Improving Controllability in RF-MEMS Switches using Resistive Damping

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Abstract. An efficient way to control the impact velocity in order to achieve soft landing and fewer bouncing phenomena is the resistive damping. This control method is also referred as charge drive and presented for first time by Castaner and Senturia [1]. Under charge control the Pull-in phenomenon of the Constant Voltage controlled electrostatic actuators does not exist and if the current drive is ideal, any position across the gap is stable. The main reason for this behavior is that the electrostatic force applied is always attractive and independent of the remaining gap of the actuator. Charge drive control incorporating constant current sources is mostly preferred to extend the travel range of electrostatic micro-actuators [2], [3], [4], [5]. Nevertheless there are very few references in the literature about charge drive control on RF MEMS. Recently published work based on numerical simulations for capacitive RF-MEMS, [6] and [7] present a learning algorithm in order to reduce fabrication variability using resistive damping for the pull-down phase. Nevertheless none of them present any details on how to implement resistive damping and any results of such kind of applications. This work presents in detail the entire procedure in calculating the bias resistance of an RF-MEMS switch controlled under resistive damping.

Key words: charge drive control, RF-MEMS switch, resistive damping, bouncing, contact force.

1. The Significance of Resistive Damping

The controllability of a switch is the key factor to reduce wear by minimizing the impact velocity. Despite the sophisticated design, adopting special cantilever shapes for contributed actuation force as well as utilizing fringing fields by making use of protruded electrodes, controllability still remains a difficult task which requires great thought and mathematical calculations. In case of a very stiff device, like the one which has been fabricated and presented by Guo, McGruer and Adams [8], the actuation control under resistive damping is the only way to achieve controllability. Due to the small switching time as well as the high actuation voltage, it is not practical to implement a tailored control pulse. Experimental results have shown that time intervals smaller than 1μs and pulses with slew-rate greater than 200V/μs are necessary in order to shape a tailored pulse for this switch, as the switching time is about 1.24μs when a sharp actuation pulse of 83V is applied. Even for the case that this fast and high in voltage pulse can be generated, there are other subjects like overshooting that they will possibly render problematic the control of the switch.

To eliminate bouncing phenomena, during the release phase of the switch, when the cantilever is oscillating within mechanical resonance frequency, the R_bC_{el} product must be equal to the period of the resonance frequency [9].

Very stiff devices [8], present high mechanical resonance frequency and make them appropriate for this kind of control as the time constant RC, which has been calculated for the pull-down phase, is near the period of the mechanical resonance frequency. Consequently, significant improvement in both switching operation phases of the switch is achieved. Thus, control under resistive damping is the only practical solution for very fast RF-MEMS switches where switching time and period of the resonance frequency are of the same order.

2. Applying Resistive Damping to Improve Controllability

The ohmic RF-MEMS switch of Fig.1 has been evaluated under the Coventorware software package examining controllability with and without resistive damping.

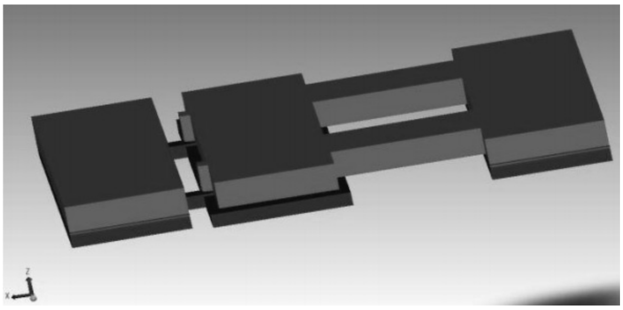

Fig. 1. The "NEU" ohmic RF MEMS Switch.

Initially, a transient analysis is performed under step pulse implementation with 83V amplitude, width p_w=48μs, rise time t_r=1μs and fall time t_f=1μs. The amplitude of 83V has been calculated in order to be high enough to ensure immunity to switch parameters uncertainty due to the tolerances of the fabrication process, and low enough to ensure plenty of room for RF signal.

The switching time obtained under the above pulse conditions was some 1.7μs for the OFF-ON transition and around 1.4μs for the OFF-ON transition, as shown in Fig. 2, the fastest ON and OFF switching time that can be achieved.

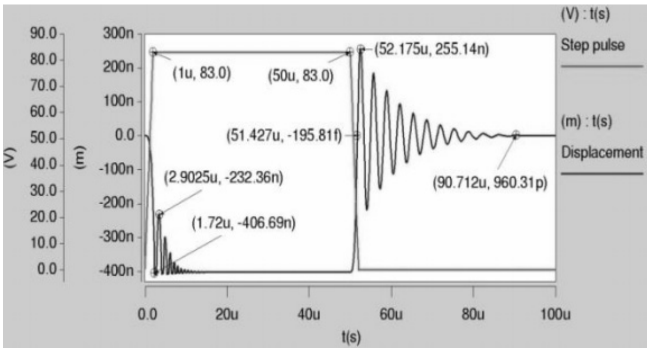

Fig. 2. Displacement under step pulse control mode.

