A System Dynamics Modelling Approach to ARGESIM Benchmark C3 'Class E Amplifier' using AnyLogic

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Simulator: AnyLogic is an object-oriented dynamic simulation tool which brings together System Dynamics, Process-centric and Agent Based approaches within one modeling language and one model development environment. AnyLogic contains a set of simple objects beside library objects and allows to model different tasks from several areas. These elements can be added to a project simply by drag and drop, and parameterized afterwards. Moreover it is possible to include java code into some elements, which can be executed on demand.

Model: The simulation of a class E amplifier, first introduced by N.O. Sokal and A.D. Sokal is described in this work. By applying Kirchhoff's circuit laws following equations are obtained:

$$dx_1 / dt = (-x_2 + VDC) / L1 \quad (1)$$

$$dx_2 / dt = (x_1 - x_2 / R(t) - x_3) / C2 \quad (2)$$

$$dx_3 / dt = (x_2 - RL * x_3 - x_4) / L3 \quad (3)$$

$$dx_4 / dt = x_3 / C4 \quad (4)$$

x_1, x_2, x_3 and x_4 represent currents and voltages in the circuit. For the simulation of the class E amplifier following elements are used: Parameters Stock, Variables, Table Functions, Flow/Auxiliary Variable. In our case the parameters represent the constant properties of electronic components like resistance, inductivity, capacity and direct voltage sources. After adding these elements the according values have to be defined.

For the definition of differential equations AnyLogic makes use of System Dynamics approach: stock variables represent states, and after the definition of a name, the derivation of it (the flow) can be used in an equation (see Figure 1). The used equation contains a parameter (C2), other stock variables (x_1, x_2, x_3) and a table function (R(t)) with the predefined function time() as argument. The circuit can be described with four differential equations and therefore also four stock variables are used (x_1, x_2, x_3, x_4). Additionally an initial value for the according stock variable has to be set.

AnyLogic uses arrows to visualize the connections of

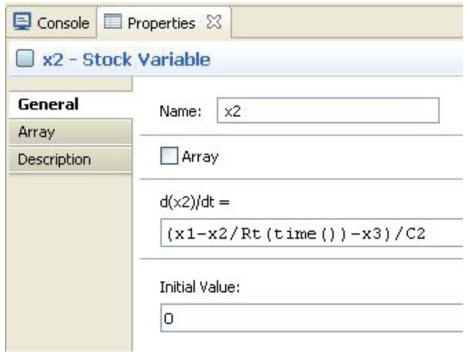

Figure 1: Syntax of AnyLogic, Equation (2)

parameters and variables depending on the input equations. An arrow from element A to element B means that the output of A is used in B (see Fig. 2).

As AnyLogic offers no signal sources we used the function 'time()' in combination with a table-function. Defined by a look-up table such a function returns an output-value depending on the input. The values in the table represent the highs and lows together with the corresponding time, values between the given times are interpolated linearly. Since time is continuously growing it will eventually exceed the period of time for which R(*t*) has been defined, in our case 10E-6 seconds. Fortunately the table function offers a feature called 'repeating' (modulo - function.

For visualization of the voltage on the load a flow variable has to be added. Afterwards a formula was defined as for the definition of the stock variables (compare Fig. 1), which writes the result to the defined flow variable. In our case this formula is simply the product of current x_3 and load resistance.

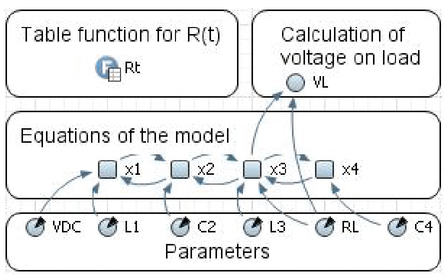

Figure 2: AnyLogic model

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A-Task: A possibility to calculate the eigenvalues of the system could not be found in AnyLogic. Determination of the eigenvalues would be necessary to determine the characteristics of the system and thus to choose an adequate ODE-solver for the model. But since AnyLogic does not offer an option for choosing a solver either, this task is redundant.

B-Task: The execution of the model is started by pressing the 'Run-Button'. Upon this any occurring errors are displayed in an extra window. The visualization of the currents and voltages of the model is done by using datasets, which store the values of variables during runtime. The sampling-interval as well as the number of points which have to be stored is adjustable in the properties of the dataset element. For the visualization it is further possible to plot datasets against time as well as against another. The quality of the visualization is dependent on the sampling interval. If it is too small the visualized curve will look rough or even worse, essential effects may be masked since the points are only connected by a straight line. Figure 3 visualizes the results of the simulation.

The output looks very similar to the results of other simulations (e.g. Matlab/Simulink) and is compatible to the theories of a class E amplifier.

Generally the simulation proceeds in real-time (what is visible on the output of the time function) and can be accelerated or even slowed down. Because of the high frequency signals in this model a real-time calculation is not possible (on an Intel Dual Core 1.88GHz processor). It took about 5 seconds to compute a period of 1 millisecond within the model. But since the period of the output is only 0.01 milliseconds and the transient effect takes not more than three periods, this is sufficiently fast.

C-Task: The purpose of task C is to analyze the impact of different rise/fall times (TRF) on R(*t*). To investigate four different TRFs in one simulation run, four separate models have to be created, although they only differ in the definition of the table function. As visible in table 1, in row two and four the TRF is the argument for the function respectively it is added to the half-period. In figure 4 the TRF is varied between 1E-7 and 1E-15.

The results are again equal to those produced with other simulation tools (Matlab/Simulink). Only the course of the phase for a TRF of 1e-7 does slightly differ.

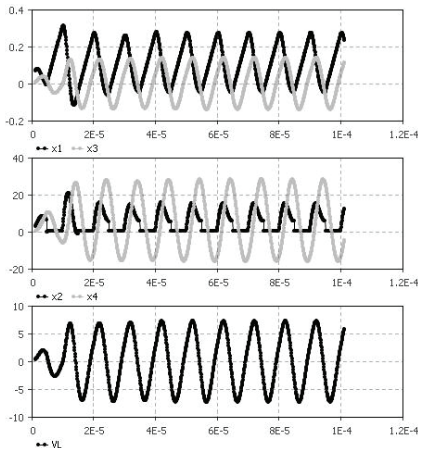

Figure 3. Simulation results

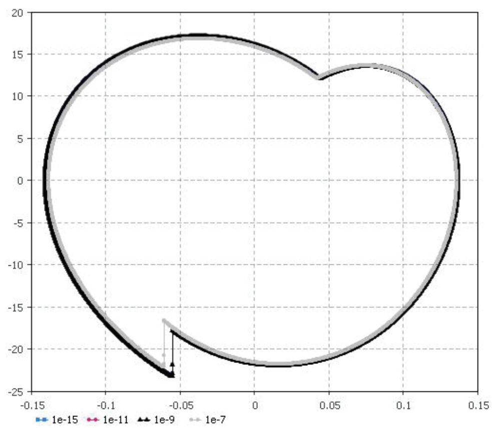

Figure 4: Phase diagram for different TRF

Resumé: As we went to create a model of the E amplifier defined by ARGESIM comparison 3 in AnyLogic, we were able to notice several interesting aspects. First of all we had to find a way to realize time-dependent variables. When trying to solve the given problem it became evident that AnyLogic is lacking the possibility to directly compute eigenvalues of the investigated system. Since this can be bypassed by the use of other (mathematic) software it does not pose a too large shortcoming. Nevertheless the lacking possibility to choose an ODE-solver does appear to be quite a problematic shortcoming. But despite this shortcoming the computed results are apparently correct.

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