Lab work for the seminaire "Energy Harvesting"

Dimitri Galayko

1 Introduction

This lab is devoted to a study of a conditioning circuit of a transducer electrostatic energy used to convert vibration energy electrical. The studied circuit was proposed by B. Yen in 2006.

2 Introduction : Getting Started with the simulation tool

We use the simulation tool from Cadence to perform simulation in the AMS environment of Cadence, which mixes different representation of electrical networks and physical systems. In particular, the model can be composed of different blocks, each one being described in a different way : electrical network (spice), VHDL-AMS, etc. In our case, we will use VHDL-AMS for definition of electromechanical models, and traditional spice representation for electrical networks.

To set up your simulation environment, perform the following steps :

- Copy the file .zip provided by the lecturer in your local directory, and unzip it with the following command in the terminal :

unzip TP_recup_energy_cadence_part1.zip

- In the terminal, enter the following command :

mv ./.artist_state ~

– Enter to the directory of the laboratory work :

cd TP_recup_energy_cadence_part1

– Run Cadence with the command

source run_cadence_ams &

The main windows of Cadence opens.

The IPs related to the laboratory work are placed in two Cadence libraries :

TP_energy_harvesting_vhdlams_models and *TP_circuits_energy_harvesting*.

The first one contains the VHDL-AMS models of the components used in the practical work, the latter contains the networks which will be studied, and which use the VHDL-AMS models.

The libraries can be browsed with the *Library Manager*, which is launched from the menu Tools of the main window.

3 Test of the variable capacitor model

The cell *capa_variable* of the library *TP_energy_harvesting_vhdlams_models* is a model of a capacitor that varies over time according to a sinusoidal law. You can open the vhdl-ams model of the cell, in order to understand how it works. Look at the parameters of this model.

To test it with default parameter values, we will model a circuit composed of a DC source connected in parallel with the variable capacitor, and we will measure current through the source. This circuit is modeled in the cell*test_capa_variable* of the library *TP_circuits_energy_harvesting*.

Open the *schematic* view of this cell, launch the ADE environment from the Launch menu of the schematic window. An ADE (Analog Design Environment) window opens. From the menu *Setup* of the ADE window, select the *ams* simulator.

Perform a transient simulation for 0.5 seconds, and visualize the current flowing through the voltage source. Which is the amplitude of this current ? Why there is a strong and short negative pulse at the beginning of the transient process ?

Exercise. Given the parameters of the variable capacity and of the voltage source provided in the model, calculate the amplitude of the variable capacity current, and compare it with the amplitude given by the simulation.

3.1 Generation of electricity with a variable capacitor

We will now make the circuit autonomous by removing the power source *Vdc* and by replacing it with a fixed capacitance 10μF, charged to 10 V. For this, (i) delete the voltage source and (ii) add instance of the capacitance (touch *I* in the schematic window). The capacitance is available from the library *analogLib*, cell *cap*, view *symbol*. In order to pre-charge the capacitance, in the component parameter "Initial Condition", indicate 10.

From the window ADE, perform a series of simulation by varying the resistance R from 1 MOhm to 30 MOhm with a pitch of 5 MOhm. Observe the current in the resistor, the voltage on the variable capacitor and on the fixed capacitor. Conclude on electric power generated. Estimate (by simulation) the power of this generation.

Observe the evolution of states of the variable capacity axes " voltage - charge " .

4 Charge pump

Now we will use the model of variable capacity to study the charge pump. The charge pump is modeled in the file cell "chargepump" of the library *TP_circuits_energy_harvesting*. Open the "config" view, and similarly with the previous exercise, open the Analog Design Environment window.

Load the window state from the menu "Session → Load state" of the ADE window. This will configure the environment for your simulation : initial values of the parameters (C_{res}, C_{store}), the definition of the output waveforms (the voltages on the capacitors and the energy of C_{res} and C_{store}).

In this circuit, the capacitor C_{res} is pre-charged to 3 Volts. You can change the initial charge of the capacitor.

Run the transient simulation, and observe the evolution of the voltages and of the energy on the capacitors. Conclude about the optimal operation mode of the circuit. Modify the initial bias voltage, setting 5V and 10 V, and do the simulation again.

4.1 Q-V cycle

Display the quantity "charge" of the capacitor model, and thanks to the function "XY graph mode" of the Waveform visualizer of Cadence, trace the state of the variable capacity in the Q-V axes .

4.2 Estimated Energy

Estimate theoretically the maximum power that the variable capacitor of the circuit *chargepump.cir* can produce, given the value of $V_{res} = 10V$ and frequency defined in this circuit. Compare with the maximum energy generation rate by the variable capacitor observed in the question 3.1 for this voltage.

4.3 Increasing the variable capacity

Increase the Cmax and Cmin by a factor of two, repeat the simulation and measure the new value of the maximum power generated by the charge pump.

Then put Cmax and Cmin their old values and increase the initial voltage (V_{res}) by a factor of two. Simulate the circuit again measure the new maximum power. What is more advantageous : increasing of the voltage or increasing of the capacity ?

5 Return circuit (flyback)

To introduce the return circuit , we provide a model of switch whose opening and closing are controlled by a voltage : the switch becomes closed when the control voltage exceeds a high threshold (V2) , and returns to the blocked state when the voltage exceeds a low threshold (V1) . For more information , see the vhdl-ams view of the cell ”switch” and the article provided by the supervisor.

This switch is controlled by the voltage V_{store}. The high threshold value (V2) is adjusted to a value lower than the saturation voltage of the charge pump. When V_{store} reaches V1, the switch becomes ON, the feedback circuit is activated and the voltage U_{store} down to V1. When U_{store} reached V1, the switch goes off.

This model is implemented in the cell *chargepump_flyback*. By default, the values of the threshold voltages are 0 and 1000 for V1 and V2, that means that the switch is always blocked and the circuit operates as a simple charge pump (do a test).

5.1 Choice of V1 and V2

From the results of simulation of the pump charge, choose appropriate values for V1 and V2, edit the parameters of the switch block in the schematic of the cell *chargepump_flyback* and run the simulation for 20 seconds of operation.

Visualize the total energy of the circuit (the sum of energy of capacitors C_{res} and C_{store}). If the values V1 and V2 are well chosen, you must have (on average) a straight line with a positive slope. That means that the energy of the system increases continuously. This is the desirable operation mode. From the slope of this line, estimate the power produced by the system.

6 Bibliography

D. Galayko et al., AMS modeling of controlled switch for design optimization of capacitive vibration energy harvester, BMAS2007 international conference, 2007, San José, CA

B. C. Yen, J. H. Lang, “A variable-capacitance vibration-to-electric energy harvester”, IEEE transactions on Circuits and Systems – I : Régular Papers, vol. 53, pp. 288-295, February 2006