# Optimization of Control Switch for Energy Harvest Circuit Using a Variable Capacitor

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***Abstract*** - This work presents an analysis of a harvesting system of vibratory energy through a variable capacitor and a DC-CD Buck converter circuit. A switch circuit architecture of the Buck converter is presented. The performance of the switch in relation to the wasted energy due to the size of the used transistor as well as the work tension over the switch was verified. The circuit was developed in the cadence scheme and it used components with 0.35 µm technology of high voltage in order to support tension up to 50 V. This circuit presents a loss smaller than 4% of the transferred energy.

***Keywords: Vibration energy harvesting, switch optimization, variable capacitance.***

## I. INTRODUCTION

With the development of the micro and the nano technology, the electronic devices have been in rapid advancement. The size reduction is followed by the power consumption reduction. Along with these advancements, a new source concept is also researched: autonomous sources. These are integrated to these devices in order to make them independent from the external power sources [1], [2], [3],. These sources are able to capture energy in different ways from the environment where the devices are.

Among these devices, we point out the use of autonomous sensors which have great advantages in relation to the conventional sensors. As examples, we have the reduction of wire quantity used for the electrical connections in a distributed net, between the source and the several sensors as well as the fact that there is no need for replacing the chemical batteries used for feeding the sensors.

Many devices can have as single way of harvesting energy the mechanical vibrations because they can be inside machines, automobiles or spacecrafts in which there is no other way of harvesting. The energy from the vibrations can be converted into electrical energy through piezoelectric materials, electromagnetic systems, or by means of electrostatic charges using variable capacitors [2], [4], [5],.

The harvesting of electrical energy through electrostatic charges is an alternative for attaining a great quantity of energy in reduced size and easy integration. The energy harvesting, in this system, is proportional to the square tension over the variable capacitor and the new technologies provide the use of higher and higher tensions. Integration becomes simpler as well because the variable capacitors can be built in their own circuit substratum.

An option for producing electrical energy through electrostatic charges is the use of two electrodes in parallel in order to form a capacitor. One of the electrodes is connected to a proof mass and it displaces itself during the vibration in relation to the second electrode which is fixed in the substratum. In this kind of transducer, the capacitance varies from a maximum value to a minimum one [2].

Equation (1) illustrates the stored charge of a capacitor due to its capacitance and its tension. By charging a variable capacitor with an initial charge**,** and then, leaving its terminals open so that the value of this charge does not change, while a capacitance variation is taking place, there will be a change in tension over the capacitor [3], [6].

The tension increase, which occurred in the capacitor when the capacitance value decreases, is used to boost electrons in the circuit, working, thus, as charge pump. The energy taken by each variation cycle of the capacitor is given by the expression (2), where Vin is the initial tension of the capacitor, Cmax and Cmin are the maximum and minimum values of the variable capacitor, respectively.

$$Q=C*V \quad (1)$$

$$E = Vin^2\,(Cmax - Cmin) \quad (2)$$

## II. CIRCUIT FOR ENERGY HARVESTING

Figure 1 presents a circuit used for electrical energy harvesting through the electrostatic charges. The circuit can be divided into two parts: the charge pump which boosts the electrons to move through the circuit composed of $C_{res}$, $C_{var}$, $C_{store}$, $D_1$ and $D_2$ and the Flyback circuit which is responsible for the $C_{store}$ and $C_{res}$ charge return. This part of the circuit is made up of L, $D_3$ and the $S_w$ switch.

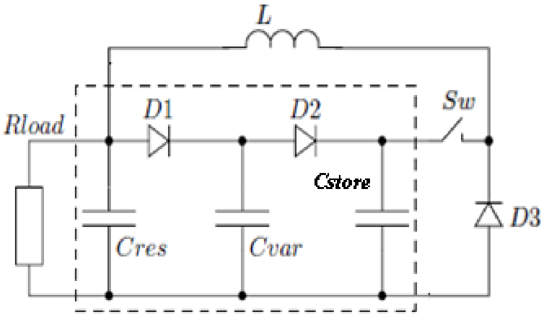


Figure 1: Circuit for Energy Harvesting

In figure 1 circuit, the $C_{var}$ capacitor is the variable capacitor which has its value modified according to a mechanical vibration. The $C_{store}$ capacitor has the function to store temporarily the charge supplied by $C_{var}$ and then send it to $C_{res}$. The $C_{res}$ capacitor has the function to supply energy for the $R_{Load}$ resistor, maintaining its tension constant and then supply charge to $C_{var}$. [3].

