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Simulation of an RF MEMS Double-Pole Double-Throw Switch Using Novel Seesaw Design

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ABSTRACT

The paper explores the modelling and simulation of a Radio Frequency Micro Electro-Mechanical Systems (RF MEMS) switch with the use of a novel seesaw design providing Double-Pole Double-Throw (DPDT) functionality. This optimises the capabilities of the seesaw design structure for use in mobile communications systems and devices. After researching other available seesaw designs, it was realised that an improvement could be achieved by applying additional contacts.

During its development, the DPDT switch achieved a low electrostatic actuation voltage of 14 V, providing the switch with improved compatibility for common voltage levels used in mobile devices.

The switch is a progression of existing Single-Pole Single-Throw (SPST) seesaw switches, with an additional set of upper and lower contacts at each side of the seesaw, offering DPDT switching capabilities. The length of the switch is 41 µm, which is a suitable size for fabrication and conforms to the Microscale, from 1 µm to 100 µm.

Copper Bulk General (Cu) was chosen for the pivot material on its merits of possessing good electrical conductivity and optimised flexibility and stiffness for elastic recovery.

The simulation attained a working switch design with an ‘Air-Gap’ of 1µm between the contacts, thus providing isolation while the switch is open-circuited.

KEYWORDS

DPDT, Micro Electro-Mechanical Systems, RF MEMS, Seesaw, Simulated, Switch.

1 INTRODUCTION

The aim of the research was to create a switch for mobile devices to allow switching between many different protocols or frequencies. The design also needed to have low power consumption for increased battery life and direct interfacing capabilities with mobile components without additional circuitry. Otherwise, this could cause high cost with additional power consumption and reduced reliability. With the use of RF MEMS switches, it is possible to meet all the criteria in a small space envelope.

Micro Electro-Mechanical Systems, also known as MEMS, is an emerging technology, which is finding its way into a number of applications, such as gyroscopes, sensors, digital imaging and mobile communications. MEMS can be broken down into sub-fields such as:

Micro-Opto Electro-Mechanical Systems (MOEMS)
Bio MEMS
MEMS audio
MEMS sensors
RF MEMS

MOEMS: used for optical imaging such as digital light projection, which is used on rear projection TV’s and digital projectors.

Bio MEMS: an example of this is ‘Lab-on-a-chip’ where numerous biological tests can be carried out more efficiently than traditional testing techniques. Another form of bio MEMS is a bio sensor that interfaces between biological materials and electronic devices.

MEMS Audio: used for microphonic sensors in commercial or studio microphones. It is also emerging into the mobile phone and portable device market.

MEMS Sensors: these include the detection of movement (in the x, y and z axes), heat, velocity and acceleration. They are widely used in the automotive and mobile device industries, such as car seat belts and air-bag deployment systems. Gyro sensors are used in entertainment, mobile and smart phone devices as well as stabilised platforms.

This paper concentrates on RF MEMS, which is used for communication devices such as mobile phones, mobile base-stations and satellite communications. More specifically, it addresses the use of RF MEMS switching on mobile phone devices. The goal is to operate at lower voltages for mobile devices. The device was required to fit within the MEMS scale of 1 µm – 100 µm, with ease of fabrication for future integration into microchips. To understand the characteristics of the design, the research adopted a simulation based approach. In order to provide effective results, Intellisuite software was used to model and simulate the RF MEMS seesaw switch.

Similar designs such as J. M. Cabral & A. S. Holmes [1] and K. Jongseok et al [4], have been researched, simulated and designed for Single-Pole Single-Throw (SPST) operation with similar voltages; however, the designs are limited to the number of switching contacts. This paper addresses this limitation with additional contacts on the beam structure, to provide increased functionality of the switch within the limited space envelope.

Intellisuite, created by Intellisense, was selected due to its software capabilities being able to provide comprehensive material databases, efficient Solid and Process modelling tools and an effective Thermo-Electromechanical analysis tool [3] [5].

The properties of the materials used in MEMS are crucial to the functionality of the design, since the use of inappropriate materials could cause a malfunction or damage to the device and its peripheral components. Common materials used in RF MEMS simulations are Silicon Bulk General (Si), Copper Bulk General (Cu) and Aluminium Bulk General (Al) [2] [4].

