Novel Ultra Low Voltage Mobile Compatible RF MEMS Switch for Reconfigurable Microstrip Antenna

Moez El-Massry[1], Moataz M. Medhat[1], and Hassan Mostafa[2]
[1,2]*Electronics and Communications Engineering Department, Cairo University, Giza 12613, Egypt*
[2]*Center for Nanoelectronics and Devices, AUC and Zewail City of Science and Technology, New Cairo 11835, Egypt*
Email: {moez.elmassry@gmail.com, moataz.m.medhat@gmail.com, hmoustafa@aucegypt.edu, and hmostafa@uwaterloo.ca}

***Abstract*— This paper presents a novel (3.3 v) mobile compatible RF MEMS switch operating in the RF range (DC-6 GHz) in order to be integrated with a reconfigurable microstrip antenna. The switch is a metal series type and utilises dual supply lines controlling 4 electrostatic actuation electrodes with two cantilevers acting vice versa, the design eliminates the stiction problems, suffers low stress levels and has a very high reliability; using gold platinum contacts thus increasing switch life cycles.**

Keywords— *RF MEMS; low actuation voltage; double actuation electrodes; dual supply switching; series metal switch; electrostatic switch; reconfigurable antenna; COMSOL.*

I. INTRODUCTION

In communication systems, a concept called Software Defined Radio (SDR) is adopted to implement a certain function using software algorithms running on a PC or an embedded system. Using SDR systems would save area, power and cost of communication devices. Also the ability to reduce the cost of updating hardware systems (i.e. installed in a mobile phone) each time a new technology evolve like WIFI, 2G, 3G & LTE. SDR different Implementations require switching between standards. Thus a reconfigurable antenna is needed to switch between different standards centre frequency and bandwidth. [1]

A typical reconfigurable microstrip antenna would require a RF switch that is near to the ideal switch performance (Open Circuit OC & Short Circuit SC modes), high switching speed (typically equal to standard frame time), almost infinite life cycle, uses 3.3 volt to operate and low power (to be compatible with mobile phones).

The latter requirements specially OC and SC constrain make it impossible for the commercial solid-state devices, such as PIN diodes or FET switches to fit this application.[2]

The importance and size of the RF market have led the researchers and industry to search for alternative ways to enhance RF devices performance.[2] And so the RF Micro-Electro-Mechanical Systems (MEMS) were introduced and resulted in low insertion loss, high isolation, low power consumption (~a few µ-watts) much lower intermodulation distortion, small footprints, low cost and lightweight.[3]

In this paper we introduce a novel RF MEMS switch that is compatible with the mobile phone reconfigurable microstrip antenna application and resulted in excellent RF performance.

The rest of this paper is organized as follows: design in Section II, structure and principle of operation in Section III, selection of materials in Section IV, electromagnetic modelling in Section V, Results in Section VI and finally Conclusion in Section VII.

II. DESIGN

Designing RF MEMS switches, certain challenges and trade-offs appear. In order to actuate the switch with a low voltage (3.3 v), it's needed to build a low stiffness cantilever. But this leads to more sensitivity to vibrations and low restoring forces making the switch more subjectable to stiction forces and may fail closed. Another way to reduce the actuation voltage is to decrease the gap between the electrode and cantilever, but this decreases the isolation in return. In the proposed design a low stiffness cantilever at a low gap height is utilized to build the switch, but at the same time eliminating the disadvantages that comes with each decision.[3]

III. STRUCTURE AND PRINCIPLE OF OPERATION

A. Structure

The proposed switch consists of two almost symmetric parts, each consists of a perforated cantilever, up electrode, down electrode and RF port as shown in Figure 1

1) Cantilever

A gold cantilever of length 220 µm and width 100 µm fixed from one end with holes to reduce air damping [3] of diameter d=1 µm with separation (S) of 3 µm between adjacent holes and the air gap between cantilever and electrode (g_0) equals to 0.5 µm. The effect of the holes on the up-state capacitance is negligible if the diameter of the holes is less than 3–4g_0 [3]. The entire cantilever is capped with 0.4 µm of Silicon nitride for stress compensation, protection from the elements [3], to prevent short circuit between cantilever and electrode and also to isolate the floating contact metal from the grounded gold layer used for the electrostatic actuation. The air gap between the two cantilevers is 1 µm.

