

Optimized Architectures for Cantilevered Beam RF MEMS Switch

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Abstract— The electronic and mechanical characteristic of RF MEMS switches depends significantly on the structure of the switch. This article proposes new optimized architectures for cantilevered beam RF MEMS switches. The modeling approach is based on nodal analysis to solve coupled non-linear differential equations that describe the electromechanical system using Matlab toolbox for MEMS called SUGAR. The model used SUGAR to calculate; netlist of a cantilever beam subjected to an external force, Static analysis of deflection, display of structure and displacement values. The switching voltage of mentioned construction for MEMS switches is determined and analyzed at different geometrical parameters. The results investigate the geometrical parameters of the five MEMS architectures that control the switching voltage to achieve a maximum frequency response for the switch at lower driving voltage. The structure of the proposed cantilever type MEMS switches indicates that the switch can operate with driving voltage of 4.2 V with maximum switching frequency of 6.65 GHz.

Keywords— MEMS Switches, Microwave Phase shifters

I. INTRODUCTION

The use of electrostatic MEMS switches is attractive because of its advantages, such as very low power consumption and high isolation. However, MEMS switches have their share of problems, such as, high driving voltage, relatively low speed and low power handling. In recent years many efforts have been done to solve these problems, e.g., decreasing the air gap between the fixed plate and the beam [1-10]. Another method is to increase the electrostatic area or decreasing the spring constant of the beam [11]. The most omnipresent structures in the MEMS area are cantilever beams. These cantilevers are generally made out of silicon (Si), silicon nitride (SiN) or polymers [12]. MEMS technology has generated a significant amount of interest in the government and business sectors. This interest is happening due to the potential performance and cost advantages with micro-scale devices fabricated based on a silicon processing technology [14]. Many previous researches focus on RF MEMS switch, which presents a good performance at microwave frequency. This result an increasing use of RF MEMS switches for telecommunication purpose in the last ten years. However, there are still some available improvement in RF MEMS switch to enhance its performance such as

switching speed, loss, isolation value and the consumption of actuation voltage. This paper purposes is to improve the performance of RF MEMS series switch for better performance in terms of voltage actuation, loss and isolation. A low voltage of MEMS switch is desirable because it will make it more convenient to be embedded into real applications [13]. In this paper we try to design new geometrical structure, parameters of the electrostatic area of the gap that control the switching voltage to achieve a maximum frequency response for the switch at lower driving voltage and beams length.

II. NODAL ANALYSIS APPROACH

SUGAR [14], is a collection of Matlab routines which implements a nodal analysis to Micro Electro-Mechanical Systems (MEMS) simulation. A wide variety of planner electromechanical systems can be simulated. SUGAR creates individual stiffness, mass, and damping matrices for each structural block. The equation of motion describing the dynamics of the entire system can be expressed in a familiar form [5],

$$M.\ddot{q} + C.\dot{q} + K.q = F \quad (1)$$

Where M, C, K are the mass, damping, and stiffness matrices respectively. The nodal displacement q is

$$\{q\} = \{x_1, y_1, \theta_1, \dots, x_N, y_N, \theta_N\}$$

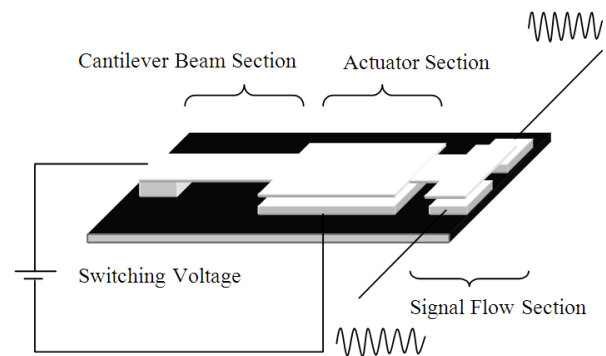


Figure .1. The Structure of Cantilever type MEMS switch.

The q Matrix is 1x3N column vector and N is the number of nodes. F is the applied driving force.

A. Static Analysis

Static analysis attempts to find the equilibrium state for MEMS device with coupled energy domains [6]. These domains include mechanical forces, electrostatic forces due to a voltage from a circuit, forces due to thermal stress ...etc. The equilibrium position due to constant mechanical forces and voltages are calculated according to [7],

$$K.q - F = 0 \quad (2)$$

Solving equation (2) using Newton Raphson method, the initial guess $\{q_0\}$ is taken which is sufficiently near a root, then approaches the solution by iteration. Iteration proceeds until certain tolerance is satisfied,

$$\|\{q_{n+1}\} - \{q_n\}\| < \xi$$

Where ξ is the tolerance.

