

Design of MEMS Switch Matrix for Satellite Payload Applications

B.Jayanthi¹, S.Shakila²UG Student, Dept. of ECE, IFET College of Engineering, Villupuram, Tamil Nadu, India¹UG Student, Dept. of ECE, IFET College of Engineering, Villupuram, Tamil Nadu, India²

ABSTRACT : An overview of the MEMS technology development and the applications is given in this paper . A special attention is paid to the RF MEMS switches .Both in series and shunt MEMS switches have been considered. It also presented a technique for modelling and design of cantilever based MEMS switch that could be used for performance in the Ku band frequency. Two designs have been developed that used more than one output. Variation in the cantilever beam design has been used to design a dual and quad output switch. The designed structure is simulated using IntelliSuite and HFSS software tools. An insertion loss of 0.8db and isolation of range 47 db for dual output and an insertion loss of around 2.2db and isolation loss in the range of 57 db for quad output structure has been observed in the Ku band frequency(12-18GHz).

KEYWORDS: High Frequency Simulator (HFSS),IntelliSuite ,MEMS,RF switch matrix, satellite payload, simulation.

I.INTRODUCTION

MicroElectroMechanical Systems (MEMS) are the integration of mechanical elements, sensors, actuators and electronics on a common substrate using integrated circuit process sequences .The electronics are fabricated using standard IC processing, micromechanical components are fabricated using compatible ‘micromachining’ processes that can selectively etch parts of the substrate, or add sections on to the top surface, leaving free standing structures. A large market already exists for micromachined sensors. In this case the microelectronic integrated circuits can be thought of as the brain of the system and micromechanical section as the ‘arms’ and ‘eyes’ of the system, sensing thermal, biological, chemical, optical and magnetic phenomena in the environment. The evolving nature of MEMS means that new applications are continually being reported. In recent years, RF and millimetre-wave MEMS have emerged from sensor based technology, they use the same fabrication techniques and have become an area of significant interest. MEMS based RF circuits could have a large impact on handset applications, because of their inherent small size and good electrical performance.

MEMS switches and other components have been very interesting area for research and development in the last few years .It is well known that they have excellent performances at microwave to mm-wave frequencies. In comparison with other types of switches (e.g. GaAs-based FET, pHEMT or PIN-diode switches), MEMS switches offer lower insertion loss and higher isolation, zero power consumption, small size and weight and very low intermodulation distortion. Of course, there are also some disadvantages of this type of switches as low switching speed (μ s range) and high actuation voltages. These disadvantages together with improving reliability, packaging and cost issues can be tolerated in many telecommunication applications, such as low-loss high isolation RF switches .In addition to the prospect of being cheaper, MEMS devices can also be more applicable than their much larger equivalents. Designing metal ball and spring accelerometers into smartphones,

Table 1: Comparison of existing switches with MEMS switches.

Characteristic	MMR	GaAs FET	PIN diode	EMR PCB	EMR SMA
Size	Small	Very small	Small	Medium	Large
Resistance	0.5Ω	1-5Ω	1-5Ω	0.1Ω	0.5Ω
Switching Power	2W CW	0.5W CW	5W CW	10W CW	35W CW
Breakdown Voltage	Low	Low	Varies	High	High
Speed	0.5-200 μs	10-100ns	10-100ns	0.8-10ms	1-40ms
Life Cycle	100 million+	Billion	Billion	0.5-5 million	0.1-2 million
Frequency	Up to 70GHz	Up to 4GHz	Up to 20GHz	Up to 5GHz	Up to 40GHz
Ins. Loss max (dB)	0.25	0.5	0.5	0.4	0.1
Isolation min (dB)	40	30	30	40	80
3rd Order Harmonics	Very good	Poor	Poor	Good	Very good
Power Consumption	Very low	Low	Low	Medium	High
Drive Voltage	5V, 28V, 48V	3V, 5V	3V, 5V	5V, 12V	12V, 28V
Integration Capability	Very good	Very good	Very good	Average	Difficult
Cost – SPDT type	8.00-20.00\$	0.50-4.50\$	0.90-8.00\$	0.85-12.00\$	38-90\$

cameras, airbag control units, or similarly small sized devices would be impractical at best; by reducing device size by several orders of magnitude, MEMS can be used in applications where a conventional sensor would be far too large.

The main research areas of MEMS include RFMEMS switches, RF MEMS passives, micro machined transmission lines, Micro machined antennas, MEMS resonators, MEMS mirrors and FBAR(Film Bulk Acoustic Resonators) devices. Amongst these devices RF mems switches is extensively used component. Enhanced performance can be achieved from conventionally used mechanical and waveguide switches. but these switches bulky and consume very high power when they are used in large numbers as switch matrices. Moreover these have low switching speed. These shortcomings are overcome by semiconductor switches but they have poor RF performance. The major benefits of RF MEMS switches are good RF performance, light weight, high speed and very low power consumption.