2) Electrodes

The switch uses dual supply lines, using 4 electrodes, each two electrodes are controlled together (connected to the same supply line), one to pull down the left cantilever and the other to pull up the right cantilever and the two other electrodes, one to pull up the left cantilever and the other to

978-1-5090-1367-8/16/$31.00 ©2016 IEEE

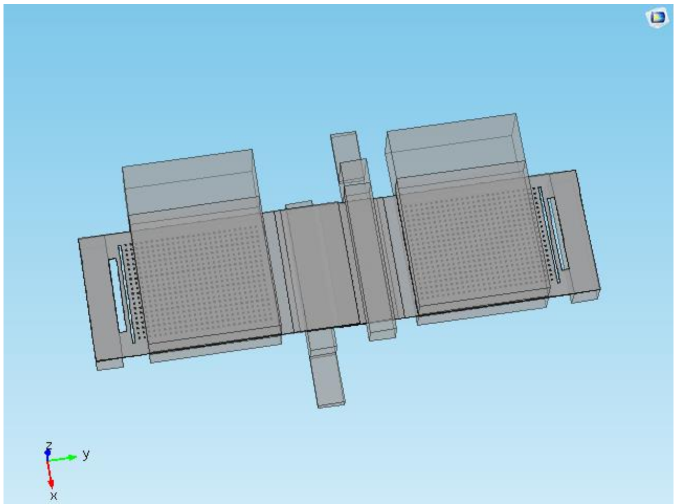

Figure 1: Tilted semi-transparent view of the switch structure (substrate not shown)

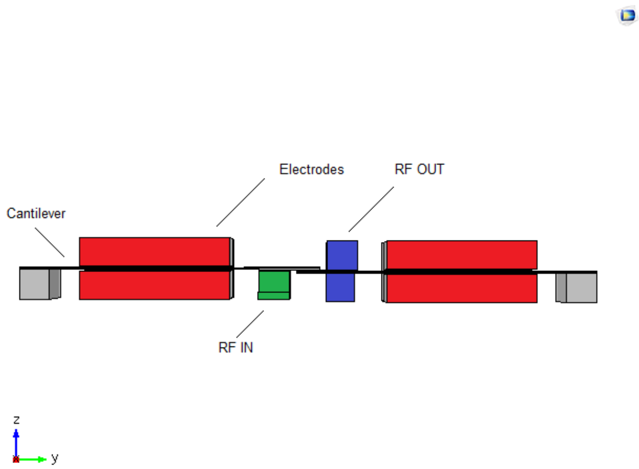

Figure 2: Side view of the switch

pull down the right cantilever as shown in Figure 2. Both up electrodes are relatively thick and properly anchored to be considered fixed thus the cantilevers are the only moving parts of the structure.

3) Anchors

5 Anchors are used for fixing, right and left cantilevers, up electrodes and RF output port.

B. Principle of Operation

The cantilever is always connected to ground and the electrodes are the controlled elements (by applying a voltage waveform). The switch operation is based on two states: the off state in which the left cantilever is pulled up and the right one is pulled down resulting in high isolation in this case. The other state is the on state in which the left cantilever is pulled down to touch the RF input port and the right is pulled up to touch the RF output port and the two cantilevers contact each other causing metal to metal contact between the two RF ports. This switching technique makes the structure less subjectable to vibrations, for a low gap height the isolation is still high (as the up state double the normal gap height and also the up-state capacitance is modeled in section IV as 3 in series capacitors which results in lower equivalent total capacitance), though structure stiffness is low thus the restoring forces are weak. The structure can return from either ON or OFF states and a faster switching speed as: each cantilever travels only half the distance and the cantilevers have a potential energy in their OFF or ON positions (mechanical restoring forces).

One of the other challenges in the operation of the switch is the failure of the contact due to the impact that occurs each time the switch is turned on, the contacts hit each other, one way to reduce this effect is to carefully choose the material of the contact. And that would be discussed in section IV. Another way to reduce the impact energy is to tailor the actuation voltage wave form as shown in Figure 3. [3]

Another reason that leads to switch failure is the dielectric charging but this is eliminated in this design as the cantilever does not touch the actuation electrodes (the displacement of the cantilever is less than the gap between the electrode and the cantilever) and also a mechanical stoppers maybe added to further prevent the cantilever from reaching the electrodes.

