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MEMS Switch Contact Bouncing Mitigation using Novel Dual-Pulse Actuation Voltage

(Pengurangan Lantunan Sentuhan Suis MEMS Menggunakan Voltan Penggerak Dwi-Denyut Baru)

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ABSTRACT

A novel dual-pulse actuation voltage that reduces dielectric charging in micro-electromechanical system (MEMS) switch and thus leading to a longer switch lifetime, are shown to simultaneously mitigate MEMS switch contact bouncing. A simple mass-spring-damper mathematical model is used to simulate movement of the switch contact as the excitation voltage is applied. The model shows that the novel dual-pulse voltages damped the acceleration of the switch membrane as it approaches the contact point, eventually slowing it down and minimizes the impact force. This has the effect of minimizing the occurrence of contact bouncing. Practical experiment on the commercial TeraVicta TT712-68CSP MEMS switch corroborates that the novel excitation voltages reduced bouncing.

Keywords: Contact bouncing; micro-electromechanical system (MEMS); radio frequency (RF); reliability

ABSTRAK

Voltan penggerak dwi-denyut baru yang mengurangkan pengecasan dielektrik dalam suis sistem mikro-elektromekanik (MEMS) seterusnya memberikan jangkahayat suis yang lebih panjang, telah didapati memperlahankan lantunan sentuhan suis MEMS. Satu model matematik jisim-spring-pelembap telah digunakan untuk mensimulasi pergerakan sentuhan suis semasa voltan pengujaan dikenakan. Model ini menunjukkan bahawa voltan dwi-denyut melembapkan pecutan membran suis apabila ia menghampiri titik sentuhan, seterusnya memperlahankannya dan meminimakan daya impak. Ini memberikan kesan mengurangkan kejadian lantunan sentuhan. Uji kaji praktikal ke atas suis komersil TeraVicta TT712-68CSP MEMS mengesahkan bahawa voltan pengujaan terbaharu mengurangkan lantunan.

Kata kunci: Frekuensi radio (RF); kebolehharapan; lantunan sentuhan; sistem mikro-elektromekanik (MEMS)

INTRODUCTION

Microelectromechanical Systems or MEMS switch is becoming the preferred choice for RF switching due to its outstanding performance when compared to the conventional solid state RF switch such as p-i-n diodes or FET transistor. RF MEMS switch has very low insertion loss but high isolation and consumes minimal power in the microwatt rather than the miliwatt that solid state switches require (Goldsmith et al. 2001).

Most MEMS switches are actuated using electrostatic force, where they usually consist of a thin metal membrane suspended microns above two separated conductors. When sufficient actuation voltage is applied to the electrodes on the actuation pad beneath the membrane, the membrane is pulled down towards the conductors by electrostatic force, creating an electrical short.

One of the main factors limiting the life of a MEMS switch is dielectric charging trapped within the switch dielectric layer due to the high actuation voltage required to actuate the switch (Goldsmith et al. 2001; Yuan et al. 2006a). Previous work (Lai & Wong 2009) has shown that the dielectric charging can be reduced by applying an excitation voltage consisting of an exponentially increasing initial voltage, followed by a lesser holding voltage when the switch is ON. Another apparent and important observation made was that the MEMS switch bounces less with the new applied excitation voltage.

The MEMS switch bounces when the applied excitation voltage is too large and too long which is the case in the square-wave voltage normally used to switch the device. When voltage is applied, the electrostatic force pulls the membrane towards the conductor. As the membrane gets nearer to the conductor the electrostatic force, which is proportionally inversed to the distance between the membrane and conductors squared, increase tremendously. This large force accelerates the membrane towards the conductors, gaining momentum as it gets closer to the conductors. Finally, when the membrane hits the conductors, it rebounds due to the large incoming momentum. The bouncing continues until the velocity of the membrane slowly dissipates. The high velocity bouncing of the membrane leads to longer switch ON time and hasten the mechanical wear and tear of the switch contacts (Czaplewski et al. 2006; Sumali et al. 2007).

This paper presents a simple model to simulate the movement of the membrane when excitation voltage is applied. Using this mathematical model, the movement of the membrane under different excitation voltage waveforms was analyzed. The novel dual-pulse excitation voltage which uses exponential increasing excitation voltage in the initial stages of the switching process and a lesser constant voltage to hold the switch membrane at close position is shown to be able to reduce the membrane velocity to sufficiently just before membrane-conductors contact is achieved.

The analysis is then corroborated through experiment where the commercially available TeraVicta (now defunct) TT712-68CSP MEMS switch is shown to bounce less when the novel dual-pulse excitation is used as compared to the normally used dual-stage square-wave excitation voltage.

DIELECTRIC CHARGING & NOVEL DUAL-PULSE ACTUATION SIGNAL

A typical capacitive membrane switches generally require 30 to 50 V of actuation voltage which will form a very high electric field in a region of 100 MV m^{-1} across the dielectric layer. In this condition, it is possible for charges to tunnel across the dielectric and become trapped within the dielectric layer through a process similar to that of Frenkel-Poole emissions in thin insulating films (Yuan et al. 2006b), where the charged trapped is exponentially related to the applied electric field. When the trapped charges build up to a level that is just enough to hold the membrane to the conductors even without the actuation voltage, the switch is stuck at the ON state.

