Low insertion loss RF MEMS Switch with Crab-leg structure for Ku-band application

V. Prithivirajan[#1], P. Venkata Krishnan[*2], A. Punitha[#3]

[#] Department of ECE, Vickram College of Engineering
Enathi, Tamilnadu, India
[1] vprithivirajan@gmail.com
[3] punitha08@gmail.com
[*] Department of ECE, K.L.N College of Information Technology
Pottapalayam, Tamilnadu, India
[2] pvkmephd@gmail.com

Abstract **- In this paper we present design and analysis of RF MEMS switches with crab-leg connection beam structures. The mechanical characteristics of switch including pull down voltage, hysteresis analysis and capacitance between beam and center conductor are studied. RF characterization of the switch including insertion loss, return loss and isolation are also investigated. Measurement results show that pull down voltage of the design is 17.5V. The mechanical design and analysis of the switch is performed using finite element method with coventorware software.**

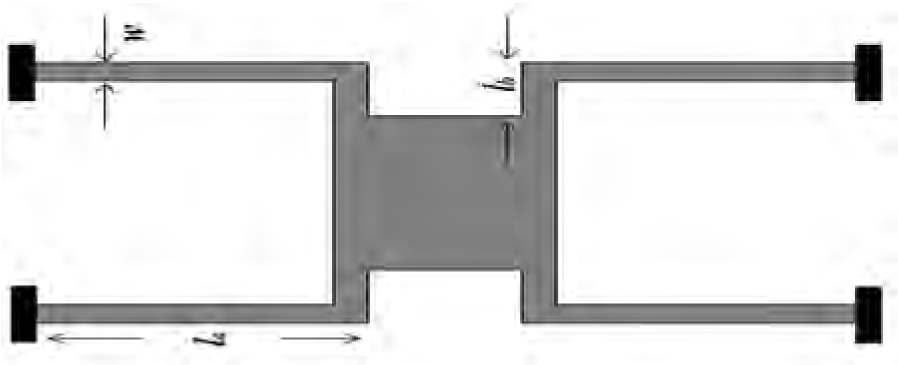
Keyword – Crab-leg, RF MEMS, Pull down, Hysteresis.

I. INTRODUCTION

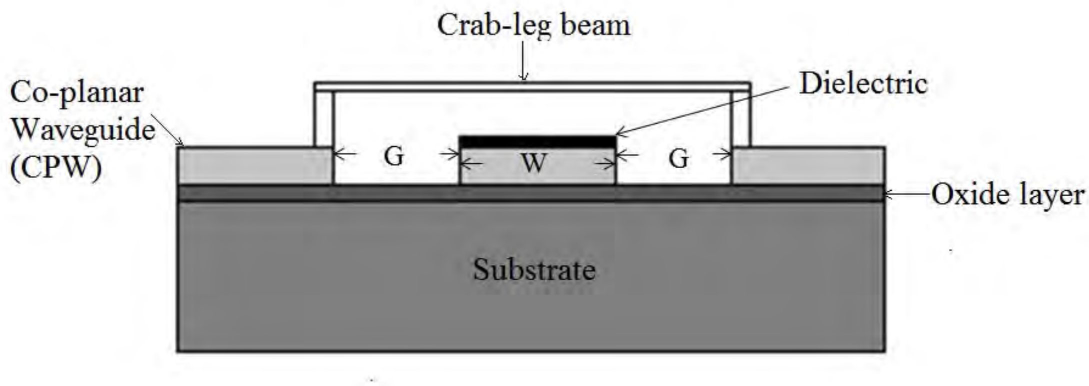
Micro Electro Mechanical Systems (MEMS) has extensive applications in radio frequency circuits [1]. The miniaturization, reliability, ease of assembly has made MEMS stand out then its counter parts for many applications such as optical, mechanical and fluidic systems. They provide high tuning ratio, low resistive losses and high self-resonant frequency. In spite of the issues like RF power handling and electrostatic discharge stresses, lot of research is being carried out to bring down the actuation voltage of RF MEMS switch. Realization of high performance microwave applications including phased array radars, tuning circuits, transceivers, phase shifters etc. with RF MEMS are made easier by combining mechanical and electrical domain. RF switches play a crucial role in today's wireless and high speed digital application. RF MEMS shunt capacitive switch exhibits good performance over the frequency ranges from Ku-band to W-band [2-4]. The main factor that impacts the characteristics of MEMS switches is the connection beam structures. In this paper the mechanical design and analysis of RF MEMS switch with crab-leg beam structures that provide a reprieve for the switch prone to non-linearity is carried out. The analysis focuses on pull down voltage, displacement and liftoff voltage of the MEMS switch using Coventorware. RF analysis was also simulated for the investigation of S parameters using HFSS.