The operating principles of an RF MEMS switch relies on an electrostatic force to close the contacts within an RF circuit [Fig. 2]. This force (F) depend on the following equation:

$$F = \frac{V^2 \varepsilon A}{2d^2} \tag{1}$$

Where,

V = Supply voltage

ε = Permittivity of free space (as 1)

A = Area of the electrostatic plate

d = Distance between the electrostatic plates

F = Force between the electrostatic plates

The simulation takes into account fringe capacitance which affects the forces on the beam. Fringe capacitance should be added to the equation as a constant (C) for a more accurate result. The simulation required a voltage of 14 volts to achieve a sufficient force using a copper pivot (Fig. 5), with a pivot thickness of 0.0476 µm. The only parameters which can be changed in equation 1, to increase this force, are the area (A) and the distance (d) between the parallel plates. As the seesaw is a symmetrical design, a degree of flexibility is required to ensure that the contacts on each side of the seesaw are closed simultaneously to provide maximum contact surface area, for a low resistance [4].

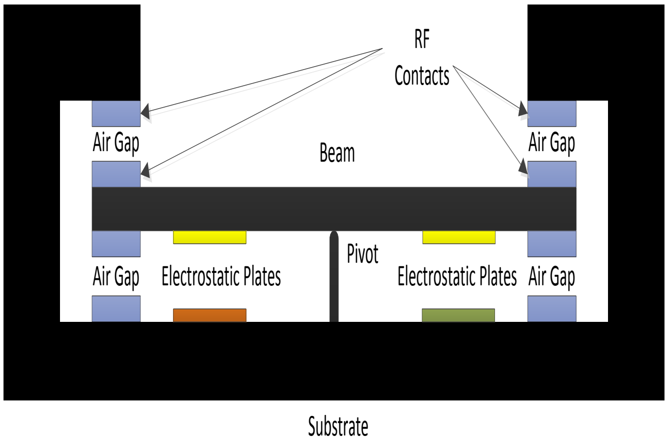

Figure 1: Cross sectional representation of the RF MEMS seesaw switch in the ‘off-state’

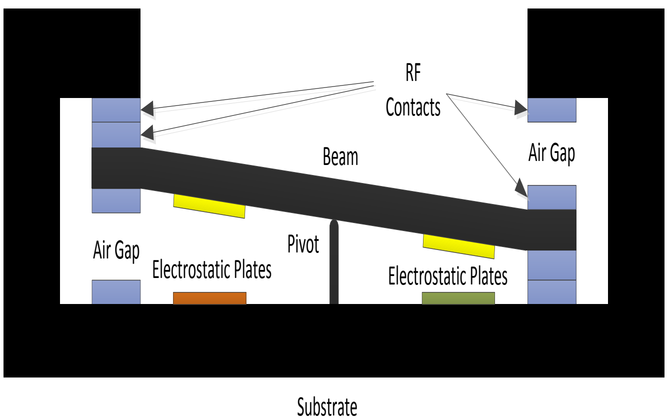

Figure 2: Cross sectional representation of the activated RF MEMS seesaw switch in the ‘on-state’

2 SUITABILITY OF THE DESIGN FOR MOBILE COMMUNICATION

The dimensions of the space envelope allow the design to be incorporated into mobile communications devices. RF MEMS provides innate advantages over conventional solid state switching materials; for example: low insertion loss, due to direct contact of low impedance materials; low power consumption, due to voltage activation rather than current activation; high isolation, due to the ‘Air-Gap’ between contacts. Compared to semiconductors, the ‘on-state’ resistance of RF MEMS is innately linear, due to its ohmic contacts. The seesaw mechanism relies on elastic recovery forces at the pivot and is controlled by two independent pull-down electrodes.

3 DESIGN

To accommodate the Microscale between 1 µm to 100 µm, a length of 41 µm was chosen to be an appropriate value, enabling the design to be large enough for fabrication and small enough for increased switching speed. The distance between the beam contacts and the fixed contacts is 1 µm when in the ‘off-state’ (see Fig. 1).

