CURRENT COMPARATOR BASED ON SHOCK-EXCITED OSCILLATOR

Maria Stanoeva, Angel Popov

Computer Systems Dept., Technical University of Sofia, "Kliment Ohridski" St. No 8, 1000 Sofia, Bulgaria, e-mail: mstanoeva@yahoo.com, anp@tu-sofia.bg

A new approach to current comparator design is proposed. It is based on the principles of resonant circuits and consists of a RLC circuit, a switch and two damping transistors. The parameters of the real inductance and their influence on its Q-factor are taken into account. The sensitivity of the comparator, as well as the processes of damping and recovery of the initial state, are investigated using time-domain analysis. Some considerations are made for comparator speed-up.

1. INTRODUCTION

The basic shock-excited resonant circuit is shown in Fig. 1. It is activated by the opening of the switch *S1*. If a non-zero current has been flowing through the circuit, it starts to oscillate. The sign of the voltage of the first half-period of the induced oscillation depends of the direction of the current trough the inductor. The magnitude and the type of oscillation vary in function of the resonant circuit characteristics.

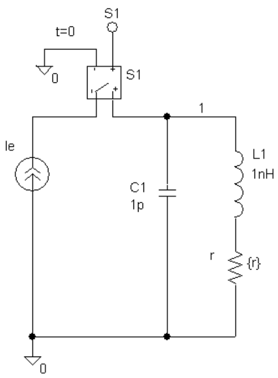

Fig. 1

The characteristic equation of the resonant circuit is

$$p^2 + \frac{r}{L}p + \frac{1}{LC} = 0 \text{, or}$$

$$p^2 + 2\alpha\, p + \omega_o^2 = 0, \quad \text{where} \quad \alpha = \frac{r}{2L} \quad \text{and} \quad \omega_o = \frac{1}{\sqrt{LC}} \tag{1}$$

$$p_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_o^2}$$

Its main parameters are as follows:

$$\omega = \sqrt{\omega_o^2 - \alpha^2}\,, \qquad \rho = \sqrt{\frac{L}{C}} \qquad \text{and} \qquad Q = \frac{\rho}{r} \tag{2}$$

Depending on the value of $\sqrt{\alpha^2 - \omega_o^2}$ three types of solutions are possible.

- $\alpha = \omega_o$ – critically damped response; $p_1 = p_2 \in R$
- $\alpha > \omega_o$ – over-damped response; $p_1 \neq p_2 \in R$ (3)
- $\alpha < \omega_o$ – under-damped response; $p_1 \neq p_2 \in I$

In order to obtain larger voltage magnitude over the circuit during the first half-period, the oscillation should not be over-damped, that is:

$$\alpha^2 - \omega_o^2 \leq 0 \quad \Rightarrow \quad r \leq 2\rho \tag{4}$$

In the case of under-damped circuit response, the oscillation of the voltage over the resonant circuit oscillates according to the dependency:

$$u(t) = U_m e^{-\alpha t} \cos(\omega t + \psi), \quad \psi = -arctg \frac{\alpha}{\omega}, \tag{5}$$

where $U_m = \rho I_e$ is the maximal voltage magnitude (6)

The voltage across the resonant circuit is shown in Fig. 2 for two different values of the resistance *r* in series with the inductance element. As shown in (6), the value of *r* has no influence on the maximal magnitude of the resonant circuit, but only on its frequency and damping ratio.

$$k_i = \frac{u_m}{I_e} \tag{7}$$

The relation (6) is similar to the transfer characteristic of a transimpedance amplifier (7). The circuit however, lacks in active components, i.e. there is no offset inherent to the active amplifiers.