II. MATERIALS AND STRUCTURES

Substrate of RF MEMS switch chosen in this work is low resistive silicon which exhibits a good behavior in device performance. To achieve low actuation voltage, the down/up capacitance ratio is made high by use of Si_3N_4 as dielectric $(\varepsilon_r = 7)$. The bridge material is gold, which has the young's modulus of 78GPa, Poisson's ratio of 0.44, and density of $19280Kgm^{-3}$.



(a). Crab-leg structure



(b). Cross section of RF MEMS Switch with Crab-leg

Fig. 1. Schematic of RF MEMS Switch with Crab-leg structure

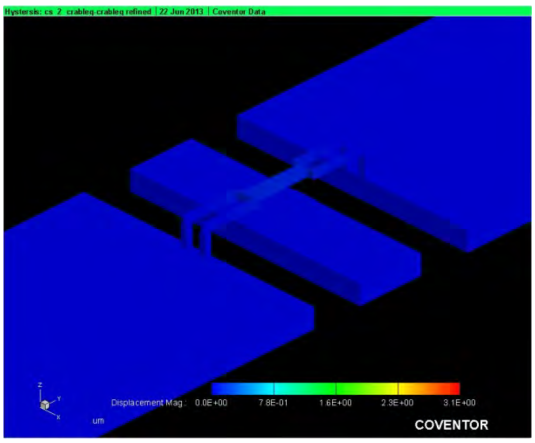
The gap height is 3 µm and the thickness of metal bridge is 1.2µm. Thickness of silicon substrate is 400µm ($\varepsilon_r = 11.9$). The CPW design parameters G/W/G is chosen to be 150/200/150µm for a 54Ω impedance transmission line [5]. The parasitic effect and the overall circuit loss can be minimized by suitable design of transmission line dimensions [6]. As geometrical shapes have much influence on mechanical and electronic characteristics of RF MEMS switches, Crab-leg structure shown in fig. 1. is chosen for beam structure in this study with l_a as 170µm, l_b as 20µm, and w as 10 µm. In Crab-leg design occurrence of non-linearity is delayed till greater displacement due to mitigation of extensional axial stress [7]. The capacitance value between movable plate and transmission line controls transmission of signal in a switch. The actuation voltage V_p is

$$V_p = \sqrt{\frac{8kg^3}{27\varepsilon_o A}} \quad \text{.... (1)}$$

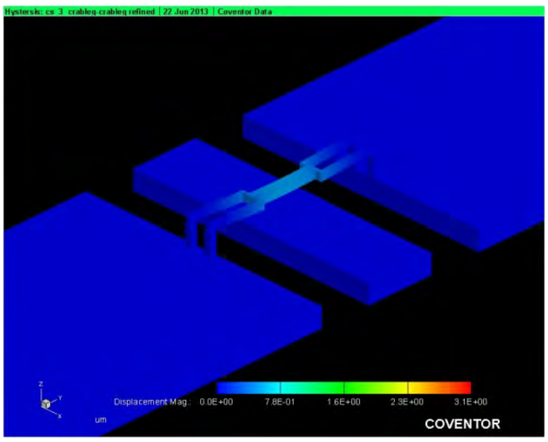
Where k is effective stiffness constant of the MEMS bridge, g the gap height between the movable plate and the dielectric layer, ε_o the permittivity of the space and A is the area of the movable plate.