B. Steady State Analysis

In the steady state analysis the following equation is solved [18-22],

$$M.\ddot{q} + C.\dot{q} + K.q = a_i \cos(\omega t + \beta_i) \quad (3)$$

where

$$a_i \cos(\omega t + \beta_i)$$

is the sinusoidal external excitation. The solution of this equation is the real part of the following complex equation,

$$M.\ddot{z} + C.\dot{z} + K.z = \beta_i e^{j\omega t} \quad (4)$$

where

$$\beta_i = a_i (\cos \beta_i + j \sin \beta_i)$$

A particular solution of equation (4) is,

$$Z = \{V\} e^{j\omega t} \quad (5)$$

Where V is a complex vector that contains the magnitude information of the system response. Substituting equation (5) into (4) to get,

$$-\omega^2.M + j.\omega C + K.V = \{B\} \quad (6)$$

Once equation (6) is solved, the magnitude and phase response for each node is evaluated. The steady state vibration of the structure can be investigated.

C. The Switch Modeling

The cantilever type MEMS switch shown in figure 1 is modeled as anchor, cantilever beam section, actuator section, signal flow section, and two isolated beams for signal line. The switching beam is electrically isolated from the upper

plate of the gap. The structure of the cantilever type MEMS switch is simulated under applied voltage V between the two plates of the electrostatic gap. The displacement of the switching beam at node off the gap is calculated. The voltage is tuned to satisfy the switching-on between the two signal line beams. This voltage is called threshold voltage V_{th} . It is calculated at different selected geometrical parameters of the structure. Figure 2 shows the reflection of choice of different beam lengths and widths on the threshold voltage. The results show that at low values of beam widths the threshold voltage is lower than that at higher values, but almost the threshold voltage decreases with increasing the beam length. Figure 3 shows the reflection of choice of different beam lengths and widths on the threshold voltage, from figure 3, it is notice that the threshold voltage is increased more than double of its value at the highest values of beam thickness. Thus we propose the lower values of beam thickness to decrease the threshold voltage required for switching on. Figure 4 presents the effect of electrostatic gap length switch.

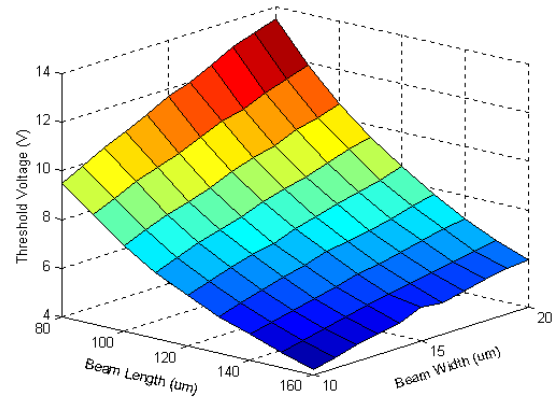


Figure 2. The threshold voltage vs. beam length at different values of beam widths.

It is useful to use the lower values of air gap thickness and higher values of gap length to satisfy a lower threshold voltage V_{th} . Figure 5 shows the first architecture of the RF MEMS switch. When a certain amount of voltage is applied between gap and the cantilever, electrostatic force is created and will pull the cantilever down from the arm of anchor and complete the RF signal path at down-state. Short circuit occurred between two terminals of RF transmission line has made the RF signal can pass through and transmitted. The cantilever is then back to the original position once the voltage supply is removed and hence disconnects the transmission of RF signals. The material and geometrical parameters of the first architecture is illustrated in table 1.

The second architecture shown in Figure 6, use two supported anchors extend two cantilever beams connected with the actuator area. The second architecture dimension is illustrated in table 2. The schematic in Figure 7 shows the third architecture with two parallel beams and two gabs and its parameters illustrated in table 3. The fourth architecture is shown in Figure 8 with two beams and one gab and its

parameters illustrated in table 4. Figure 9 shows the fifth architecture with one main beam and six gabs and its parameters illustrated in table 5.