The seesaw pivot was designed using single polarity supply voltages across each pair of electrostatic plates, which are driven alternately with pulse voltage waveforms. This allows reduced external control circuitry and circuit complexity. With the use of the DPDT switch design [1] [4], the RF MEMS seesaw device accommodates two distinct radio frequencies which communicates simultaneously. By taking into account the area of the device (41 µm x 9 µm or 369 µm2), this increases functionality within the space envelope. With the use of elastic recovery, the device is set to the ‘off-state’ (see Fig. 1) without any voltage being used.

Using a minimum design size causes fabrication constraints due to the pivot being the thinnest component of the structure at a thickness of 0.0476 µm. This restricts the design for use only with advance fabrication techniques such as 32 nm fabrication. The seesaw provides an advantage during the etching process because of its simple design, as it allows the etching solution to run though the structure without being held in the gaps.

The seesaw RF MEMS enables switching between a dual input and output configuration, depending on the application. For primary use, it is configured for switching between two RX (receive) and TX (transmit) frequency bands. Other configurations may be used by employing RF mixers at the input to the seesaw RF MEMS, to provide simultaneous RX and TX for two distinct RF frequency bands. This in turn, provides a dual RX/TX switch with a total of four frequencies. The seesaw RF MEMS switch is designed to be used for mobile communications devices for common protocols such as GSM, Wi-Fi, 3G, 4G, WiMAX, Bluetooth, GPS and many other protocols. Depending on the

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capacity of the antennas, all protocols can be implemented as most of them use frequencies that are less than 5.8 GHz.

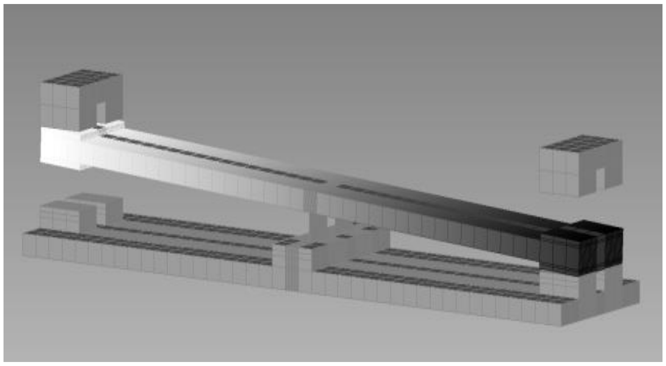

Figure 3: Activated RF MEMS seesaw switch. An early prototype simulation, of an oblique view in the 'on-state'

4 TECHNIQUES OF THE SWITCH

The RF MEMS device employs two Single-Pole Double-Throw (SPDT) switches, which are mounted at each end of a beam. The beam is balanced on a central pivot to provide a seesaw mechanism. During operation, each electrostatic plate is activated alternately to control the seesaw motion. Since the switches are mechanically linked via the beam, they are inversely synchronized with each other and may be considered as one Double-Pole Double-Throw (DPDT) switch.

The seesaw motion of the beam is controlled by two complementary, electrostatic control signals, in the form of digital voltage pulses. The electrostatic forces, generated by these pulses are used to alternately pull down each side of the seesaw to activate the switches.

5 DESIGN PROCEDURE

By looking at existing seesaw designs available, it was discovered that an improvement could be achieved by adding additional contacts. The SPST Seesaw switch [1] [4] could be improved to a DPDT switch by adding a set of upper and lower contacts to each side of the seesaw.

One of the important design requirements for the seesaw switch is the pivot, as it is necessary for the switch to be used in three dimensions. In order to allow the beam to pivot in any orientation, consideration was given to the effect of gravity.

To keep in control of the movement, it is vital that the pivot is attached to the beam, for elastic recovery.

Standard materials were used from the Intellisense materials database. Silicon Bulk General was used for all of the substrates, and Aluminium Bulk General was used for the contacts and the electrostatic plates, as shown in Table I. For the pivot, two Copper Bulk General material thicknesses were considered, in order to evaluate their properties. The elastic recovery of the materials is an important property of the pivot to enable the 'off-state' of the switching to occur.