II. SERIES SWITCHES

MEMS switches are devices which operation is based on the use of mechanical movement to achieve a short circuit or an open circuit in the RF transmission line. Electrostatic, magnetostatic, piezoelectric, or thermal designs can be used to obtain required forces for the mechanical movement, but up to date only electrostatic type switches have been used. The advantages of MEMS switches over other traditional switches have already been discussed. However, there are also some problems related to RF MEMS switches: low speed, power handling, high actuation voltage, reliability, packaging (MEMS switches need to be packaged in hermetic or near-hermetic seals and packaging costs are high), cost (these switches have potential of very low cost manufacturing, but adding cost of packaging and high-voltage drive chip price is significantly increased). The main applications of MEMS switches are: radar systems for defence applications, automotive radars, satellite communication systems, wireless communication systems, instrumentation systems etc. The actuation mechanism is achieved using an electrostatic force between the top and bottom electrodes, and is given by

$$F = \frac{QE}{2} = \frac{CVE}{2} = \frac{AV^2}{(1+t_d\epsilon_r)^2}$$

where V, g, and C are the voltage, gap distance, and capacitance between the lower and upper electrodes, respectively, and A is the area of the electrode. The bottom electrode is often covered by a dielectric layer (thickness t_d and a relative dielectric constant ϵ_r) to prevent a short-circuit between the top and bottom plates.

Equation (2) presents a widely cited formula for calculating the required DC actuation voltage, i.e. pull-in voltage of fixed-fixed beams or air bridges

$$V_p \approx \sqrt{\frac{8K_z g_0^3}{27\epsilon_0 A}} \quad (2)$$

K_z is the equivalent spring constant of the moving structure in the direction of desired motion (typically the z-direction), g_0 is the gap between the switch and the actuation electrode, ϵ_0 is the free-space permittivity, and A is the switch area where the electrostatic force is applied. Equation (2) implies that there are several ways that may decrease the required actuation voltage. For example, reducing g_0 is one way, but it affects the high-frequency off-state switch performance by comprising the switch isolation or insertion loss. A second approach in lowering actuation voltage is by increasing the actuation area A .

$|S_{21}|^2 = 4\omega^2 C_u^2 Z_0^2$ where C_u is the up state capacitance and Z_0 the transmission line impedance.

$|S_{21}|^2 = 1 - R_S/Z_0$

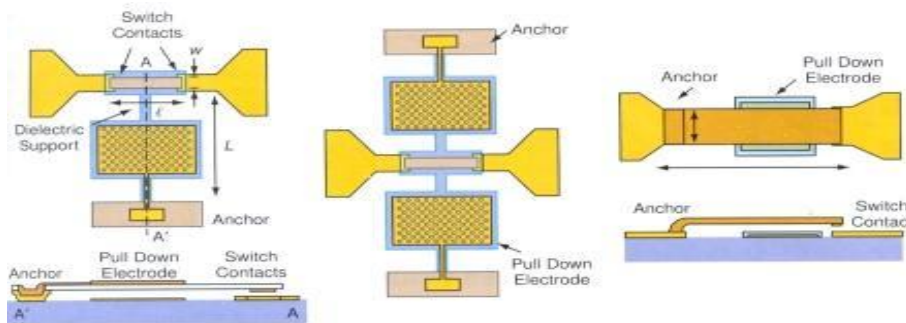


Fig 1. Series switches

III .SHUNT CAPACITIVE SWITCHES

There are different types of MEMS capacitive switches, which provide different performances. One example of those switches is given in fig. And usually shunt switches is based on fixed-fixed beam design. The anchors are connected to the CPW ground plane, and the membrane is grounded. The centre electrode provides the electrostatic actuation and the RF capacitance between the transmission line and the ground. When the switch is in the up-state it provides low capacitance and it does not affect the signal in transmission line. The up state capacitance is

$$|S_{11}|^2 = \frac{\omega^2 C_u^2 Z_0^4}{4}$$

Where C_u is the up state capacitance of the switch. The down state isolation is

$$|S_{21}|^2 = \begin{cases} \frac{4R_s^2}{Z_0^2} & , f = 0 \\ \frac{4\omega^2 L^2}{Z^2} & , f \gg f_0 \end{cases}$$