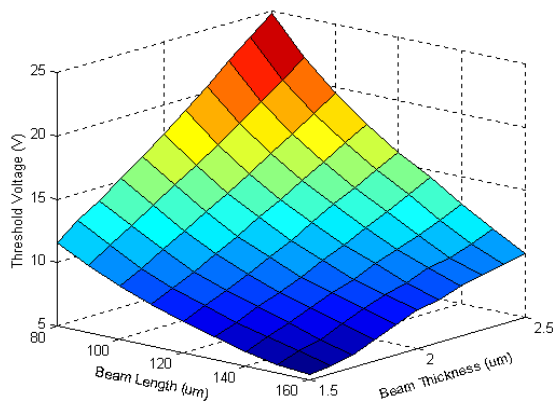


Figure 3. The threshold voltage vs. beam length at different values of beam thickness.

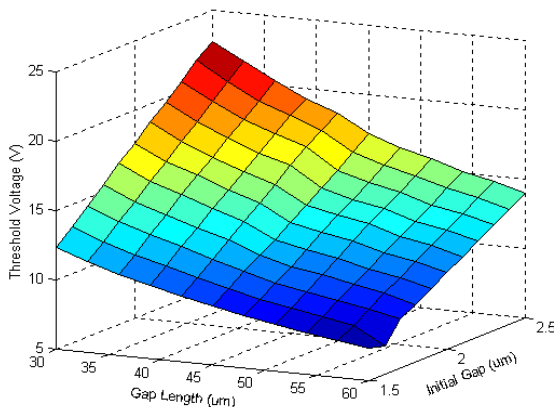


Figure 4. The threshold voltage vs. gap length at different values of air gap thickness.

III. SIMULATION RESULTS

Five cantilever RF MEMS switches architectures are designed, simulated and optimized for minimum driving voltage while maintain maximum switching frequency. Table (6) illustrate the architectures behavior demonstrate the driving voltage, displacement, frequency, and the actuator electrostatic area. The first architecture record the minimum driving voltage of 4.2V with 1.03 GHz switching frequency. The fourth architecture record a maximum frequency response of 6.65 GHz with 6.6 V of the driving voltage. These two architectures are suitable for radar antenna applications.

TABLE 1. MATERIAL AND GEOMETRICAL PARAMETERS FOR CANTILEVER TYPE MEMS SWITCH

Parameter	Value
Material	Polysilicon
Poisson's ratio	0.3
Young's modulus	1.65E11 N/m ²

Sheet resistance	20 Ω/
Anchor	
Length	20 μm
Width	30 μm
Thickness	8 μm
Beam	
Length (L)	80 : 160 μm
Width (w)	15 μm
Thickness (h)	1.5 : 2.5 μm
Gap	
Length (G _L)	30 : 60 μm
Width (W _G)	30 μm
Upper plate thick.	1.5 μm
Lower plate thick.	1.5 μm
Air gap thick.	1.5 : 2.5 μm
Switching beam	
Length (L _S)	75 μm
Width	30 μm
Thickness	1.5 μm
Signal line beam	
Length	30 μm
Width	90 μm
Thickness	7 μm

TABLE 2. THE SECOND ARCHITECTURE PARAMETERS

Parameter	Beam Angle	gap Length	gap width	Beam width	Extended Beam length
Value	45°	50 μm	45 μm	15 μm	45 μm

TABLE 3. THE THIRD ARCHITECTURE PARAMETERS

Parameter	Beam Angle	gap Length	gap width	Beam width	Extended Beam length
Value	90°	45 μm	45 μm	10 μm	60 μm

TABLE 4. THE FOURTH ARCHITECTURE PARAMETERS

Parameter	Beam Angle	gap Length	gap width	Beam width	Extended Beam length
Value	45°	45 μm	45 μm	10 μm	100 μm

TABLE 5. THE FIFTH ARCHITECTURE PARAMETERS

Parameter	Beam Angle	gap Length	gap width	Beam width	Extended Beam length
Value	90°	100 μm	100 μm	10 μm	100 μm

The simulation results compared to previous MEMS switches design and show acceptable results.

IV. CONCLUSION

This paper investigates the geometrical parameters of the five MEMS architectures that control the switching voltage to achieve a maximum frequency response for the switch at

lower driving voltage. The structure of the proposed cantilever type MEMS switches indicates that the switch can operate with driving voltage of 4.2 V with maximum switching frequency of 6.65 GHz. These two architectures are suitable for radar antenna applications. The simulation results compared to previous MEMS switches design and show acceptable results.