Table I: Materials and beam specification

Materials	
Substrate	(Si) Silicon Bulk General
Pivot width 0.048 µm	(Cu) Copper Bulk General
Pivot width 0.053 µm	(Cu) Copper Bulk General and (Al) Aluminium Bulk General
Beam	(Al) Aluminium Bulk General
Contacts	(Al) Aluminium Bulk General
Electrostatic Plates	(Al) Aluminium Bulk General

Seesaw Dimensions	(µm)
Air Gap	1
Beam Length	41
Beam Height	4
Beam Width	5

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6 METHODOLOGY OF TESTING THE PARAMETERS

The technique of testing was by using Intellisense simulation software. The parameters of the simulation provide the electrostatic plates with controlled pulse-widths. If the beam does not respond to the pulse, the amplitude is increased in increments until the correct response in displacement is observed. The results are displayed, graphically, by the simulation package, and the associated data exported to an Excel spread-sheet for numerical analysis.

7 EXPERIMENTAL ANALYSIS

Fig. 4 shows that the displacement reaches 1 μm (thus enabling the contacts to close) when a voltage of 14 volts is applied across the electrostatic plates, for copper using static simulation for a ranged voltage analysis.

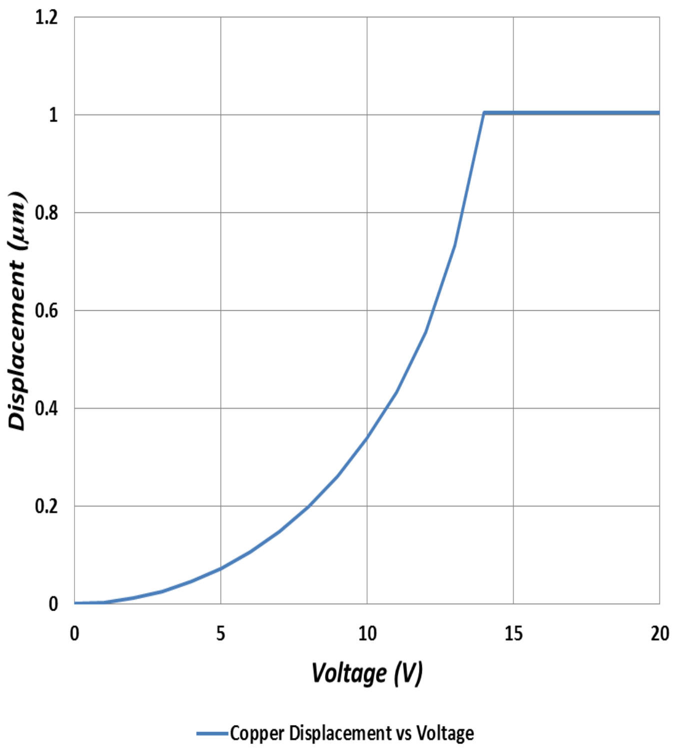

Figure 4: Displacement vs. Voltage for copper width of 0.048μm

This displacement is also shown in Fig. 5 and Fig. 6 as a function of time with pivot widths of 0.048 μm and 0.053 μm, respectively. The 0.053 μm thick pivot does not allow sufficient displacement due to its stiffness and prevents the contacts closing.