IV. SELECTION OF MATERIALS

The main reason of switches failure is the contact [3], so the good selection of its material is very important, typically gold is the most suitable material for the contacts, as it has good conductivity, high chemical resistance to corrosion and contamination. Despite its advantages, the gold is a soft metal, so it usually fails due to contact wear or to contact stiction.

In this paper [4] an experimental study shows that stacking thin layers of platinum between gold layers increases gold hardness. Accordingly the contact of the proposed switch is made of gold-platinum-gold layers. (This advantage of course results in a more complex fabrication process)

Note that the switch has 4 contact spots, all to be built as mentioned above; the two cantilevers and the two RF ports contact areas.

Attached in Table 1 switch main components materials and dimensions

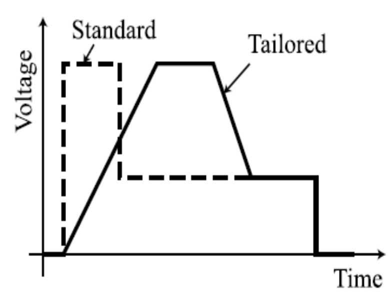

Figure 3: Actuation voltage waveform to reduce the impact energy

V. ELECTROMAGNETIC MODELING

It is a series metal to metal contact switch working on two states: the ON state and the OFF state. The structure proposed exhibits a very good performance in terms of insertion loss in the ON state and isolation in the OFF state

Table 1: Main switch structure componenets specifications

Description	**Specifications (in µm)**			
	Material	***Thickness***	***Length***	***Width***
Cantilever	Si_3Ni_4-Au-Si_3Ni_4	.4-.4-.4	220	100
Electrodes (up & down)	SiO_2-Au	7-.5	120	100
Contacts	Au-Pt-Au	.3-.003-.2	40	100
RF IN Port	Au-Pt-Au	7.3,.003,.2	40	100
RF Out Port (Cantilever)	Au-Pt-Au	6.8,.003,.2	20	100

A. *Insertion loss*

In the ON state, a metal to metal contact occurs between the two signal lines which leads to a low insertion loss compared to capacitive switching technique.

B. *Isolation*

In the OFF state, the up state capacitance is approximated as a three in series capacitors between the two signal lines:

1. Capacitance between first signal line (RF IN port) and cantilever contact.
2. Capacitance between the two cantilevers contacts.
3. Capacitance between second signal line (RF Out port) and cantilever contact.

This leads to a low up state capacitance. Leading to high isolation.

VI. RESULTS

A. *Mechanical*

In order for proper switch contact, each cantilever contact must achieve .5 µm displacement to just touch the RF ports and touch each other as well. In real life certain restrictions and mismatches appear as: a low drop in battery voltage (i.e. from 3.3 to 3.2 v), effective contact area is not as the physical contact area due to surface roughness and small mismatches in the fabrication of the switch. That's why the cantilever contact must achieve more than .5 µm to withstand voltage and fabrication variations and increase contact force to increase effective contact area.

The structure is simulated using COMSOL Multiphysics platform.

Several reductions in the model are performed to reduce the computation time and reduce hardware requirements. The structure is modelled as one cantilever, the pull down electrode and a symmetry boundary condition is made to reduce the model to half its original.

1) *Displacement*

In the shown Figure 4, the displacement of cantilever is plotted against its length, note that the contact length is 40 µm (from 160 to 200 in the figure). The results achieve the targeted displacement (.5 µm) starting from .515 to .65 µm at the tip of the cantilever.

2) Stress

In Figure 5 a maximum stress level is observed to be 38.8 MN/m^2 which is still in the safe range and that value would considerably be dropped if a rounded fillet is used to distribute the stress around the corners.

B. *RF Performance*

The RF performance calculations is done using HFSS, the structure is simulated in two positions, ON state (when the contacts be in touched), Off state (when the contacts are separated).

The structure modeled in the HFSS is reduced to two RF ports with 2 hanging metal (Au) plates as shown in Figure 6

The substrate used to simulate the RF performance is Rogers RO4350 with thickness .168 mm and dielectric constant of 3.48.