In order to improve the lifetime of the switch, a novel dual-pulse waveform as shown in Figure 1 has been proposed in (Lai & Wong 2009). The novel actuation waveform increases the actuation voltage exponentially at the beginning of the ON period, rather than a short constant pulse. This reduces the dielectric charging by effectively minimizing the time where high voltage is applied across the gap of two electrodes. Another advantage of this excitation waveform is that it can be easily produced using analog circuit implementation.

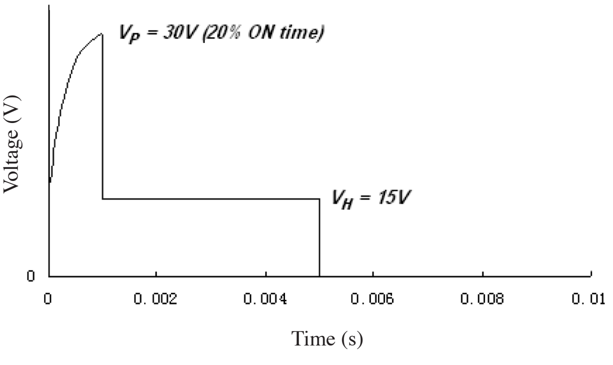

FIGURE 1. The novel dual-pulse actuation signal. The usual dual-stage square-wave excitation voltage is replaced by an exponentially increasing voltage followed by a lesser holding voltage

In the next section, the effect of the novel dual-pulse actuation voltage on the response of the membrane movement during actuation period and therefore on the switch bouncing will be analyzed.

MODELING OF MEMS SWITCH MOTION

The electrostatic force experience by the MEMS switch membrane can be ideally modeled as a parallel plate with linear restoring force as shown in Figure 2 (Sumali et al. 2007). The electrostatic force acting on the membrane is:

$$F_{electrostatic} = \frac{1\varepsilon_o AV^2}{2(g-x)^2}, \qquad (1)$$

where ε_o is the permittivity of air, A is the effective area, V is the applied voltage and g is the gap between the actuation pad and the membrane at its initial position when $V = 0$.

The dynamic motion of the membrane can be modeled as:

$$m_{eff}\frac{d^2x}{dt^2} + k_{eff}x = F_{electrostatic}, \qquad (2)$$

where m_{eff} is the effective mass of the moving membrane, K_{eff} is the effective spring constant and x is the average displacement of the membrane from its initial position towards the actuation pad. $F_{\text{electrostatic}}$ is the applied electrostatic force as in Eq. (1). The initial conditions are $x = 0$, $dx/dt = 0$ at $t = 0$. This equation is only valid for $x \leq g$.

Using this model, though not shown here, the effect of different actuation voltage waveforms on the membrane movement was investigated. Figure 3 shows the membrane movement when a typical exponential voltage is applied and removed. From the figure, the membrane moves slowly at the beginning and when the voltage is removed, the membrane slows down. Careful tuning of the timing for voltage increase and decrease could ensure that the switch arrive at the contact with minimum velocity and thus avoiding bouncing.

Presently, the tuning is done by trial-and-error but a thoroughly calculated pulse duration such as that proposed in (Sumali et al. 2007) can be carried out. However, due to the difficulties in generating the waveform and the uniqueness of each individual switch that requires different timing values, this approach is not favored in this work. On the other hand, the trial-and-error tuned values used in this work, which implementation is wholly possible and simple using analog electrical components, has proven to work for all MEMS switches. Though this is only a simple model offering a rough indication on how the membrane moves as compare to a full fledge 3D finite element model, this simple model is sufficient to demonstrate the effectiveness of the novel dual-pulse voltage in mitigating switching bounces as compared to the conventional dual-stage square-wave.

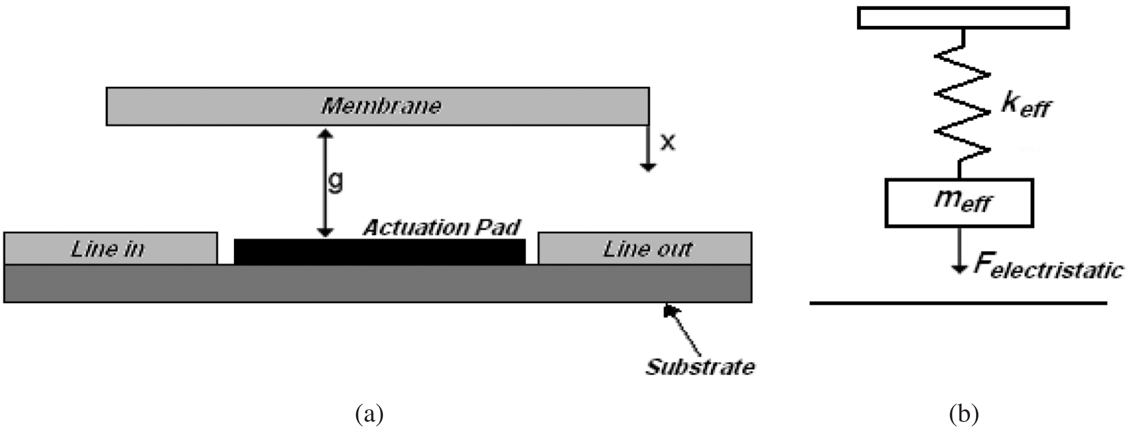

FIGURE 2. (a) A cross-section view of the MEMS switch. (b) A mechanical model of the MEMS switch with effective spring constant k_{eff}, effective mass m_{eff}, and the electrostatic force Felectrostatic