In the Figure 1 circuit, the $VC_{res} = V_{var}r = V_{store,}$ condition adopted initially [2]. When the *Sw* switch is open and a capacitance decrease occurs, which is carried out by vibration, there will be an increase in the $C_{var}$ tension. Thus, the $D_2$ diode will remain directly polarized and this capacitor's charge will be transferred to the $C_{store}$ capacitor, increasing the tension on it.

The charge supplied by the $C_{var}$ capacitor to $C_{store}$, for a vibration cycle is given by the expression (3):

$$Q = (Cmax - Cmin) * \left[\left(\frac{Cmax}{Cmin}\right) * Vres - Vstore\right] \qquad (3)$$

The tension that $V_{store}$ reaches for each vibration cycle is given by the expression (4), where *n* is the number of times that the capacitor varies.

$$Vstore_n = Vstore_{n-1} + (Cmax - Cmin) * \left[\left(\frac{Cmax}{Cmin}\right) * Vres - Vstore_{n-1}\right] / Cstore \qquad (4)$$

When capacitance increases, the tension on $C_{var}$ decreases and as a result $D_1$ will be directly polarized, carrying charges from $C_{res}$ to $C_{var}$. This process repeats itself during vibration and while the $C_{store}$ tension increases, the $C_{res}$ tension decreases due to the energy which is supplied for the charge and the $C_{var}$ as well.

At the moment in which the switch is closed, the Cstore energy is transferred to $C_{res}$, recharging it. When the switch is opened, the inductor discharges its energy into $C_{res}$ making up a serial circuit among inductor, $C_{res}$ and $D_3$. From this point, the circuit starts effectively to gain energy because $V_{res}$ starts increasing and its tension will be higher than the tension it initially had [7]. Figure 2 presents the waveforms about the circuit. The bottom part of the figure shows the current on the inductance when the switch is closed

The energy amount that the system gained in a specific interval of time can be found by subtracting the final energy over $C_{res}$ and $C_{store}$ from the initial energy over these capacitors. The expression (5) shows the calculus of the total gain of energy. Where *f* and *ini* rates indicate the final and initial values, respectively, of each variable.

$$GE = (Eres_f + Estore_f) - (Eres_{ini} + Estore_{ini})$$

$$GE = \frac{1}{2}\left[(Cres * Vres_f^2 + Cstore * Vstore_f^2) - (Cres * Vres_{ini}^2 + Cstore * Vstore_{ini}^2)\right] \qquad (5)$$

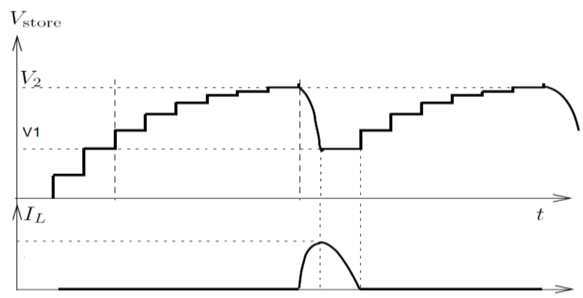


Figure 2: tension waveform on Cstore

In this circuit the switch fulfills a noteworthy function transferring the $C_{store}$ charges to $C_{res}$, once every time $C_{store}$ tension reaches a maximum value of V2 the *Sw* switch must be activated [8]. In this way, its efficiency should be the best possible so that the circuit losses are minimized. In this work we propose a switch circuit which presents an optimal performance and low energy consumption.

## III. PROPOSED SWITCH

The switch configuration is represented in figure 3. In this circuit, components with 0,35µm technology of high voltage in order to support tension up to 50 V were used as well as higher tensions so that the maximum energy can be harvested. The initial switch circuit is composed of Mo transistor from P channel which will guide the carrying current of charges among the capacitors. The other $M_1$ transistor of N channel has the function to control the Mo gate tension from an external tension. The $R_1$ resistance has the function to supply tension for the $M_0$ gate aiming to block it.

In the Figure 1 circuit, the switch is activated by an external control circuit which contains the activating logic of the switch. When this switch is activated, it has the function to transfer charges stored in the Cstore capacitor to the $C_{res}$ capacitor. Thus, for the performance analysis of the switch, the Cstore capacitor was connected with the initial conditions in the input, the $C_{res}$ capacitor in the output, besides the inductance and the Flyback circuit diode, as figure 3 presents. The switch will be analyzed in the same conditions of the energy harvesting circuit.