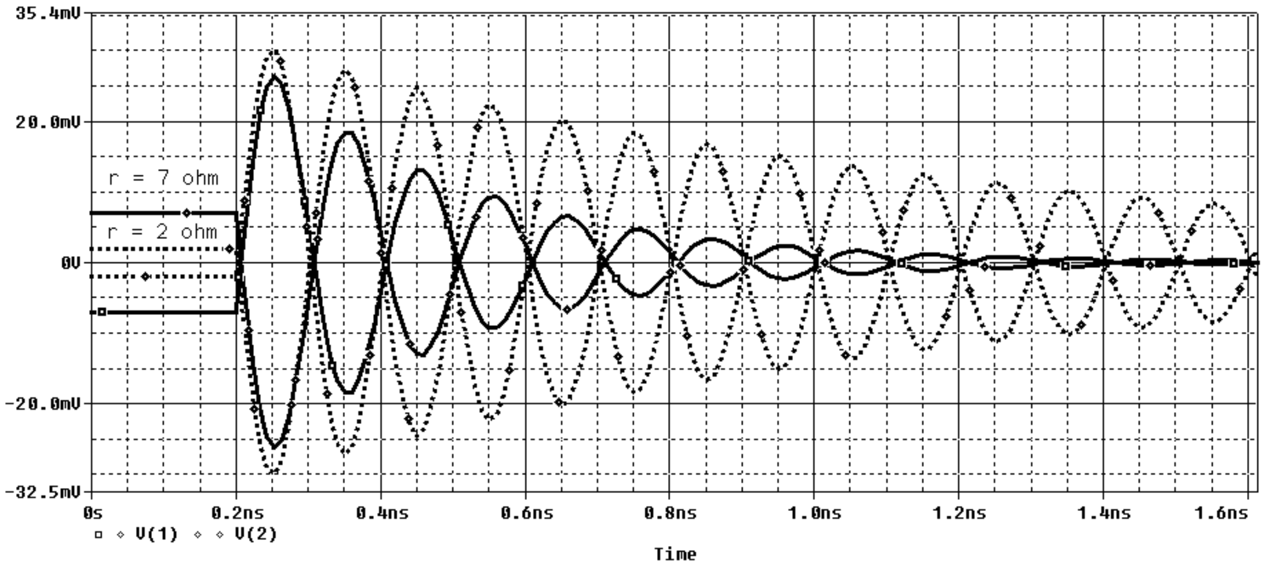

Fig. 2

2. PRINCIPLE OF OPERATION

The model of comparator is shown in Fig. 3. It consists of analog behavioral modeling for the voltage controlled switch *Sbreak* and the hard limiter *Limit* (*Abm.lib*) and electrical modeling for the resonant circuit and the damping resistor.

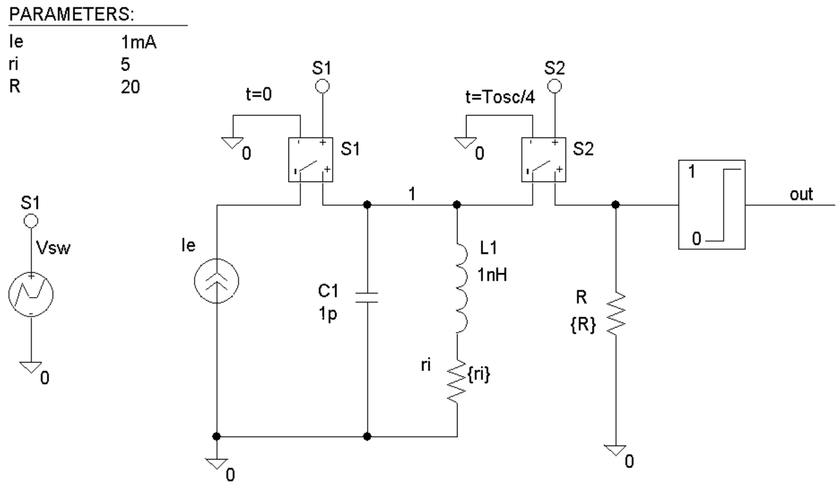

Fig. 3

The comparison process can be divided into three stages – excitation of the circuit, damping of subsequent oscillations and recovery of the initial state. In the first stage, the circuit is excited and the magnitude of the voltage over the resonant circuit is measured. In the second stage the subsequent oscillations must be damped. This is done by coupling a parallel resistance to the resonant circuit in the moment $t \approx T_{osc}/4$, that is when u_C is near its maximum and i_L is zero. In the last stage the input current is turned back on and the damping resistor is turned off in order to recover the initial state.

