Journal of Scientific & Industrial Research
Vol. 79, July 2020, pp. 595-597

Design of Step down Structure RF-MEMS Shunt Capacitive Switch for Low-Pull-In Voltage

K Girija Sravani[1], K Guha[1]*, I E Lysenko[2], K Srinivasa Rao[3] and Ameen El Sinawi[4]

[1]Department of ECE, National Institute of Technology, Silchar 788 010, India
[2]Department of Electronic Apparatuses Design, Southern Federal University, Taganrog 347 922, Russia
[3]MEMS Research Center, Department of ECE, Koneru Lakshmaih Education Foundation, Green Fields, Vaddeswaram, Guntur 522 502, India
[4]Department of Mechanical Engineering, Khalifa University, Abu Dubai, UAE

Received 10 April 2019; revised 23 July 2019; accepted 22 May 2020

In this paper, designs and simulations of a new RF MEMS step-down structure of a capacitive shunt switch using different meandering methods are presented. The beam and dielectric materials are taken as gold and silicon nitride for the proposed switch. The switch required actuation voltage is 7.9 V for the non-uniform one meander technique.

Keywords: Meander Techniques, Perforations, Pull-in Voltage, RF-MEMS Shunt Switch, Spring Constant

Introduction

In modern days, the RF MEMS switches are performing an essential trade-in all electronics device like reconfigurable antennas, filters etc., because of compact size, inexpensive and less power consumption.[1–6] These switches possess leading-performance characteristics while associated among the conventional switches like PIN and FET in applications.[7,8] In previous studies, few RF MEMS Switch designs are proposed but they suffer from stiction problems, switching speed, isolation and mainly pull-in voltage.[9–13] In this paper, a novel type structure along with serpentine meander is proposed to suspend the central beam to actuate at the minimum actuation voltage.

Experimental Details

Shunt type switch is designed with two anchors, attached at both ends, and the middle part of the beam is diverted towards the CPW lines to improve the status of the switch. The step structure switch has a silicon substrate with a high dielectric constant of a thickness of 840 μm. An insulating layer 1 μm thick is applied to the substrate to avoid leakage currents. A 2 μm thickness of the CPW having a CPW 60/100/60 signal line is viewed above a dielectric layer to generate an RF signal. The depth of the dielectric layer is 0.3 μm, applied on this CPW to build a capacitive way for generating the signal. Here, the device having two moving pads are considered within the RF line, and the ground planes, located under the inner beam with 3 μm gap. The electrostatic force is employed on these electrodes and central beam for some movement of the device, and during the operation, the signal is isolated by the actuation-voltage. The thickness of the central beam is consists of 3 μm and it is placed between the two side beams. The two anchors are located at the ground planes. So, the middle beam is placed among the anchors above the co-planar wave guide.

Results and Discussion

Accuracy, reliability and stability of a switch is defined by varying the electrostatic force over the beam due to applied actuation voltage. The non-uniform one meander step structured switch possesses a stress value of 13.9 MPa without perforation and 11.4 MPa with perforation by applying a force of 21 uN. The buckling effect happens when the voltage exceeds a threshold value, which is defined as a critical voltage.

$$\sigma_{cr} = \frac{\pi^2 \varepsilon t_b^2}{3 l_b^2 (1-\nu)} \quad \ldots (1)$$

Where "l_b" beam length, and "ν" is defined as the material poisons ratio. The above Eq. 1 is called a Euler buckling criterion. The device needs to resist significant

*Author for Correspondence
E-mail: koushikguha2009@gmail.com

(critical) stress on the tensile stress to minimize the impact of beam stability. Numerical analysis showed that the compression stress of gold and aluminium as 5–20 MPa, and 4–15 MPa. From the observations, the thickness of the beam decreases then the buckling effect increases for various beam materials. So, there should be a trade-off between beam thickness and length to minimize the effect of buckling. Therefore, the beam width for the step structure device has taken 1.2 µm with gold as beam material to withstand tensile stress as well as the critical stress.

As the length of the meandering section increases the spring constant and pull in voltage decreases but if meandering section increases at a certain point there is no change in spring constant and pull-in voltage value. So, there should be a tradeoff between span beam length and spring constant. Here meandering section with 100 µm span beam length results in low actuation voltage. While the meandering section increases the spring constant decreases even though higher meandering section switch was not feasible for fabrication because of its complexity and poor inductance tuning. Non-uniform one meander with a gap of 3 µm having a beam thickness of 1.2 µm shows spring constant of 2.1 N/m consider among all the cases based on its overall switch performance.