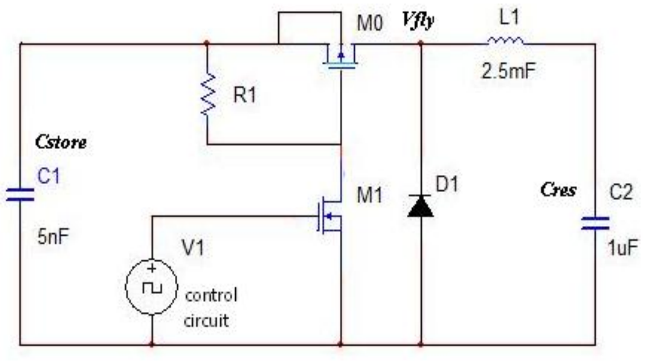


Figure 3: Control switch circuit

The tension waveforms on the $C_{store}$ capacitor and $V_{fly}$ as well as the current on the $C_{store}$ capacitor are represented in figure 4. The difference among these tensions is the one on the $M_0$ transistor of the switch. The smaller such tension difference is, the smaller the losses are.

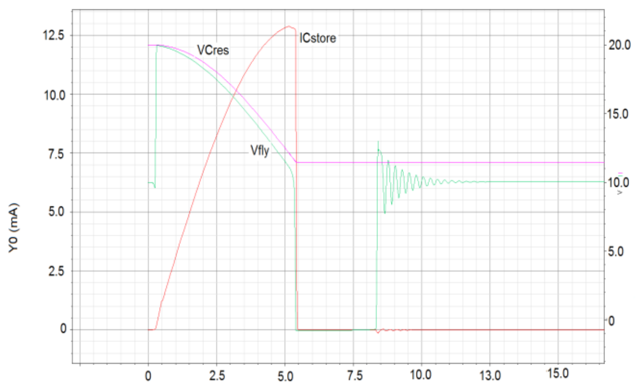


Figure 4: waveform on the switch.

## IV. RESULTS

As concerns the switch analysis, it can be perceived that the smaller the tension on M0 is, the smaller the resistance among the drain and source terminals and the losses will be. In this way, the bigger the transistor is, the smaller the losses will be. Figure 5 graphic represents the behavior of the switch losses due to the transistor size.

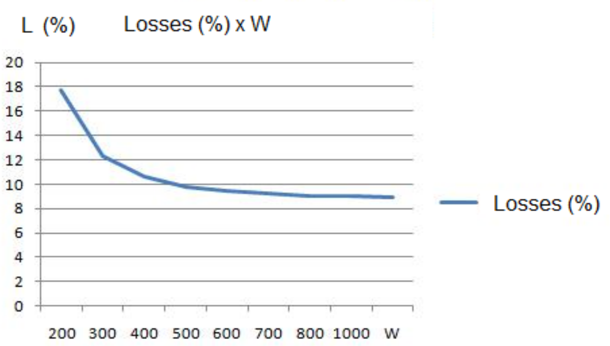


Figure 5: Switch loss in % for W, for L = 1,4. $V_{Store}$ = 20V, $V_{res}$=10V.

Another result which can be attained refers to energy loss on the switch. When $C_{store}$ tension varies, this capacitor can be carried with different tensions by the variable capacitor. This occurs if the switch is commutated in different times. Figure 6 shows the energy loss due to the variation of $C_{store}$ tension maintaining the $C_{res}$ tension of 10V. The energy supplied by Cstore when it stores a 50V tension is about 6μJ and for 20V tension it is 0,7 μ J.

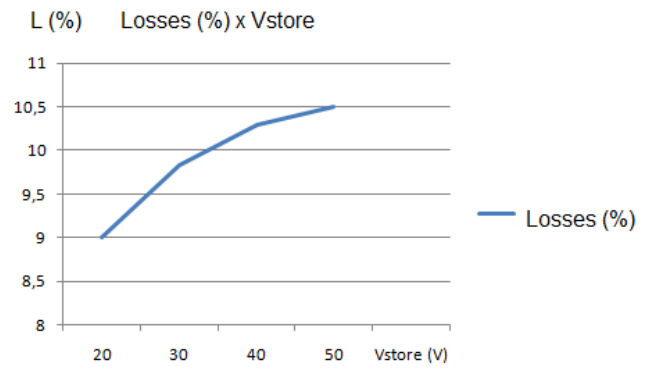


Figure 6: energy loss due to variation of Cstore tension

At the moment the switch commutates, the *M0* transistor gate current occurs due to the charge and discharge of the M0 transistor gate capacitor. This current determines the ideal value for the R1 resistance. Figure 7 illustrates the graphic of the maximum value of the $M_0$ transistor gate current in function of the transistor size.