The damping resistance *R* and the switch are replaced by two parallel complementary MOS transistors (Fig. 4). In order to operate in the resistive area of the pass-gate characteristics, the gate voltages must satisfy with the relation:

$$|U_{GS}| - |V_T| > |U_{DS}| \tag{8}$$

The two complementary transistors must be geometrically identical. In this way the signal feed-through due to the parasitic gate-drain capacitances is cancelled by the opposite transistor gate signals.

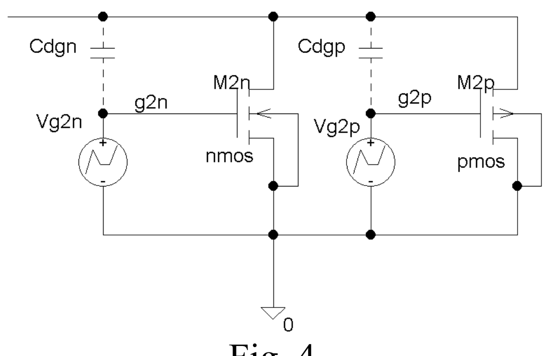

Fig. 4

The values of the input current and the gate voltage of both transistors are shown in Fig. 5 and the response of the resonant circuit to positive and negative input current is given in Fig. 6. The value of its Q-factor is 4.5. In Fig. 7 the same circuit is given with Q = 16. Although damping and recovery phases are initiated simultaneously, the overall operation time is much larger.