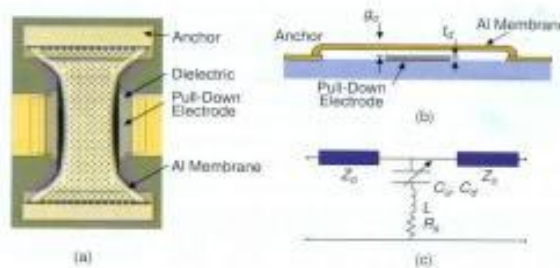


Fig 2. Shunt capacitive switches

IV. DUAL AND QUAD OUTPUT SWITCHES

The basics of MEMS , different types of switch configuration based on the actuation mechanism and fabrication. Out of various actuation mechanisms electrostatic actuation is considered to be the best. The two basic configuration of RF MEMS switches are series contact and shunt capacitive switches. The major factor affecting the reliability of the switches is the variation of the actuation voltage with spring constant of the cantilever beam and mechanical modelling. This paper reveals a novel concept for 3D RF MEMS switches based on integrating MEMS actuators with wave guide structures. Prototype units for both C-type and SPST switches gave a good return loss of -20db and a high isolation of 35-40db over a band of interest. The overall focus of this paper has been on multiport switching and switch matrices for redundancy and signal routing in satellite communication. High performance RF MEMS switch with low actuation voltage and high isolation and low insertion loss was designed and simulated through IntelliSuite . Besides this few parameters could be concluded while optimizing the RF MEMS switch design such that the height of the air gap has negligible effect on the maximum displacement in each direction, larger air gap will increase the value of the actuation voltage and a design of support beam will decrease the value of actuation voltage during operation.

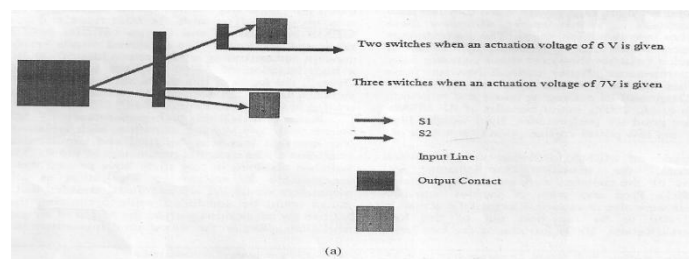


Fig 3. dual output switches

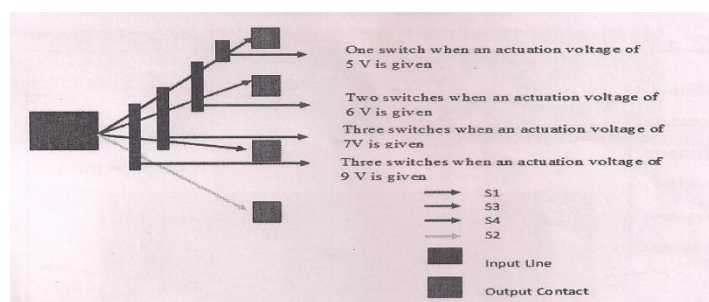


Fig 4. Quad output switches.

The cantilever switch shown in the above figure consists of top and bottom electrode separated by an air gap. When an actuation voltage is applied between these two electrodes the electro static force generated will pull the cantilever beams together thus closing the airgap in the transmission line and completing the path.

V. SWITCH DESIGN

The basic cantilever switch consists of silicon substrate on top and bottom lies the electrode. An airgap separates the top and bottom electrode. The materials used for the top and bottom electrode may be a good conducting material like aluminium or gold. On simulation it was found that an actuation voltage of 30V was needed which was quite high. From (3) that the actuation voltage is directly proportional to the spring constant of the beam which can be varied by varying the dimension and the materials used. By the young's modulus and the poisson ratio of the beam can be determined as, further the actuation voltage is a function of spring constant and is expressed as,

$$V = \sqrt{\frac{8k}{27\epsilon W w}} d^2$$

Where d-the height of airgap

W-the width of pull down electrode

w-the width of the beam

K-spring constant.

It is evident that by modifying the spring constant and the beam design and the materials used the actuation voltage is decreased which is suitable for the satellite payload.

