Designing of RF-MEMS Capacitive Contact Shunt Switch and Its Simulation for S-band Application

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Abstract This paper presents design and simulation of RF-MEMS capacitive type shunt switch. The main parameters of electromagnetic and electromechanical analysis are performed by utilizing COMSOL and HFSS tools. The performance of the switch is enhanced by including perforation and non-uniform meandering technique. Here, to design an RF-MEMS switch with a change in dimensions and different air gaps, and thickness of the beam for low frequency applications. The actuation voltage of the proposed switch having 10.6 V, the upstate capacitance is 6 × 10ˆ−15. The stress of the beam was obtained as 41.7 MPa. The switch has shown higher isolation and lower insertion loss while implementing the microwave and mm-wave circuits. The S-parameters like return and insertion losses are having −22.37 dB, −0.11 dB, the isolation is obtained −21.89 dB at 2 GHz frequency.

Keywords RF-shunt switch · Pull-in voltage · S-Parameters

1 Introduction

Micro-electromechanical systems or MEMS technologies are defined as micro mechanical and electromechanical components with a micromachining processed devices used in our daily life. These can be done using materials such as ferroelectric, magnetic, ceramic, and semiconductor materials. The physical size of the MEMS is 1–100 μm and MEMS devices can vary from micrometer to millimeter. Unlike the other technologies like transistor devices which are also minute devices, these

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T. R. Lenka et al. (eds.), *Micro and Nanoelectronics Devices, Circuits and Systems*, Lecture Notes in Electrical Engineering 781,
https://doi.org/10.1007/978-981-16-3767-4_43

MEMS have a moving element in it that can be moved with the help of different types of physics like electrostatic, electrothermal [1–4]. The basic MEMS have a moving element of one and for the complex ones, it can have multiple moving elements.

MEMS technology is coming into the picture over the last few decades. The researchers and developers have invented a large number of MEMS devices for every possible sensing modality for temperature, pressure, chemical, magnetic fields, radiation, etc.

MEMS can be used in a different type of application like biological MEMS, radiofrequency MEMS. RF-MEMS has switches, phase shifters, and resonators. RF-MEMS switch has two basic types which are capacitive and ohmic type. The capacitive switches have a moving plate which changes the capacitance. The ohmic switches have cantilevers that are controlled by electrostatic force. While implementing the RF-MEMS switch we can use the two types of modes, i.e., parallel and series modes.

Compared to electrothermal, electrostatic actuation is preferred [5, 6] the phase-change and phase-transition materials [7] there is no necessity for external heating sources and high resistivity of silicon due to low power consumption [8–11], and no use of heat for glass substrates and also fused-silica [12–15], or technology of CMOS [16–19]. RF-MEMS switches of electrical and mechanical designs excellent performance at the microwave to mm-wave frequencies compared to other types of switches such as GaAs-based FET [20].

The steps followed in this paper are, in the first part, an introduction of MEMS with brief details of RF-MEMS switch and, in second part, description of the proposed design and its theoretical parameters and specifications. In part three, results and discussions after that final section concludes the paper.

2 Proposed Design

The switch has a substrate and CPW line. The CPW is a combination of a two ground plane on either side with a signal line in middle. The dielectric layer is located above the signal line of CPW to oppose the additional deficiency of signal. In this process, the electric signal flow is controlled and RF signal becomes transmitted [21, 22]. The proposed switch is having silicon substrate and the dielectric layer is silicon nitride. The planar beam consists of perforations and meanders, it is taken as gold material, and the diagrammatic illustration of the proposed switch is as shown Fig. 1. The switch specifications are also mentioned in Table 1.

