimulationX from ITI is a modelling and simulation software based on the Modelica standard, for valuation of the interaction of components of multi domain technical systems. It is the universal CAE tool for modelling, simulation and analyzing of physical effects – with ready-to-use model libraries, like for example 3D multibody systems, power transmission, hydraulics, thermodynamics, electrics, electrical drives, magnetics as well as controls – postprocessing with powerful features included.

Model: The basic class-E power amplifier was introduced by N.O. Sokal and A.D. Sokal in their classic paper from 1975. It is a switching-mode amplifier that operates with zero voltage and zero slope across the switch at switch turn-off. The equations describing the circuit are the state-equations where inductor currents and capacitor voltages are chosen as system variables. By using the Kirchhoff voltage and current laws we get the following differential equations:

$$dx1/dt = (-x2 + VDC)/L1$$
$$dx2/dt = (x1 - x2/R(t) - x3)/C2$$
$$dx3/dt = (x2 - RL*x3 - x4)/L3$$
$$dx4/dt = x3/C4$$

The aim was to implement these equations into simulationX structure. Therefore two different ways have been chosen to model these equations. The first solution is realized by using a block diagram model. The differential equations above were built by block integrator, add/subtract and gain, also defining a function block as division for $x2/R(t)$ and defining a signal generator for the constant voltage VDC. The time dependent resistor is built by a type designer block using Modelica code. The graphical representation of the model is given by Figure 1. The code for the time dependent resistor is as follows:

```
1  algorithm
2     if (0<=t_red) and (t_red<TRF)
3       then Rt:=(5e-2)+k*t_red;
4     elseif (TRF<=t_red) and (t_red<(5e-6))
5       then Rt:=5e+6;
6     elseif (5e-6<=t_red) and (t_red<5e-6+TRF)
7       then Rt:=(5e+6)-k*(t_red-(5e-6));
8     elseif 5e-6+TRF<=t_red and t_red<10e-6
9       then Rt:=5e-2;
10    else
11      Rt:=-5;
12    end if;
13 equation
14    t_red = mod(time,10E-6); k =5e+6-5e-2/TRF;
```

Listing 1. Time Dependent Resistor algorithm

The second solution uses an electrical model representation. Designing the model by using basic resistor, inductor, capacitor, ground and constant voltage as VDC. The time dependent resistor was built by type designer using Modelica code. The model of the system is shown in Figure 2.

The code for the time dependent resistor looks as follows:

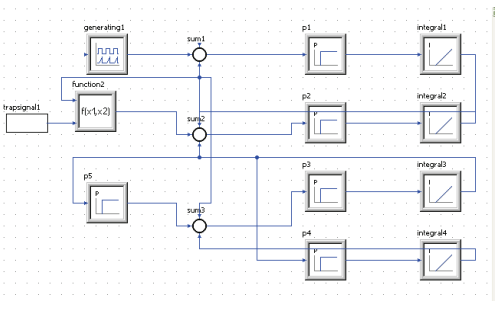

Figure 1. Model of the System as classical block implementation with SimulationX

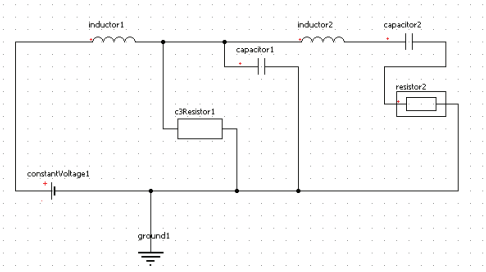

Figure 2. Electrical model implementation

```
1  equation
2     v = pin1.v - pin2.v; v = R*i;
3     pin1.i = i; pin2.i = -i; tred =
         mod(time, 10E-6); k=((5e+6)-(5e-2))/TRF;
4     if (0<=tred) and (tred<TRF)
5       then R = (5e-2) + k*tred;
6     elseif (TRF<=tred) and (tred<(5e-6)
7       then R = 5e+6;
8     elseif (5e-6<=tred) and (tred<5e-6+TRF)
9       then R = (5e+6) - k*(tred - (5e-6));
10    elseif (5e-6+TRF<=tred) and (tred<10e-6)
11      then R = 5e-2;
12      else R = 0;
13    end if;
```

Listing 1. Equations including the code for $R(t)$

Setting up the simulation parameters and simulation process are done in *simulation tab*. The results of simulation were shown in the model view section.