III. RESULTS AND DISCUSSION

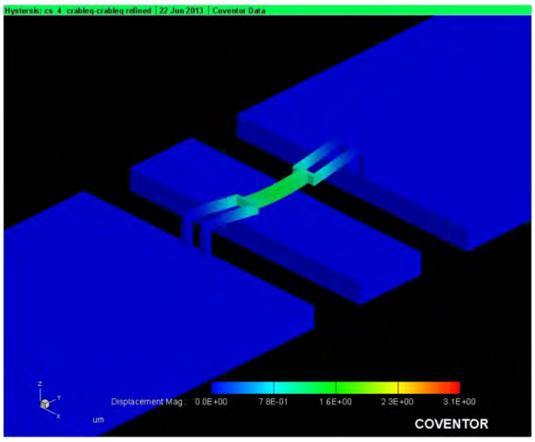
As the potential difference between membrane and center conductor increases, the membrane deflects and gap between electrodes decrease. At a threshold voltage defined as actuation voltage, the membrane become unstable (at a critical gap height of $2/3g_o$) and collapses onto the bottom electrode [8]. For the beam under consideration the actuation voltage is found to be 17.5V from the simulation results. The pull in voltage reported by Muldavin and Rebeiz is 35V [9], M.Tang is 20.8V [10]. Fig. 2 shows the mechanical design and analysis of the MEMS switch performed using finite element method with Coventorware software at different voltages. As the voltage is increased gradually the beam starts collapsing and touches the bottom electrode at $2/3^{rd}$ of the gap height.



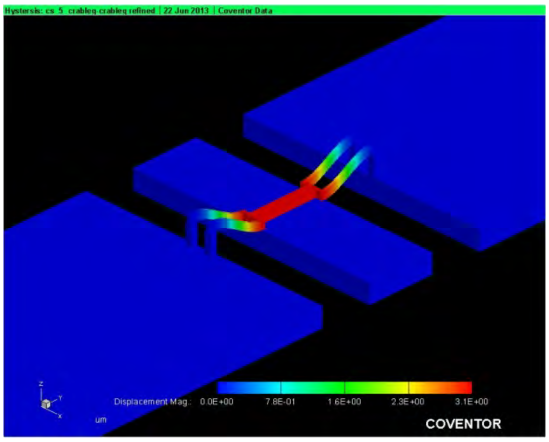
(a) 0 V



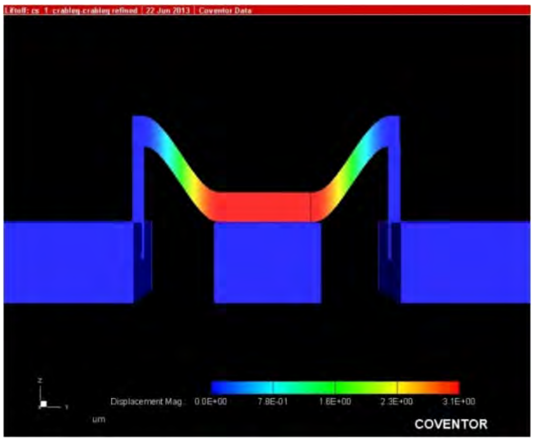
(b) 5 V



(c) 10 V



(d) 15 V



(e) 17.5 V

Fig. 2. Simulated results for beam displacement at different voltages using Coventorware.

Fig. 3 shows displacement characteristics of RF MEMS switch with crab-leg structure. The maximum displacement is 2µm. Gap versus lift off voltage is shown in fig. 4. It can be inferred that pull in voltage and lift off occurs at 17.5V and 10V respectively. As the applied voltage is increased, gap height decreases and consequently capacitance increases.