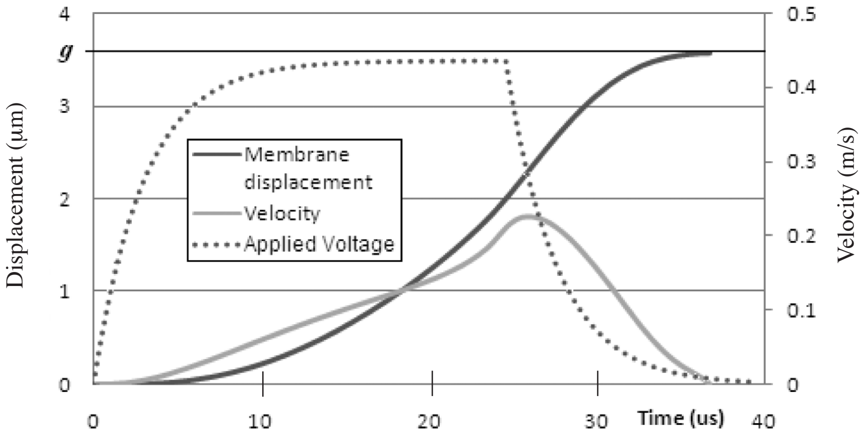

FIGURE 3. Membrane movement when an exponential voltage is applied and removed. These waveforms suggest that the novel dual-pulse actuation could mitigate the switching bounces

EXPERIMENTAL SET-UP

Figure 4 shows the experimental set-up to investigate the switching bounces. The MEMS switch used is the commercially produced TT712-68CSP SPDT RF MEMS switch fabricated by TeraVicta. The switch was actuated at 200 Hz, with 200 μs of high voltage at 68 V followed by a 55 V holding voltage for the rest of the ON time. A DC signal of 130 mV is applied to the switch input and the output is measured using oscilloscope.

From the results shown in Figure 5, it is clear that the exponentially increasing switching voltage in the novel dual-pulse technique generate less bouncing when the switch closes.

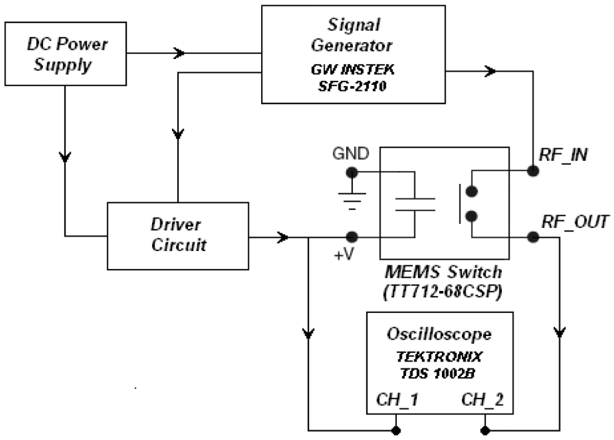

FIGURE 4. Block diagram of MEMS switch testing

CONCLUSION

A simple mass-spring model was used to study the MEMS switch membrane movement under different excitation voltage waveforms. It was found that the novel dual-pulse voltage waveform proposed previously to reduce dielectric charging can at the same time slow down the membrane as it contact is made, therefore mitigating the occurrence of switching bounces.

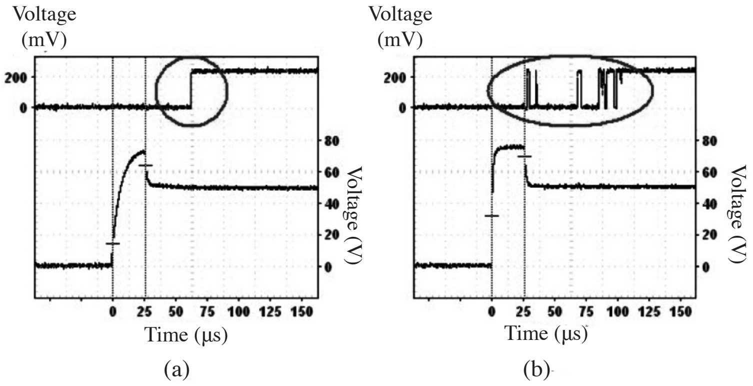

FIGURE 5. Switching transition when (a) novel dual-pulse actuation signal, (b) dual-stage square-wave actuation signal is applied

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