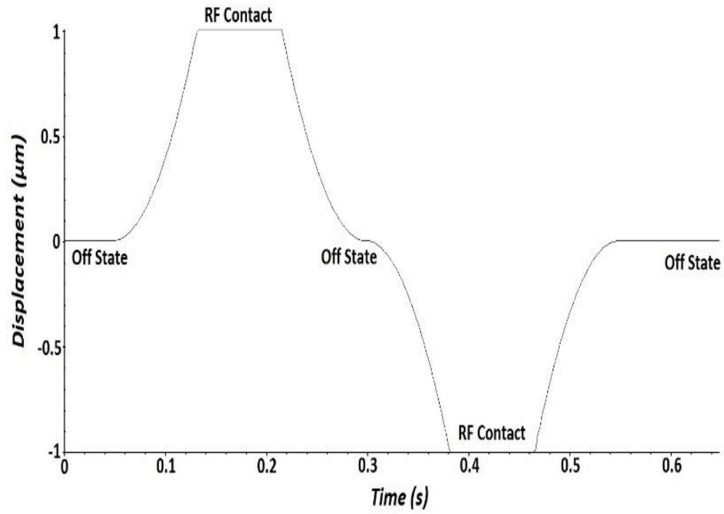

Figure 5: Displacement vs. Time using a copper pivot width of 0.048 μm

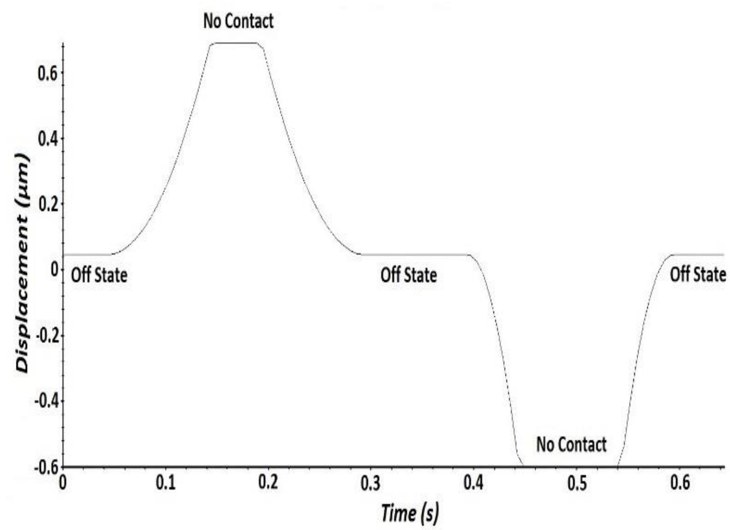

Figure 6: Displacement vs. Time using a copper pivot width of 0.053 μm

Fig. 7 also shows a graph of displacement as a function of time, using Aluminium. Although Aluminium was the same pivot thickness of 0.053 µm as the copper pivot shown in Fig. 6, it provided a displacement which reaches its target destination due to the innate flexibility of the material.

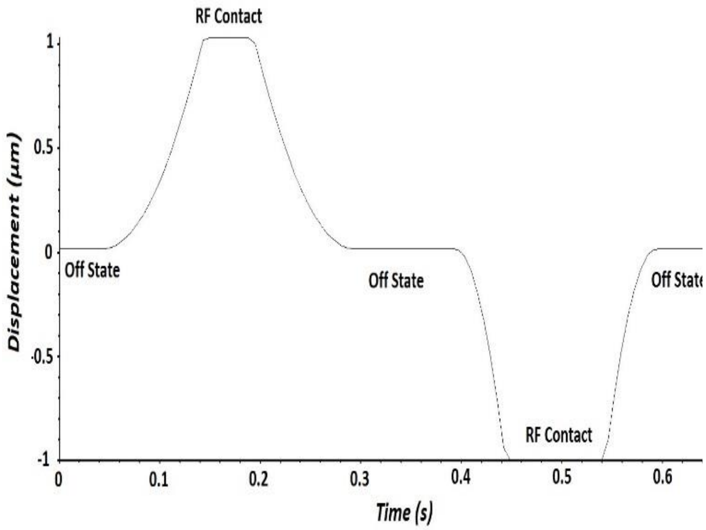

Figure 7: Displacement vs. Time using an Aluminium pivot width of 0.053 µm

A dynamic simulation was carried out using Aluminium with a pivot thickness of 0.048 µm, however, the software reported that the Aluminium pivot material exceeded boundary conditions.

A separate experiment was conducted for the thickness of the pivot. Figures 8 and 9 show von mises stress and displacement vs the thickness of the Aluminium and Copper respectively, with a pulling voltage of 3V. The experiment shows Aluminium to provide high flexibility over copper at a thickness of 0.05µm, but compromises von mises stress, which goes beyond its ultimate yield strength. However Copper provides an optimum displacement at the same thickness, with von mises stress under the yield strength, this guarantees no deformity of the material during the electrostatic pulling force.