Note that in the real life operation the effective contact area is less than the physical contact area and is affected by the contact force and surface roughness. The results shown below are based on ideal contact, that is, when effective contact area=physical contact area. So the RF performance would be degraded in real life tests.

In Figure 7 and Figure 8, it's shown that the switch exhibit excellent RF performance.

Note that these simulations are considered a pilot study to give an indication of the switch RF performance, before fabrication of the switch an accurate study must be done, which includes: exact substrate that the switch would be manufactured on (i.e. Alumina), exact substrate of the reconfigurable microstrip antenna (where the switch would be integrated), full model of the switch included in HFSS (including contact pads and packaging) and taking in consideration the effective contact area.

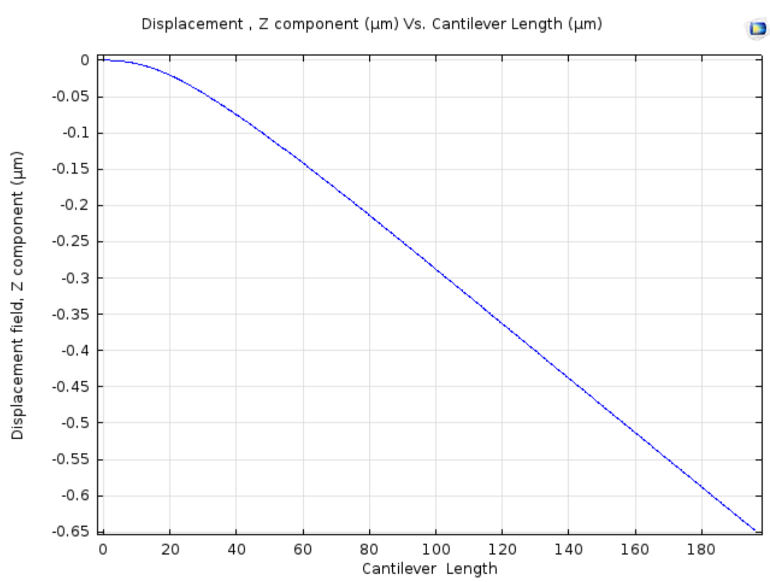

Figure 4: Cantilever Displacement (Z-Component) Vs. Cantilever length in µm on COMSOL Multiphysics Platform

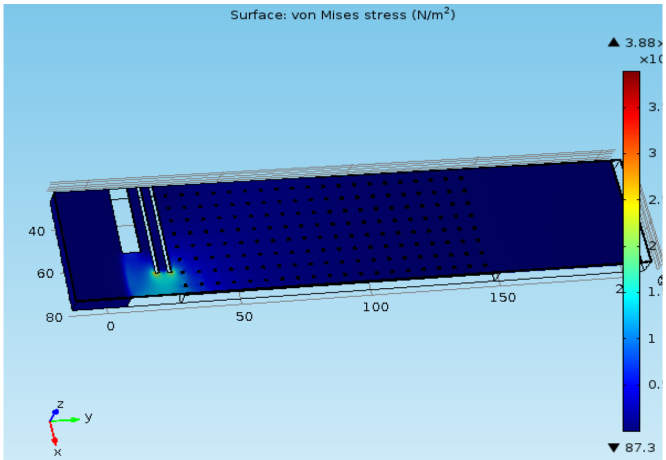

Figure 5: Stress distribution on the switch structure, half model only without the up electrode and RF port on COMSOL Multiphysics Platform