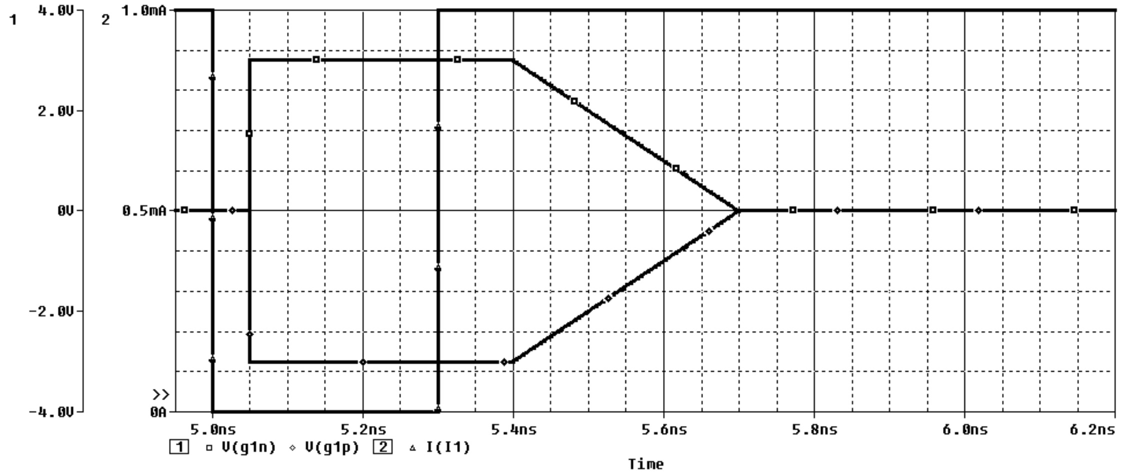

Fig. 5

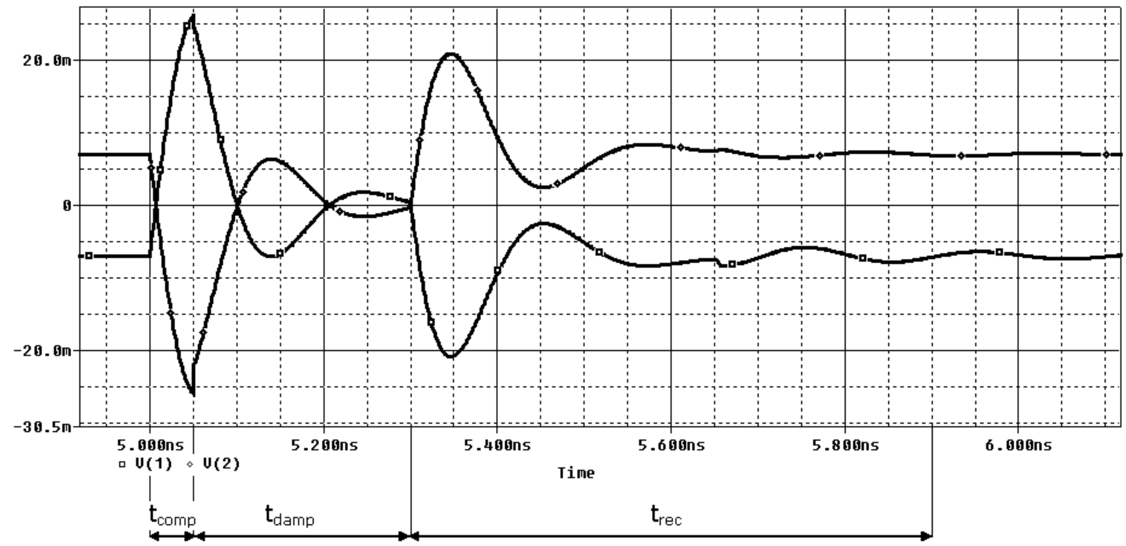

Fig. 6

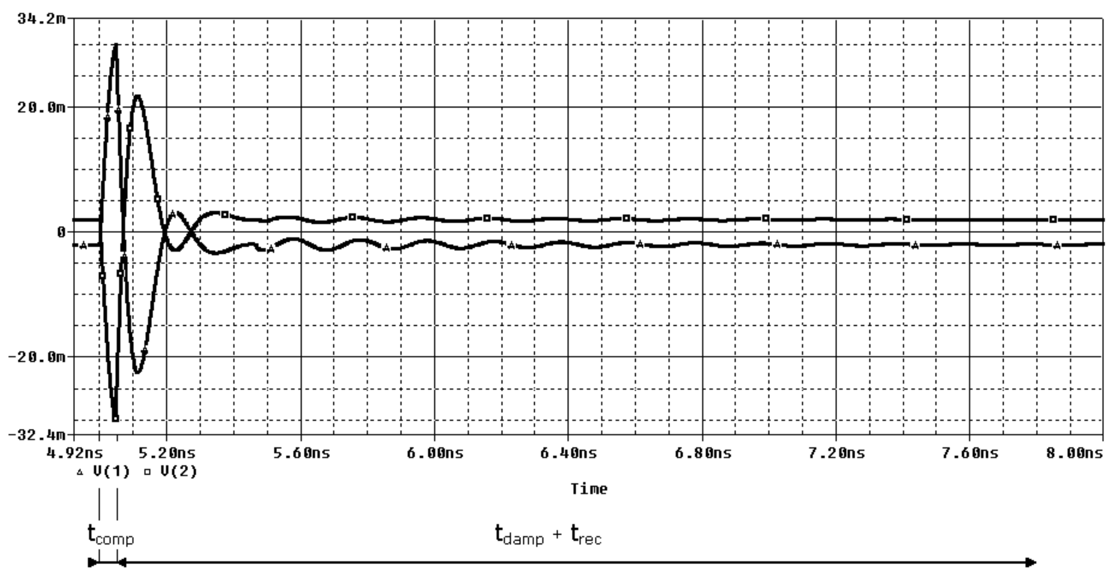

Fig. 7

3. SPEED INVESTIGATION

The speed of the comparator depends on the duration of its three phases of operation. The proposed optimal solution is to run both processes of damping and initial state recovery simultaneously.

4. SENSITIVITY

The voltage across the resonant circuit is shown in Fig. 8 and Fig. 9 in function of the input current for different values of the circuit's characteristic resistance. Its maximal magnitude is $U_m = \rho I_e$ (6). It must be amplified by a factor of k_U and limited to the output magnitude $U_{out} = V^1 - V^0$, where V^1 and V^0 are the corresponding logic signal levels. The sensitivity of the comparator is:

$$I_e > \frac{U_{out}}{\rho k_U} \quad (9)$$

For instance in order to attain a sensitivity of $10\,\mu A$ and $U_{out} = 3V$, the product $\rho k_U = 3.10^5$. For recently implemented integrated inductors $\rho = 30 \div 100$ and k_U must be in the range $3.10^3 \div 10^4$.