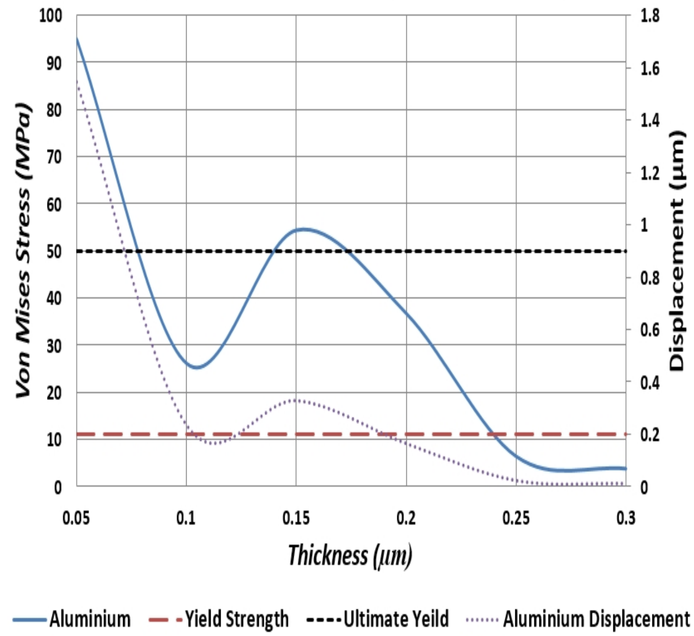

Figure 8: Von Mises Stress and Displacement vs Thickness of Aluminium pivot at 3V

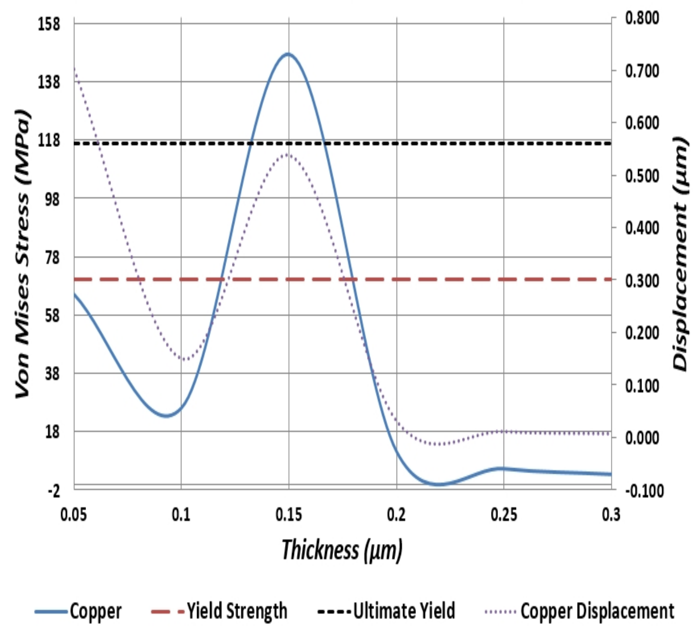

Figure 9: Von Mises Stress and Displacement vs Thickness of Copper pivot at 3V

8 CONCLUSION

After numerous iterations of the design, the electrostatic supply voltage was reduced significantly from typical values exceeding 40 volts [1] to 14 volts for Copper Bulk General. A working simulation was achieved without compromising the 'Air-Gap' between the contacts, which retained isolation when the switch is open-circuited. Alternating pulses, using dynamic analysis on Intellisuite, enabled the seesaw action to occur.

The seesaw RF MEMS switch is an improved concept over existing designs, which are limited to Single-Pole Single-Throw (SPST) switching [1] [4]. Additional contacts, in the improved design, achieve DPDT switching, at a faster rate, and require lower control voltages, due to the reduction in size.

9 ACKNOWLEDGMENT

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11 ABBREVIATIONS

3G	Third Generation
4G	Fourth Generation
BIO MEMS	Biological Micro Electro-Mechanical Systems
DC	Direct Current
DPDT	Double-Pole-Double-Throw
GHz	Giga-Hertz
GPS	Global Positioning System
GSM	Global System for Mobile Communications
MEMS	Micro Electro-Mechanical Systems
MOMEMS	Micro-Opto Electro-Mechanical Systems
ms	Milliseconds
SPST	Single-Pole-Single-Throw
RX	Receive
RF MEMS	Radio Frequency Micro Electro-Mechanical Systems
TV	Television
TX	Transmit
µm	Micrometre
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access