Table 2: Comparison of theoretical and simulated outputs

Airgap (μm)	Theoretical calculation of actuation voltage (v)	Simulated of actuation voltage (v)
0.8	6.77	5.0
1	9.46	7.0
1.4	12.675	9.0

A range of voltages from 2V to 14V was applied to the above structure with an airgap of 0.8μm and it was found that the actuation voltage was 5V which was much less than the basic cantilever structure. The theoretical value of airgap was given and the values is given in table 1.

$$K = 32Ew \left(\frac{t}{i}\right)^3 \left(\frac{27}{49}\right)^{8\sigma} (l - v) w \left(\frac{t}{i}\right)$$

where E is the young's modulus and says the dependence of spring constant on the material of the beam. The dimensions also say the dependence of spring constant. The second term in the above expression takes into account biaxial residual stress and poisson's ratio. This is valid for the beam where both the ends are fixed. Therefore the expression is modified as

$$k = \left(\frac{2}{3}\right) Ew \left(\frac{t}{i}\right)^3$$

The structure of single input to dual output switch is shown in Fig5. The dimension of the beam and the material used was modified in such a that each switch operates under different actuation voltage. The blue strip represents the

common RF line input. the design of each layer is shown in Fig.4. IntelliSuite was used to build the 3D model and simulated to find the variation of the actuation voltage. This same concept extended to four output structure also. The structure of four output structure is shown in Fig.6. The blue strip indicated the common RF input line.

VI. DIMENSION OF QUAD OUTPUT STRUCTURE:

- Total length=400µm
- Total width=300µm
- Length of the switch=180µm
- Width of the switch=120µm
- Width of the RF line=80µm
- Height of the airgap=0.5µm

The structure composed of several layers this is shown in Fig.6&7. Layer 0 is the silicon substrate. Layer 1 in green represents the silicon nitride on top of which lies the electrode and the common RF line which is composed of conducting materials like aluminium and gold. Layer 4 and Layer 5 form the cantilever beam which can be altered.

VII. RESULTS AND DISCUSSION

Analysis on actuation voltage:

The designed structure were simulated using thermoelctro mechanical module in Intellisuite. the variation of displacement with the actuation voltage was studied. for the structure in Fig2. An air gap of 1.8µm neede an actuation voltage of 9.5 and 11V, respectively for both S1 and S2. At an voltage less than 9.5V both the switches are OFF at 9.5V switch1 is ON and switch 2 is OFF at voltage further increasing the voltage beyond 11V both the switches are ON. is depicted in fig.9 the working range of the switches has been summarized in table2.

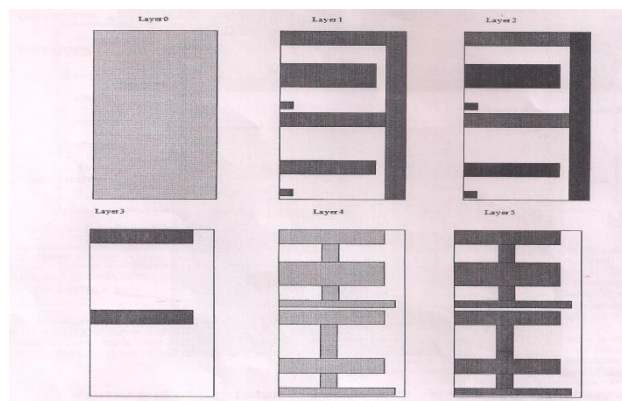


Fig 8: design of single input dual output structure.

Table 3: summary of operation of dual output switches

Actuation Voltage (v)	S1 (μm)	S2 (μm)
9.5	1.8*	1.47
11	2.59*	1.88*

*Represents ON position

Actuation Voltage (V)	S1 (μm)	S2 (μm)	S3 (μm)	S4 (μm)
5	0.67*	0.18	0.42	0.36
6	1.01*	0.27	0.73*	0.43
7	1.05*	0.28	0.76*	0.67*
9	1.74*	0.57*	1.26*	1.11*

*Represents ON position

The above explanation holds good for the case of quad output switches the actuation voltage of switches are S1, S2, S3, S4 is 5V, 6V, 7V, 9V respectively. When the voltage is less than 5V all the switches are in OFF condition. When the voltage is greater than 9V all the switches are in ON condition.

RF performance:

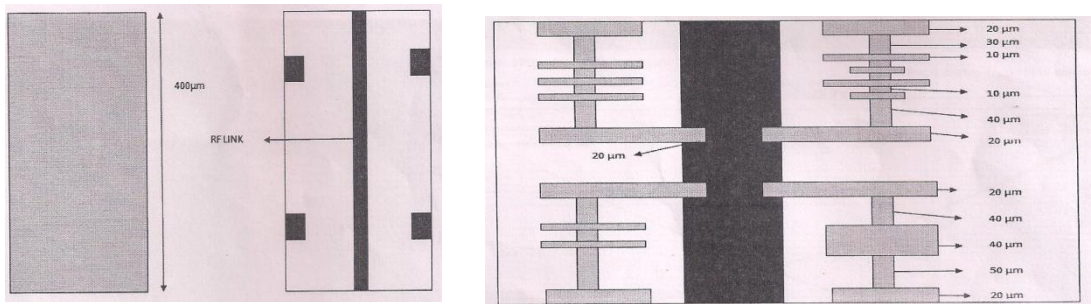


Fig 9: Design of single input quad output structure.