The same figure illustrates the bouncing problems during the pull down (max. bounce=174μm) and release (max. bounce=255μm) phases. High settling times are observed also due to the stiffness of the cantilever (k≈1000 N/m), which are some 11μs for the pull down phase and roughly 39μs for the release-phase. In Fig. 3 other characteristics of the switch under step pulse implementation are illustrated, such as the contact area (11.566pm^2), the conductance per contact area (2.53S which corresponds to a resistance of 0.394Ω) and the contact force (99.3μN). Control difficulties are illustrated also as concerns the high initial contact force (almost 496μN) due to the high impact velocity (around 65.9cm/sec). In order to introduce resistive damping, a bias resistor is necessary to be calculated. Having calculated the capacitance within the electrode area (C_{el}=30fF) and with a pulse amplitude of 83V and rise time of t_r=1μs, the bias resistance can be calculated has been extracted.

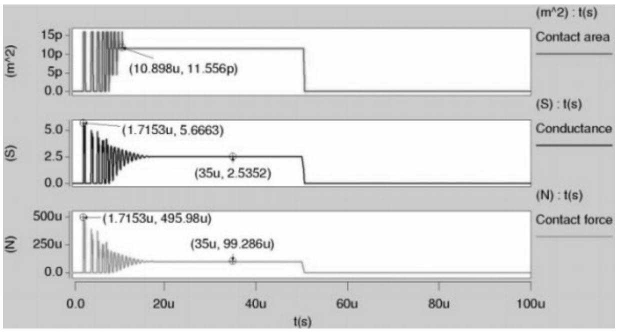

Fig. 3. Characteristics under step pulse control mode.

$$R_b \, C_{el} = t_r = 1\mu\text{m} => R_b \approx 33\text{M}\Omega \tag{1}$$

Figure 4 illustrates the characteristics of the switch under step pulse implementation with resistive damping. >

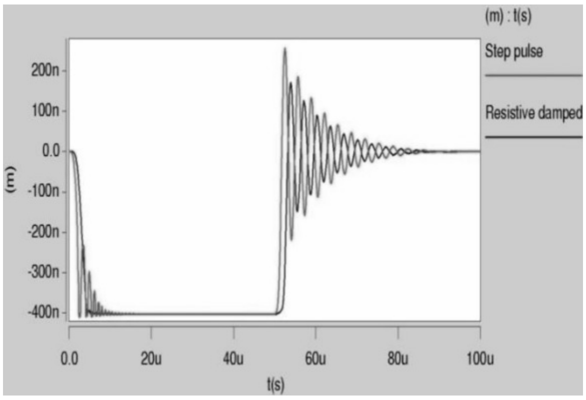

Fig. 4. Comparison between step pulse and resistive Damping modes.

The simulation results with R_b=33MΩ shown excellent response of the switch during the pull down phase as elimination of the bouncing phenomena is observed as well as dramatic reduction of the initial impact force (the high impact velocity has been reduced to 13.2 cm/sec from 65.9cm/sec), with only a small increase in the switching time (3.47µN from 1.72µN). During the release phase a significant reduction of the amplitude of bouncing is observed too (174nm instead of 255nm).

A comparison between step-pulse and step pulse with resistive damping actuation modes is presented in Fig. 5.

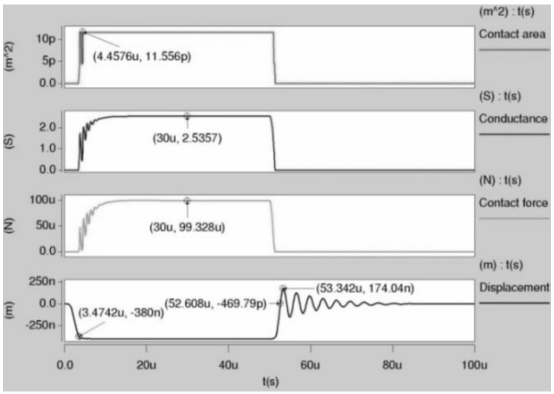

Fig. 5. Characteristics under resistive damping control.

It is obvious that the control of the switch under resistive damping excels the corresponding with the step pulse in both OFF-ON and ON-OFF transitions slightly sacrificing in the switching time. Finally, in Fig. 6, the power consumption of the switch under the previously mentioned actuation control modes is presented. It is clearly shown that under resistive control mode the switch requires much less power to be actuated.

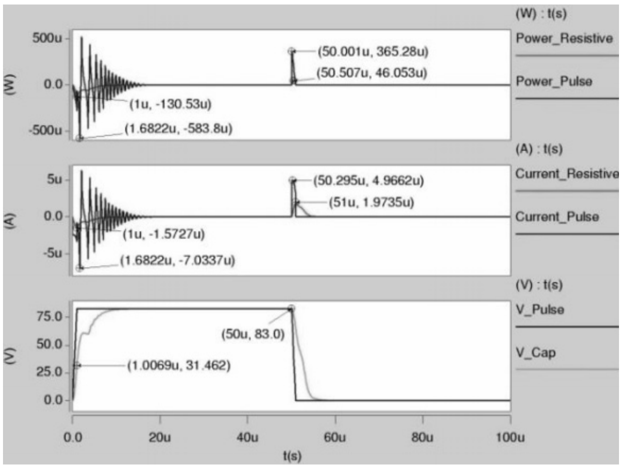

Fig. 6. Power requirements under Pulse and resistive damping modes.

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