



Comparison of Circuit Diagram Modelling and ODE Modelling for ARGESIM Benchmark C3 ‘Class-E Amplifier’ using Dymola

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Simulator: Dymola is a multi domain simulation tool based on the Modelica standard for complex dynamic systems. It enables the user to modify existing or create custom libraries especially for physical modelling.

Since the simulator includes already a wide range of predefined libraries, Dymola can be used in various areas of engineering including electronics and mechanics.

The models can be created graphically (using real world elements as resistors or capacitors) with ideal components or also with “real world” elements or text based. Furthermore it is possible to script the simulation, so a re-simulation can be done very easily.

Model: A class-E power amplifier circuit was modelled. Basically it is an amplifier circuit with a switching resistor (R). Its schematic can be found in Figure 1.

The resistance-time diagram of the switching resistor R can be found in Figure 2. It enables the circuit to generate an AC signal out of a single DC voltage source. A combination of capacitors and inductors are used to smooth the output signal. Therefore, instead of a rectangular signal, a nearly perfect sine signal is produced.

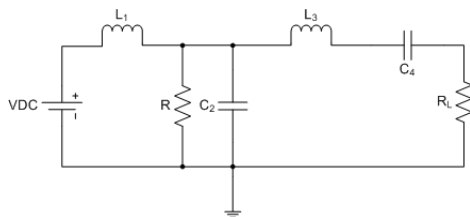


Figure 1. Class-E Amplifier circuit with time-dependent resistance R

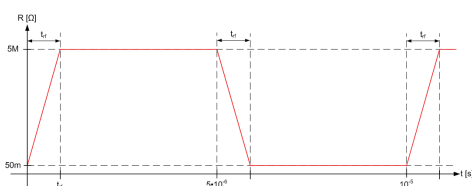


Figure 2. Resistance-time diagram of switching resistor R. In the “on”-period the resistance is only 50 mΩ, hence nearly a short-circuit.

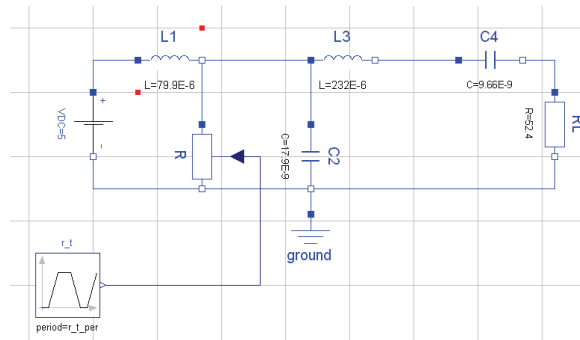


Figure 3. Dymola Circuit Model defined in the *Diagram* layer with components from the Modelica standard library

We have decided to model the circuit in two different ways. The first solution is modelled directly as circuit using the predefined electronic components. Furthermore, we have textually modelled the system using its differential equations.

In the first case, the circuit was directly input into the modelling system. The resistance-time diagram for the switching resistor was modelled as a *trapezoid* signal, from Modelica.Blocks.Sources. The model can be found in Figure 3.

In the second case we have written a text based model description. This description contains the parameters of the circuit, its system matrices (with switched on and off resistor), and the state variables of the system. Additionally the eigenvalues are calculated by using the function *eigenValues* in the Modelica.Math.Matrices library.

In the equation section the differential equations are defined. The model can be found in Listing 1.

```

1 model class_e_amplifier_dgl
2   // Circuit parameters
3   parameter Real u = 5.00E+00;
4   ...
5   // Resistance diagram of R
6   Modelica.Blocks.Sources.Trapezoid r_t(
7     period = r_t_per,
8     offset = r_t_on,
9     ...
10  // System matrix (in ON and OFF state)
11  parameter Real system_matrix_on[4,4] =
12    [0,    -1/l1,    0,    0;
13     1/c2, -1/(r_t_on*c2), -1/c2,  0;