Thus, the spring constant of the proposed switch can be estimated as

$$\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \frac{1}{k_4} + \frac{1}{k_5} + - - - - - + \frac{1}{k_n} \quad \ldots (2)$$

Where k_1, k_2, k_3---k_n are the individual spring constants.

$$K_{eff} = 4K_m \quad \ldots (3)$$

By using various serpentine meanders, the spring constant of the structure is minimized. From the results (Table 1) it observed that non-uniform meanders show very low spring constant value when compare with the uniform. As the meandering sections increases spring constant value decreases. From Table 1, the different spring constant value for different span beam length of the various serpentine meanders with a thickness of the beam of 1.2 µm and an air gap of 3 µm. The Non-uniform 3-meander gives low spring constant value than the rest of the meanders. But due to fabrication complexity, 2, 3-meandered serpentine structures are ignored, only Non-uniform one meander having a spring constant value of 2.14 N/m has taken for switch design.

To achieve minimum pull-in voltage various meandering techniques are used. Here, the pull-in voltage is calculated by

$$V = \sqrt{\frac{8K}{27\epsilon_0 W_w}} g_0^3 \quad \ldots (4)$$

where, 'ε_0' is permittivity of free space, 'g_0' is gap between the electrodes, W, w -Area of the overlap.

The beam shows abrupt displacement at 7.9 V and falls on the dielectric medium where further bending is not possible and is clearly represented in Fig. 1. From

Table 1 — Comparison of Spring constants of the proposed RF MEMS Switch

Span Beam length	Spring Constants					
	Uniform Meander			Non-Uniform Meander		
Without meander	One-Meander	Two-Meander	Three-Meander	One-Meander	Two-Meander	Three-Meander
100	16.3	7.9	5.1	2.1	0.1	0.01
110	12.3	7.4	4.9	2	0.04	0.01
120	9.4	6.8	4.6	1.86	0.04	0.01
130	7.4	6.3	4.3	1.81	0.04	0.01
140	5.9	5.2	3.9	1.5	0.04	0.01

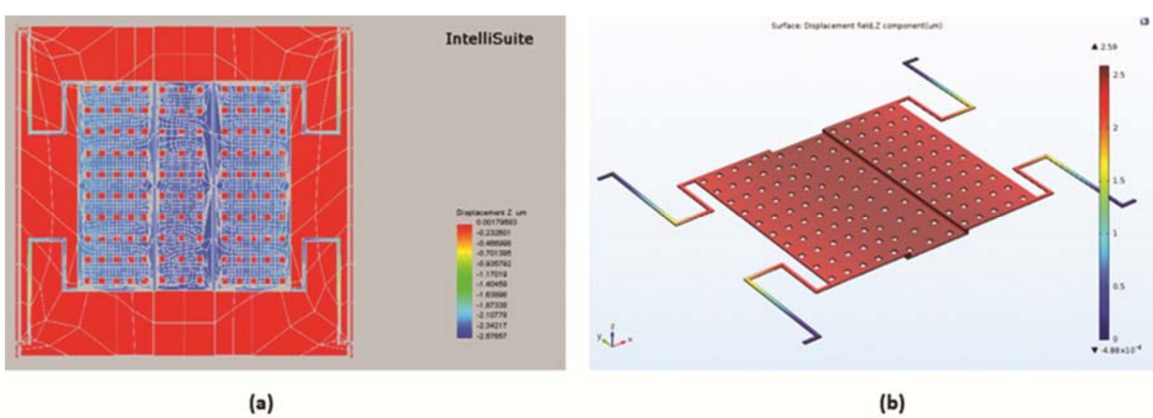

Fig. 1 — Displacement Vs voltage of proposed RF MEMS Switch (a) by Intellisuite software (b) by COMSOL software

Table 2 — Comparision of Pull-in voltages of the proposed RF MEMS Switch

Span Beam length	Pull-in voltages					
	Uniform Meander			Non-Uniform Meander		
Without meander	One-Meander	Two-Meander	Three-Meander	One-Meander	Two-Meander	Three-Meander
100	21	15	10.1	7.9	1.9	0.58
110	20	14.5	10.1	7.5	1.1	0.58
120	16.5	13.9	10.0	7.3	1.1	0.58
130	14.6	13.5	10	7.2	1.1	0.58
140	13	12.2	9.9	6.7	1.1	0.58

the results (Table 2), it is mentioned that the actuation voltage decreases with thickness of beam is 1.2 µm and air gap of 3 µm for increasing Meanders. Minimum actuation voltage will improve the acceleration of the device. From the results, it has been observed that step structured switch with non-uniform one meander section possessing a good switching time of 89 µs with a V_p of 7.9 V. Two, three meandered step structures also possess high switching time when compare with one meandered section because of its low spring constant. So, there should be a trade-off between spring constant and switching time to achieve high reliability of the switch.