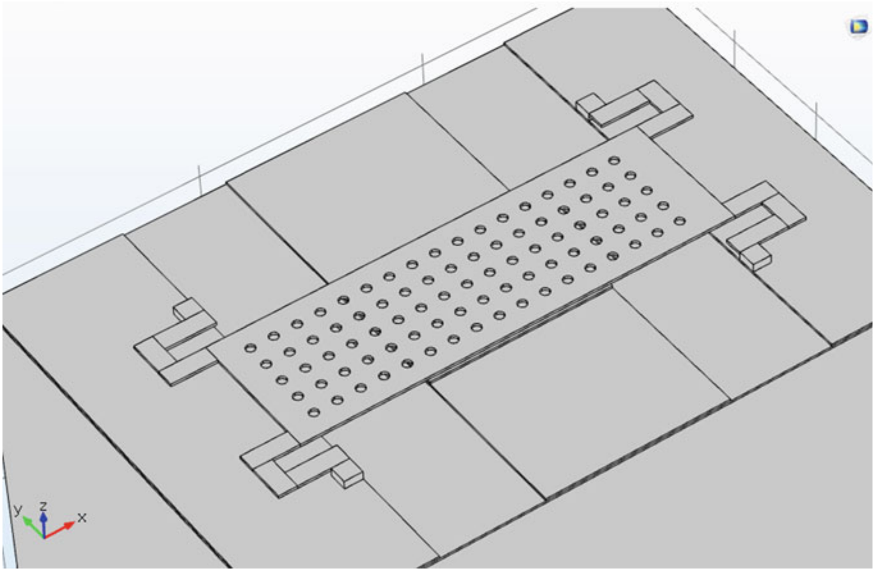

Fig. 1 The diagrammatic illustration of the capacitive contact switch

Table 1 Dimensions of various parameters in the switch

Parameters	Materials	Width	Depth	Height
Substrate	Silicon	290	200	200
Oxide	Silicon nitride	290	200	1
Ground	Gold	60	200	1
Signal	Gold	80	200	1
Dielectric	Silicon nitride	80	60	1
Electrode	Gold	25	40	1
Beam	Gold	190	160	1.2

All dimensions mentioned are in µm

2.1 Electromechanical Analysis

2.1.1 Spring Constant

A nonlinear mechanical behavior, in other terms force needed to pull the beam divided by the distance beam, gets longer. It is denoted as 'k' [23],

$$k = \frac{EWt^3}{l^3} \tag{1}$$

Here 'E,' 'W,' 't,' 'l' are the young's modulus, width, thickness, and length of the beam, respectively.

2.1.2 Pull-in Voltage

The minimum voltage is required to actuate the switch. It is denoted as V. The pull-in-voltage mainly depends on spring constant K.

$$V_P = \sqrt{\frac{8Kg_0^3}{27\varepsilon_0 A}} \tag{2}$$

Here, 'K,' 'g_0,' 'ε_0,' 'A' are the spring coefficient, length of the gap between the beam and dielectric, permittivity and contact area, respectively.

2.1.3 Capacitance

The capacitance of an operation is calculated at two stages, upstate capacitance and downstate capacitance. The upstate capacitance means the value of capacitance when switch is in ON state mode. The downstate capacitance means the capacitance value of switch in OFF state mode.

$$C_u = \frac{\varepsilon_0 A}{g_0 + \frac{t_d}{\varepsilon_r}} \tag{3}$$

The calculation of downstate capacitance C_d[24],

$$C_d = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \tag{4}$$

Here, 'A,' 'g_0,' '$\mathcal{E}_o$,' '$\mathcal{E}_r$,' 't_d' are addition of area of overlapping and area of two electrodes, length of the gap between the beam and dielectric, relative permittivity of free space, dielectric permittivity, and thickness of beam, respectively.

2.1.4 Stress

The analysis of stress helps to understand the unnecessary deformation in the beam.

$$\sigma_{cr} = \frac{\pi^2 \mathrm{E} t^2}{3l^2(1 - v)} \tag{5}$$

Table 2 Dimensions of various meanders in the switch

Meander	Length (um)	Width (um)	Thickness (um)
$K1$	20	8	1.2
$K2$	16	8	1.2
$K3$	22	8	1.2
Fixed block	22	8	3.7

All dimensions mentioned are in μm

where 'E,' 't,' 'l' are young's modulus, thickness, and length of the beam, respectively.

2.2 Electromagnetic Analysis

Electromagnetic analysis means analyzing the behavior of the device under electric field and magnetic field. In this analysis, we analyze the S-parameters (S_{11} (return loss), S_{12} (insertion loss), and S_{21} (isolation)).

The capacitive contact parallel switch is also called a fixed–fixed capacitive shunt switch. This type of switch is the most used RF-MEMS switch. This is a composition of a movable beam, fixed supports, dielectric, electrodes, signal, ground, oxide layer, and substrate [25]. The meanders support movable beam are attached to fixed supports. The dimensions of meanders are mentioned in Table2.

3 Results and Discussion

The simulation part is done in two parts, electromechanical analysis and electromagnetic analysis. The electromechanical analysis is done in COMSOL software and the electromagnetic analysis is done in High-Frequency Structure Software (HFSS). The displacement, upstate capacitance, downstate capacitance, and stress analysis are done in COMSOL software. The S_{11}(return loss), S_{12}(insertion loss) and S_{22}(isolation) are calculated using the HFSS software. The total displacement of the beam is observed as in Fig. 2, the upstate capacitance is 6.03 × 10^−15 shown in Fig. 3, it is depending on the dielectric thickness and material.