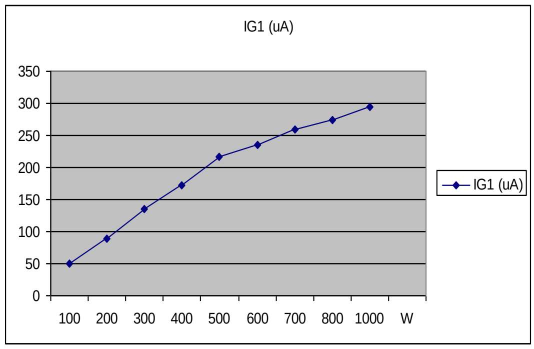


Figura 7:Corrente de gate de M0 em função de W

For the figure 3 circuit, the R1 resistance has the function to supply tension for the $M_0$ gate so that this transistor can cut or conduct. For higher tensions supplied for its gate, the transistor cuts and, for lower tensions, it conducts. The resistance value determines the current with which the gate capacitor, internal to the $M_0$ transistor, will charge. The faster this charge is, the faster the transistor commutates. The transistor takes some time to switch so it determines the transistor losses and, consequently, the switch losses. Figure 8 illustrates the switch losses in function of $R_1$ resistance value. It can be observed that the smallest loss, 10,2% value, occurred for a $R_1$ value = 100K_Ω._These measurements were accomplished for the following circuit parameter values: $V_{store}$ = 20V, $V_{res}$ = 10V, W = 400.

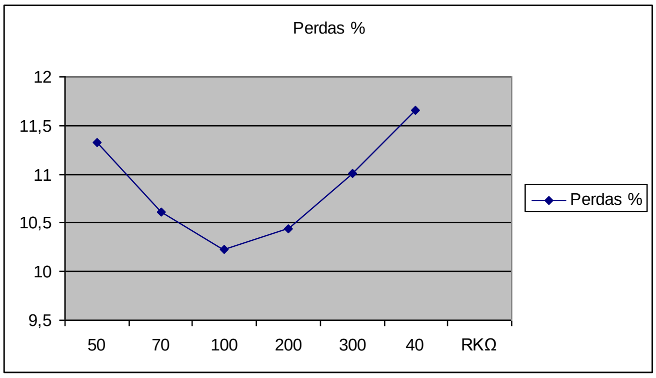


Figure 8: Switch losses in function of R1 resistance

It is represented in figure 9 a change in the switch aiming to its better efficiency. This circuit has three more transistors as compared to the previous one in replacement of the circuit resistance, improving, thus, its yield.

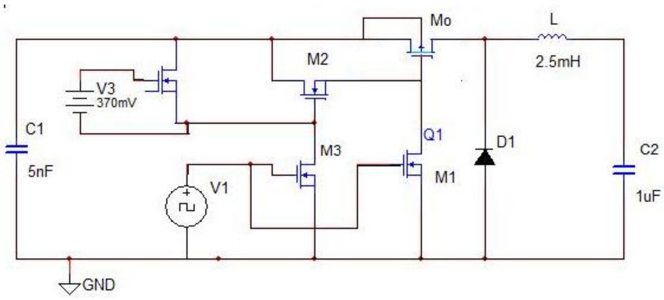


Figure 9: Circuit of the changed switch

Figure 10 graphic represented the switch losses in relation to the transistor size and to Cstore tension. It reveals that such losses reduce when we increase the transistor size and they do increase due to the Cstore tension. These are important results because, by means of them, we can quantify the circuit losses for each switch cycle, intending, thus, the study of the amount of energy harvested by the circuit.

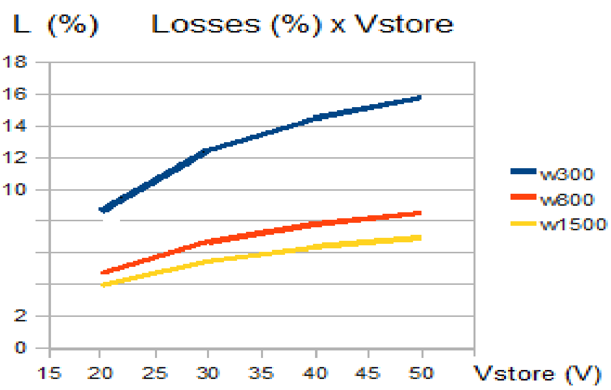


Figure 10: Circuit losses in relation to Vstore tension for different transistor size.

V. CONCLUSION

We can verify that the two circuits presented for the switch have very low losses. Figure 3 circuit presents a minimum energy loss due to the energy supplied by $C_{store}$ which is about 10% while figure 7 circuit is about 4%. So, this last loss can be considered as very low in such a way that figure 9 circuit can be used by the energy harvesting circuit with an outstanding efficiency.

We can also conclude for the switch that: For the figure 3 circuit, the *R1* resistance value is directly related to its efficiency. The bigger the transistor size for both circuits is, the better its efficiency will be. The higher the tension difference between $V_{store}$ and $V_{res}$ is, the higher their losses will be.

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