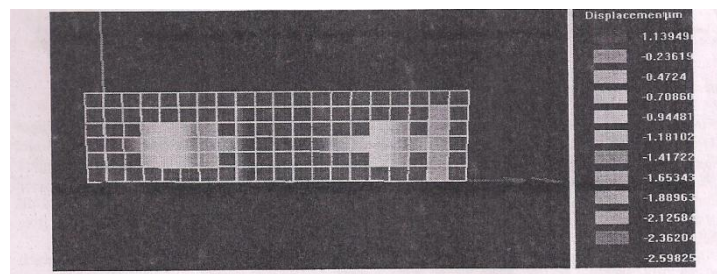


Fig 10. Implementation in HFSS.

RF parameter is essential for the MEMS switch as it will apply in high frequency. The switch is configured to connect to ports in ON state the input and output states are connected in OFF state it is disconnected. Both insertion loss and isolation values can be obtained from the transmission coefficient, in decibels, between the input and output of transmission line. There should be low insertion loss and isolation loss represents there is low coupling between the input and output. The performance was found using HFSS in Ku band of frequency. For dual output the insertion loss was 0.8 db, while an isolation loss of 47db has been observed. For quad output it is 2.2db insertion loss and an isolation of 57db.

VIII .CONCLUSION

A novel cantilever beam MEMS switch has been designed and simulated that facilitates single input dual output and quad output operation. The dual output and quad designs have demonstrated good RF performance in Ku band of frequency . The dual output structure has exhibited insertion loss of less than 0.8db and isolation of 47 db while the same values for the quad output structure are 2.2 and 57db. The actuation voltage of the individual switches in both the structures is less than 11V. The performance of the switch indicates that it is suitable for application in a satellite payload . Further it is expected to design switch matrices which could be used in satellite payload application.

Table 4 : Simulated results

Switch cell type	Insertion loss (dB)	Isolation loss (dB)	Operating frequency (GHz)
C Type (Schaffner <i>et al.</i> , 2003)	0.5	25	0-25
R Type (Daneshmand <i>et al.</i> , 2006)	1	20	0-20
T Type (Chan <i>et al.</i> , 2008)	1	30	0-20
Cross bar (Chan <i>et al.</i> , 2008)	0.5	35	0-20
This work* Dual Output	0.8	47	0-20
Quad Output	2.2	57	0-20

* Simulated Results

REFERENCES

1. J. B. Muldavin, G. M. Rebeiz, "High-Isolation Inductively-Tuned X-Band MEMS Shunt Switches", *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, Massachusetts, pp. 169-172, USA, June 2000.
2. J. Y. Qian, G. P. Li, F. De Flaviis, "A Parametric Model of MEMS Capacitive Switch Operating at Microwave Frequencies", *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, Massachusetts, pp. 1229-1232, USA, June 2000.
3. J. B. Muldavin, G. M. Rebeiz, "30 GHz Tuned MEMS Switches", *1999 IEEE MTT-S Int. Microwave Symp. Dig.*, Anaheim, CA, pp. 1511-1514, USA, June 1999.
4. J. Y. Park, G. H. Kim, K. W. Chung, J. U. Bu, "Fully Integrated Micromachined Capacitive Switches for RF Applications", *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, Massachusetts, pp. 283-286, USA, June 2000.
5. D. Peroulis, S. Pacheco, K. Sarabandi, L. P.B. Katehi, "MEMS Devices for High Isolation Switching and Tunable Filtering", *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, Massachusetts, pp. 1217-1220, USA, June 2000.
6. H. J. De Los Santos, *Introduction to Microelectromechanical (MEM) Microwave Systems*, Artech House, Boston - London, 1999.
7. CST MicroWave Studio, *Version 4.1*, 2003.
8. Aplac, *Version 7.80*, 2002.
9. G. M. Rebeiz, J. B. Muldavin, "RF MEMS Switches and Switch Circuits", *IEEE Microwave Magazine*, Vol. 2, No. 4, pp. 59-71, December 2001.
10. T. Campbell, "MEMS Switch Technology Approaches the "Ideal Switch"", *Applied Microwave & Wireless*, Vol. 13, No. 5, pp. 100-107, May 2001.
11. S. Cass, "Large Jobs for Little Devices", *IEEE Spectrum*, Vol. 38, No. 1, pp. 72-73, January 2001.