```



```

14     0,    1/13,          -r1/13, -1/13;
15     0,    0,            1/c4,   0];
16 ...
17 // State variables of the circuit
18 Real x1(start = 0), x2(start = 0),
19     x3(start = 0), x4(start = 0);
19 // Additional interesting signals
20 Real y, v_l3, i_r;
21 // Calculation of the eigenvalues
22 parameter Real eigen_values_on[4,2] =
23     Modelica.Math.Matrices.
24     eigenValues(system_matrix_on);
23 parameter Real eigen_values_off[4,2] =
24     Modelica.Math.Matrices.
25     eigenValues(system_matrix_off);
24 equation
25 // System differential equations
26 ...
27 // additional signals
28 y = r1*x3; i_r = x2/r_t.y;
29 v_l3 = der(x3)*l3;
30 end class e_amplifier_dgl;

```

Listing 1: Differential Equation model of the class – E amplifier as defined in ARGESIM Benchmark 3

The whole simulation process was scripted using the built-in function of Dymola. Therefore it is possible to resituate and view the results with just one mouse click.

Note: Task A was only done using the second model. Task B and C were executed on both models.

A-Task – Calculation of the eigenvalues: The resulting eigenvalues are:

| On period | Off period |
|-------------------------------|--------------------------------|
| $-1,1303e+005 + 6,5835e+005i$ | $-5,4708 e+004 + 1,0407e+006i$ |
| $-1,1303e+005 - 6,5835e+005i$ | $-5,4708 e+004 - 1,0407e+006i$ |
| $-6,258e+002$ | $-5,8228e+004 + 5,3275e+005i$ |
| $-1,117e+109$ | $-5,8228e+004 - 5,3275e+005i$ |

B-Task: In this task we have simulated the initialization of the circuit in the time interval of 0 to 100 μ s. As integration algorithm Dassl was used, because it offers adaptive step size. The tolerance was set to 10^{-5} . The resulting voltage-time diagram can be found in Figure 4.

Furthermore the values of the state variables at the end of the simulation were exported into a script file. This script is used in Task C to initialize the circuit.

C-Task: In this task a parameter study was done. Therefore the rising and falling time of the switch resistor R were varied. The used values are: 1fs, 10ps, 1ns, 1 μ s, 10 μ s.

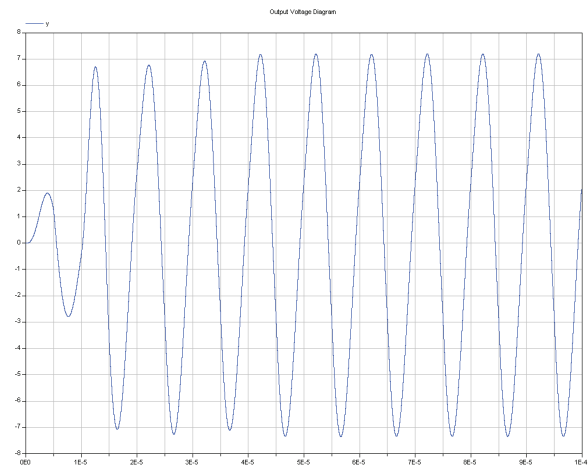


Figure 4. Output voltage at the load-resistance

The same simulation settings as in Task B were used. Only the simulation interval was changed to [100 μ s, 109 μ s]. The differences in the output voltage as well as the resulting voltage-current diagrams of inductivity L_3 were analyzed (Figure 5).

Résumé: The tasks have been done in textual mode and with electrical modelling Modelica standard library. The eigenvalue calculation has been done by using a Modelica function.

Using script files affords easy parameter variation and rollback of simulation tasks with predefined solver parameters.

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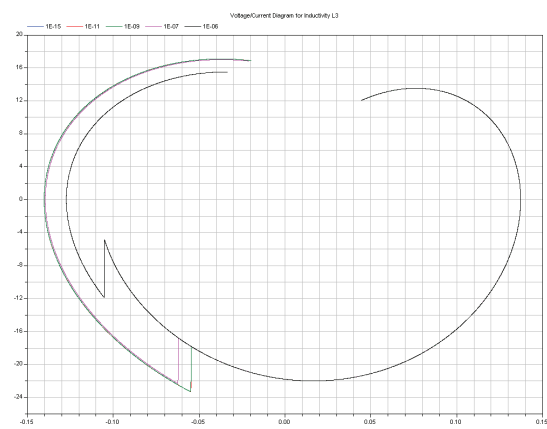


Figure 5. Voltage-Current Diagram of L_3