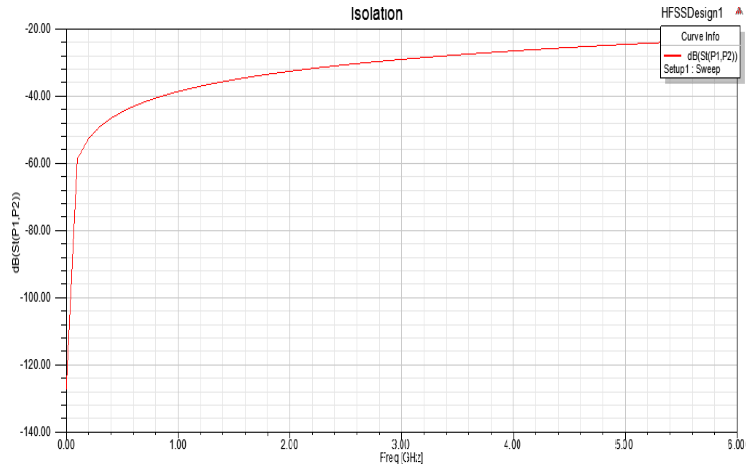

Figure 8: Isolation from DC to 6 Ghz on HFSS

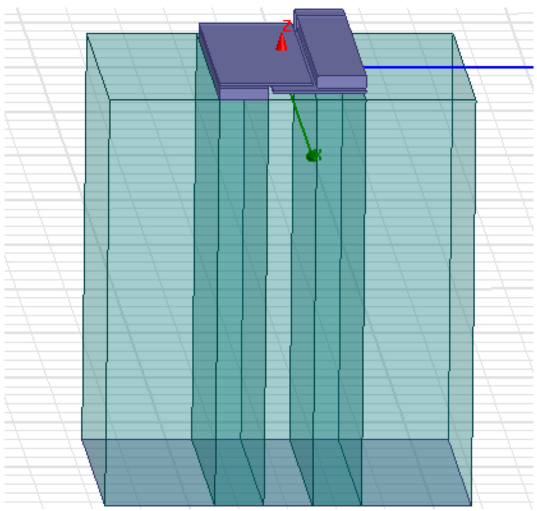

Figure 6: Simplified Structure on HFSS

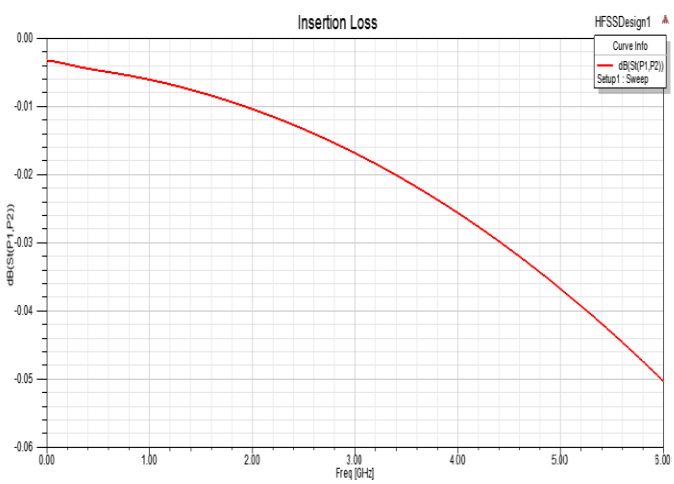

Figure 7: Insertion Loss from DC to 6 Ghz on HFSS

VII. Conclusion

The proposed design presents a novel RF MEMS switch which is voltage compatible with mobile batteries (3.3 v) operating in the range of DC-6Ghz to be integrated with a reconfigurable microstrip antenna, the switch resulted in excellent performance in terms of insertion loss (.05 dB at 6 Ghz), isolation (21 dB at 6 Ghz), low actuation voltage (3.3 v), low level of stress (< 40 MN/m^2) and is expected to achieve very good life cycles due to its contact material composition and used control voltage waveform. Of course considering latter advantages, a penalty which is the complexity of the fabrication process is paid. Future work will include optimizing this design with current fabrication processes and do real life tests to get exact and acceptable switch characteristics after fabrication.

Acknowledgment

The authors would like to thank Mostafa Zaky, Omar Sherif and Ahmed Farghaly for their support. This research was partially funded by Cairo University, ITIDA, NTRA, NSERC, Zewail City of Science and Technology, AUC, the STDF, Intel, Mentor Graphics, SRC, ASRT and MCIT.

References

[1] E. Grayver, *Implementing Software Defined Radio*. 2013.

[2] G. Patil and N. Kolhare, “A Review Paper on RF MEMS Switch for Wireless Communication,” *Ijettjournal.Org*, vol. 4, pp. 195–198, 2013.

[3] G. M. Rebeiz, *RF MEMS: Theory, Design and Technology*. 2003.

[4] V. Mulloni, B. Margesin, F. B. Kessler, R. Marcelli, G. De Angelis, C. Roma, and P. Farinelli, “Cycling reliability of RF-MEMS switches with Gold-Platinum multilayers as contact material,” *Symp. Des. Test Integr. Packag. MEMS MOEMS*, pp. 0–4, 2015.