The return loss, insertion loss, and isolation are calculated in High-Frequency Structure Software. Figure 5 shows the return loss as −22.37 dB, Fig. 6 shows the insertion loss as −0.11 dB. Figure 7 shows the isolation which obtained as −21.89 dB at 2 GHz frequency. The overall S-parameter values are measured in the frequency range of 1–4 GHz. During the upstate return and insertion loss are calculated while the isolation is in the downstate.

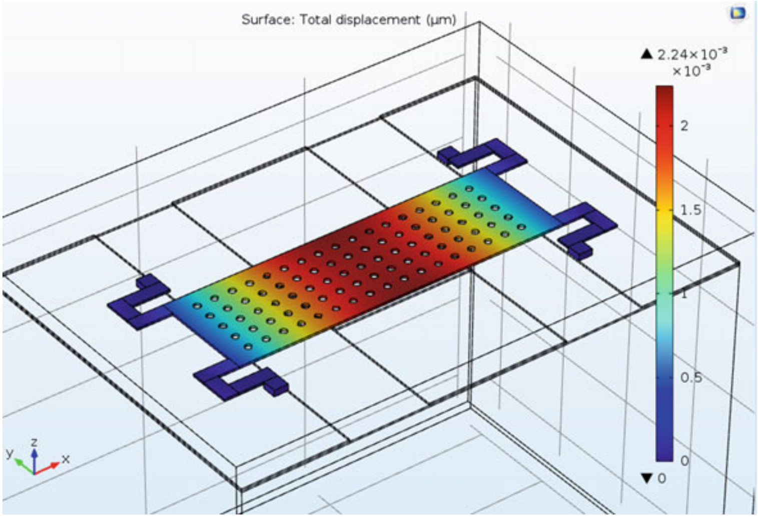

Fig. 2 Displacement of the beam observed at 10.6 V

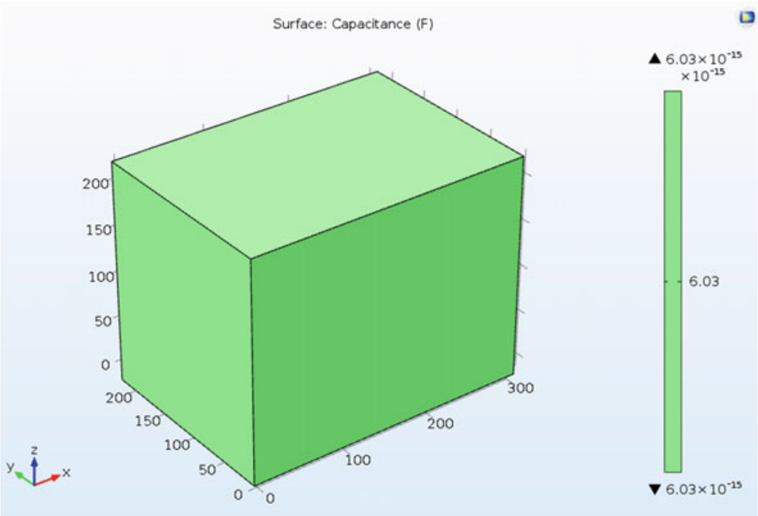

Fig. 3 Upstate capacitance of switch

The stress analysis of the proposed switch is observed that the switch can resist by having stress which is 41.7 MPa as shown in Fig. 4.