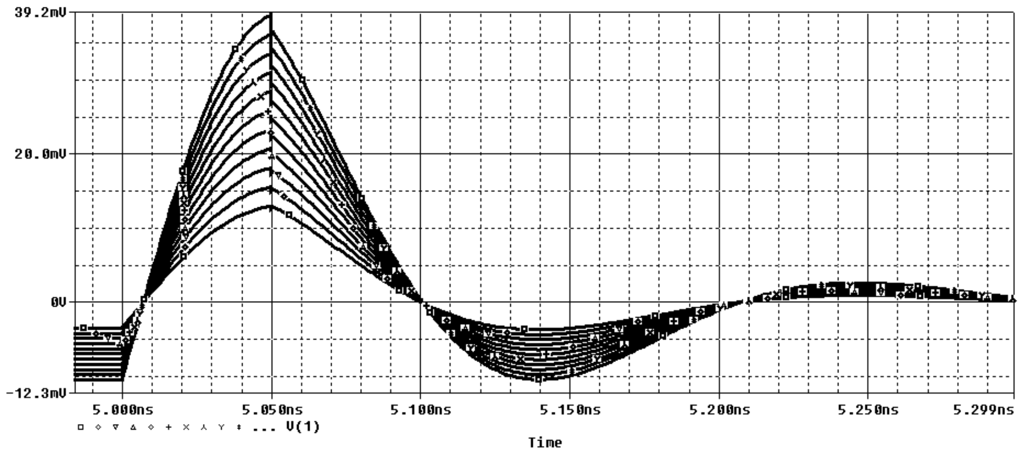

Fig. 8

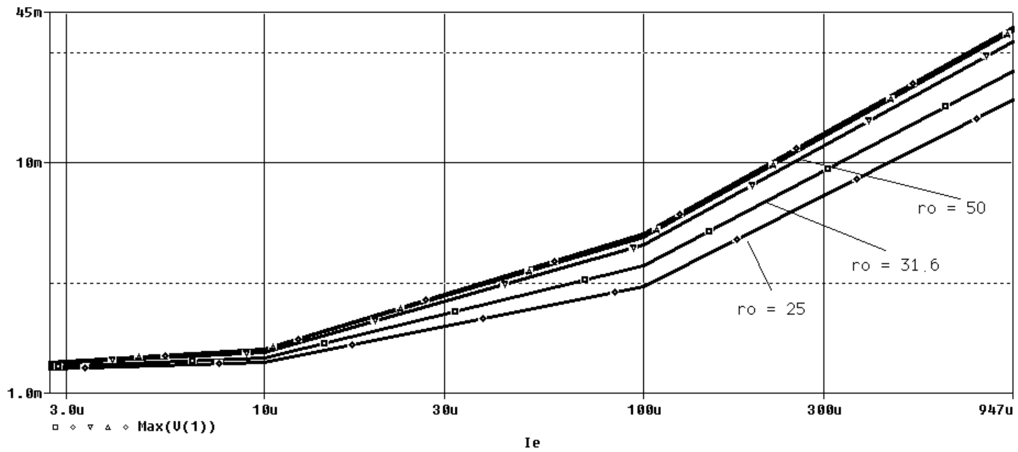

Fig. 9

5. CONCLUSIONS

A new method for comparator design based on shock-excited oscillator has been proposed and investigated. The analytical and simulation results prove the feasibility of the circuit. Nevertheless, there are some open problems to be resolved:

- The parameters of present integrated resonant circuits constrain the sensibility and speed of the comparator. Technological development will allow the realization of the proposed circuit.
- The operation of the comparator can be accelerated by finding an optimal shape of the gate control signal, obtained by additional simulations.

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6. REFERENCES

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