Conclusions

This research work presented a new type of step type switch for less pull-in voltage. The variation of span beam lengths includes a connector beam and spam beam length, describes the performance of two meander sections. Due to the device optimization and fabrication feasibility the device with one non-uniform meander having a span beam length of 100 µm considering actuation area of (100 µm x 315 µm) offer the actuation voltage as low as 7.9 V are optimized for proposed switch design. It is mentioned that the proposed switch with three meanders of both uniform and non-uniform showed less pull in voltage but actually due to fabrication complexity and some reliability issues, non-unifrom one meander section is good enough to fabricate a shunt switch. The proposed device shows better performance by non-uniform meanders.

Acknowledgement

The authors would like to thank the National MEMS Design Center, National Institute of Technology, Silchar for providing the required software tools for this research work.

References

1 Sulyman A I, Nassar A T, Samimi M, McCartney, G R, Rappaport T, & Alsanie A, Radio propagation path loss models for 5G cellular networks in the 28 GHZ and 38 GHZ millimeter-wave bands, *IEEE Comm Magz*, **52** (2014) 78–86.

2 Siddaiah N, Manjusree B, Aditya, A L G N, Reddy D V Rama Koti, Design simulation and analysis of U-shaped and rectangular MEMS based triple coupled cantilevers, *J Sci Ind Res*, **76** (2017) 235–238.

3 Lee Y C, Influence factor analysis of MEMS and IC integration technologies, *J Sci Ind Res*, **77** (2018) 168–171.

4 Manivannan M, Daniel R J & Sumangala K, Low actuation voltage RF MEMS switch using varying section composite fixed-fixed beam, *Int J Microw Sci Technol*, doi:10.1155/2014/862649.

5 Batmanov A, Hamad, E K I, Burte E P & Omar A S, Design of H-shaped low actuation-voltage RF-MEMS switches, *Asia-Pacific Microwave Conference*, (2006) doi:10.1109/apmc.2006.4429697.

6 Shekhar S, Vinoy K J, & Ananthasuresh G K, Design, fabrication and characterization of capacitive RF MEMS switches with low pull-in voltage, *IEEE International Microwave. and RF Conference* (IMaRC), Bangalore, 2014, p. 182–185, doi:10.1109/imarc.2014.703898.

7 Mathura M, Vats A, & Agarwal A, A new design formulae for feed line dimensions of the rectangular Microstrip patch antenna by using equivalent design concept, *International Conference on Signal Processing and Communication*, Noida, (ICSC), 2015, 105–110 doi:10.1109/icspcom.2015.7150629.

8 Sharma A K, and Gupta N, Pattern reconfigurable antenna using non-uniform serpentine flexure based RF-MEMS switches, *PIERS proceed*, (2015) 2840–2843.

9 Singh V K, Ka-band micromachined Microstrip patch antenna, *IET Micro Antennas & Propag*, **4(3)** (2016) 316–323.

10 Raji G, Kumar C R S, Gangal S A, Design of a frequency reconfigurable pixel patch antenna for cognitive radio applications, *International Conference on Signal Processing and Communication*, (2016) 1685–1688.

11 Mirzajani H, Ilkhechi A K, Zolfaghari P, Azadbakht M, Aghdam E N, & Ghavifekr H B, Power efficient low loss and ultra-high isolation RF MEMS switch dedicated for antenna switch applications, *Microelectonics J*, **69** (2017) 64–72.

12 Lakshmi Narayana T, Girija Sravani K, Srinivasa Rao K, Design and analysis of CPW based shunt capacitive RF MEMS switch, *Cogent Eng*, **4** (2017) 1–9.

13 Srinivasa Rao K, Ashok Kumar P, Guha K, Baishnab K L, Girija Sravani K, Design and simulation of fixed-fixed flexure type RF MEMS switch for the reconfigurable antenna, *Microsyst Technol* (2018), doi:10.1007/s00542-018-3983-2.