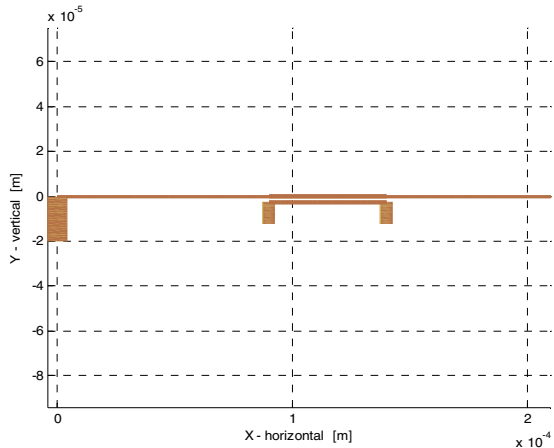


Figure 5. Model 1 of the cantilever type MEMS switch.

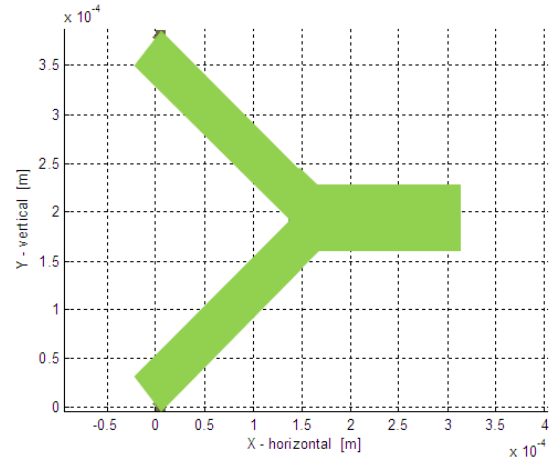


Figure 6. Model 2 of the cantilever type MEMS switch.

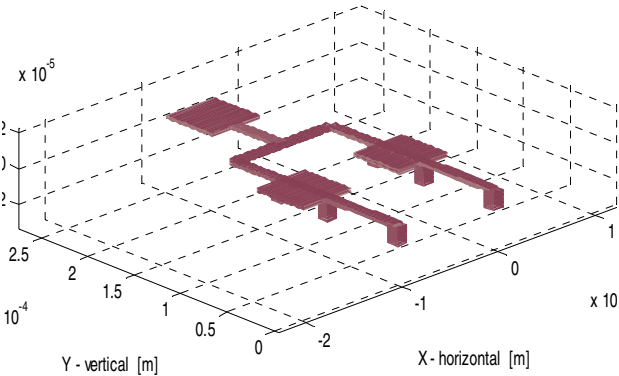


Figure 7. Model 3 of the cantilever type MEMS switch.

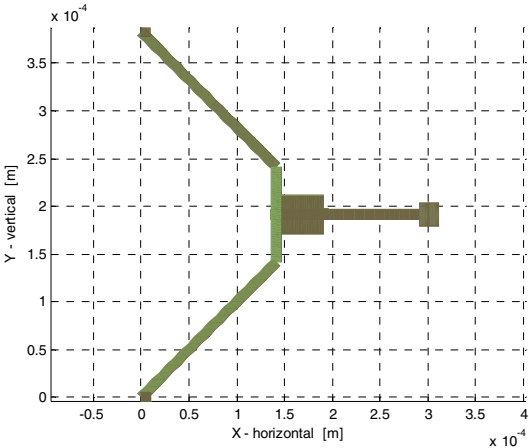


Figure 8. Model 4 of the cantilever type MEMS switch.

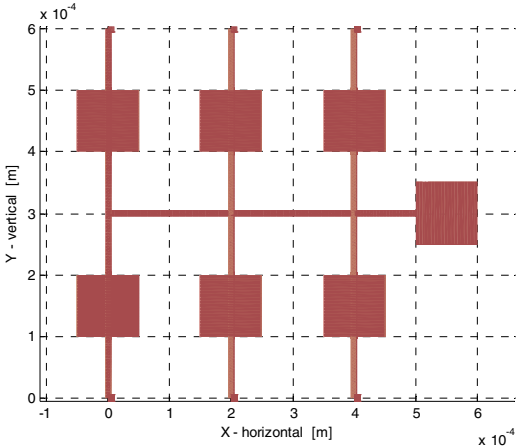


Figure 9. Model 5 of the cantilever type MEMS switch.

TABLE 6. SIMULATION RESULTS

		Driving Voltage (V)	Switching Frequency (GHz)
Proposed Architectures	1	4.2	1.0374
	2	9	2.5337
	3	6.5	3.0024
	4	6.6	6.6571
	5	4.6	1.5594
Previous work	[1]	7	5
	[2]	6.39	5
	[3]	5	5

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BIOGRAPHIES



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