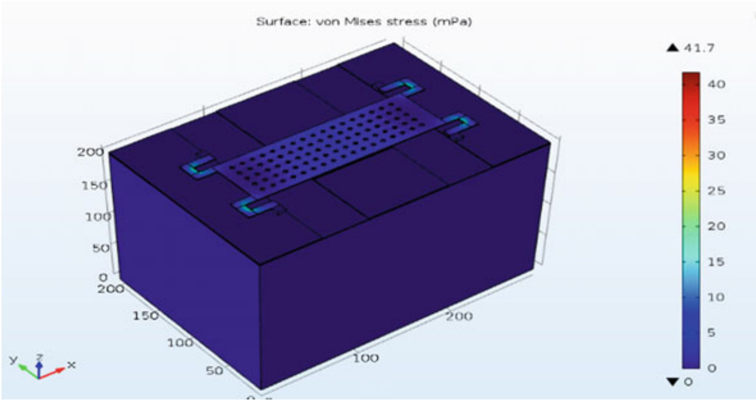

Fig. 4 Stress analysis of switch

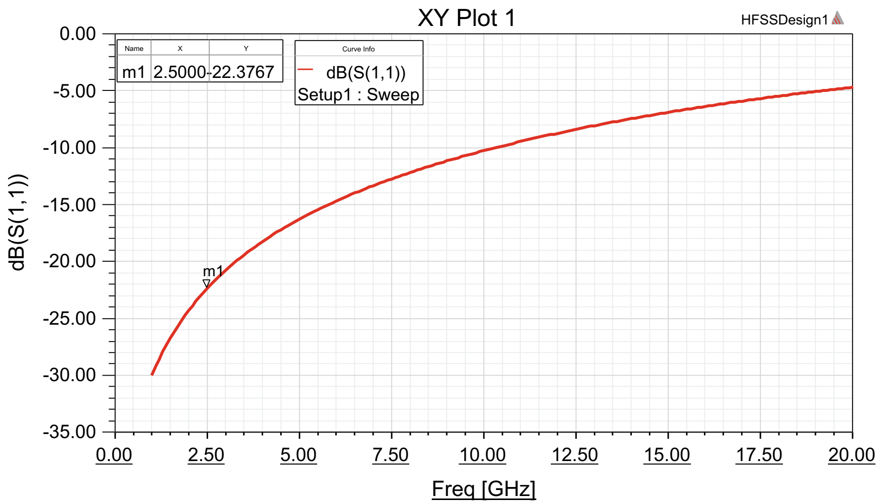

Fig. 5 Return loss measured at 2.5 GHz

4 Conclusions

In this paper, the designing and simulation of capacitive type shunt switch is done. The switch analysis of pull-in voltage (V_P), capacitance (C_u, C_d), stress, and S-parameters are analyzed and simulated with the help of COMSOL and HFSS tools. The focus of the switch is tried to reduce the pull-in voltage (V_P) and improved the isolation. Here, the meanders and perforations are utilized to reduce the pull-in voltage (V_P), the obtained actuation voltage is 10.6 V and upstate capacitance analysis is 60.4 fF, and the stress is maintained as 41.7 MPa. The electromagnetic

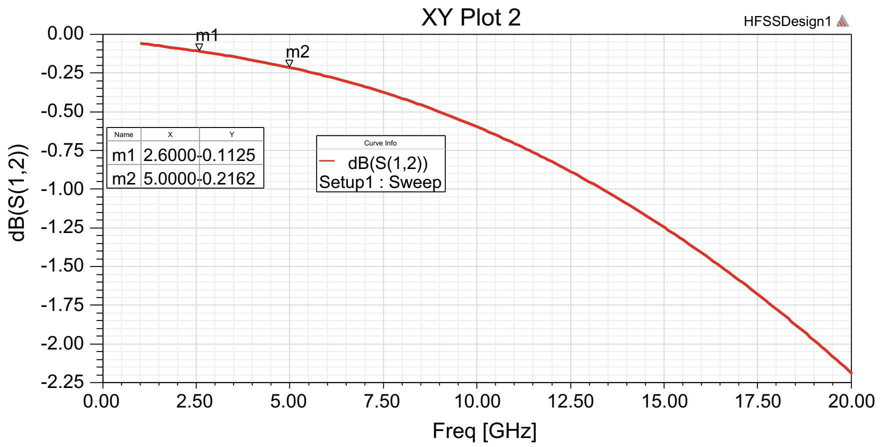

Fig. 6 Insertion loss measured at 2.5 GHz

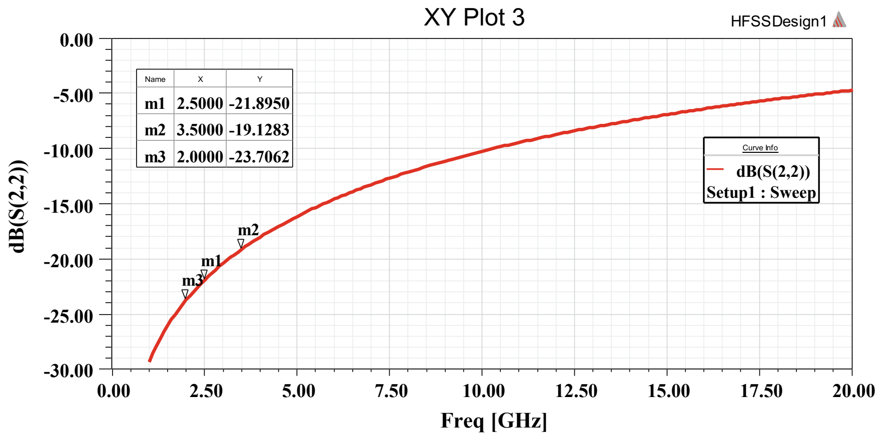

Fig. 7 Isolation measured at 2.5 GHz

analysis of S-parameters such as S_{11}(return loss) and S_{12}(insertion loss) is having −22.37 dB, −0.11 dB and the S_{21}(isolation) is −21.89 dB observed at 2 GHz frequency. The proposed switch is obtained better results at 2 GHz, so it is utilized for the S-band frequency (2–4 GHz) applications.

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