A-Task: The eigenvalues of the system are calculated for the two states when $R(t) = 5m\Omega$ (on) and when $R(t) = 5M\Omega$ (off), respectively, by simulating the whole system first and then going to the tab *analysis* (natural frequencies and mode shapes). In simulationX the eigenvalues are calculated automatically. The calculated eigenvalues are shown in Table 1 for all solutions.

B-Task: In task B the system is simulated by setting the BDF- method as integration solver, $1a$sec as minimal step size, $1p$sec as minimal output step size, $10n$sec as absolute tolerance, $0...100\mu$sec as simulation time interval and $1e-8$ as relative tolerance. Using the intial value zero for $x1, x2, x3$ and $x4$, the result for the variable current at time dependent resistor $IR(t)$ and output voltage VRL is depicted in Figure 3. It took 1.2528s to simulate task B for the first solution and 0.8461s for the second solution, using a standard home PC.

C-Task: The parameter of TRF is varied as follows: 1fsec, 10psec, 1nsec, 100nsec. The initial value for task C is equal to the final solution from task B. The time interval is $0\ldots9\mu$sec. As result, the phase plane curve $dx3/dt = VL3$ as a function of $x3 = IL3$ is shown in Figure 4. The four simulations are executed separately.

Eigenvalues $R(t)$ OFF	Eigenvalues $R(t)$ ON
-54708+1,0408E+5i	-1,11731E+9
-54708-1,0408E+5i	-625,78
-58228+5,3275E+5i	-1,1304E+5 +6,5835E+5i
-58228+5,3275E+5i	-1,1304E+5 -6,5835E+5i

Table 1. Eigenvalues of $R(t)$

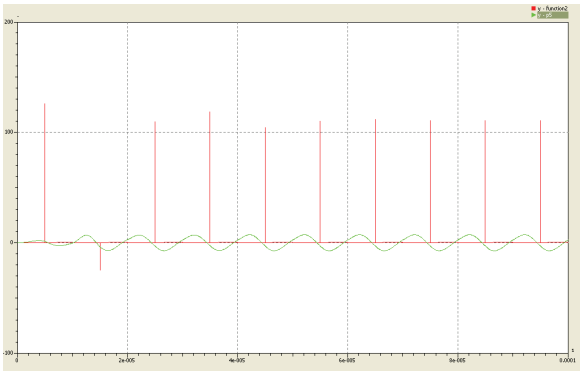

Figure 3. Time Curve $IR(t)$ and VRL.

Resumé: SimulationX is a simulation tool that offers all necessary features to model the system in a convenient way. Users can build their own model blocks based on Modelica language, a free common used standard for physical modelling.

Eigenvalue calculation is provided automatically for every simulation process. The postprocessing offers time curve plots as well as phase plots. Reinitialization of the startparameters of $\vec{x}$ with the final value from task b for task c was done manually.

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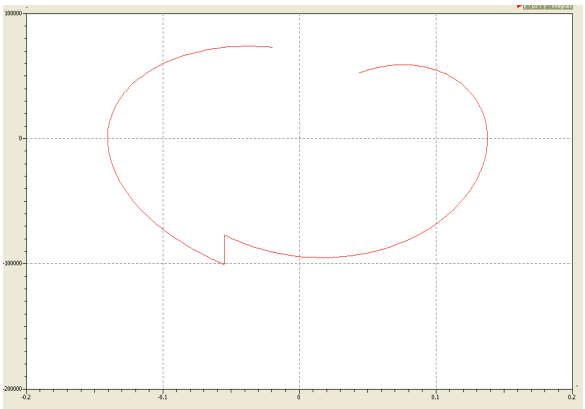

Figure 4. Phase plane curve $VL3$ function $IL3$