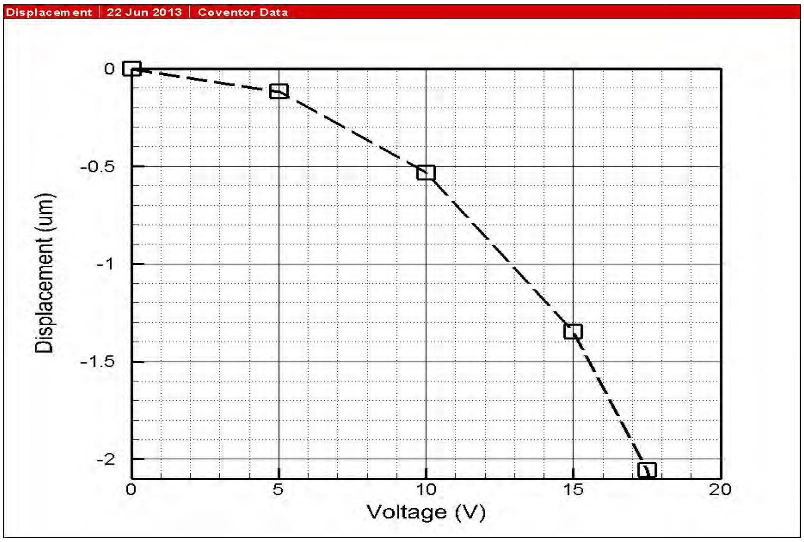


Fig. 3. Voltage vs. Displacement

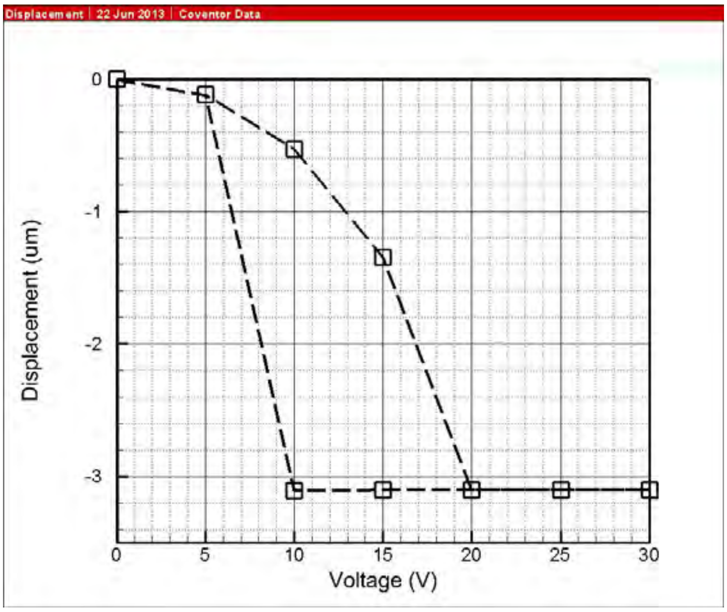


Fig. 4. Hysteresis graph between Voltage vs. Displacement

Scattering parameters of the crab-leg switch simulated using HFSS. The layout model of the proposed design is given in fig. 5. The switch has low insertion loss of -0.04dB because of minimum coupling capacitance from beam at 40GHz as shown in fig. 6. The return loss characteristic of the switch in upstate varies from -43.05dB to -10.95dB for the frequency range from 1 to 40GHz. It is also inferred that the return loss is -0.07dB at resonant frequency which is structure dependent that makes the switch suitable for Ku band applications. In the down state, the switch provides a high isolation of -44.02dB at 13.5GHz as depicted in fig.7.

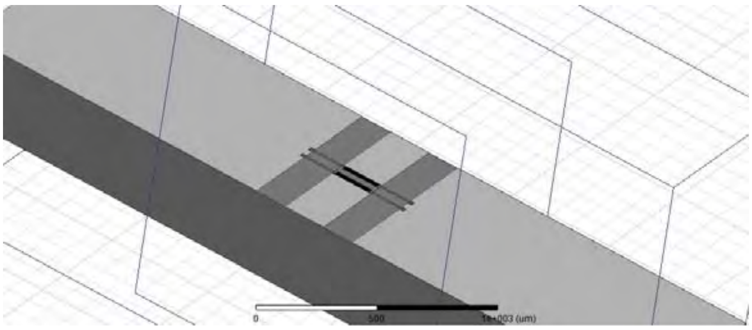


Fig. 5. Layout model of crab-leg using HFSS

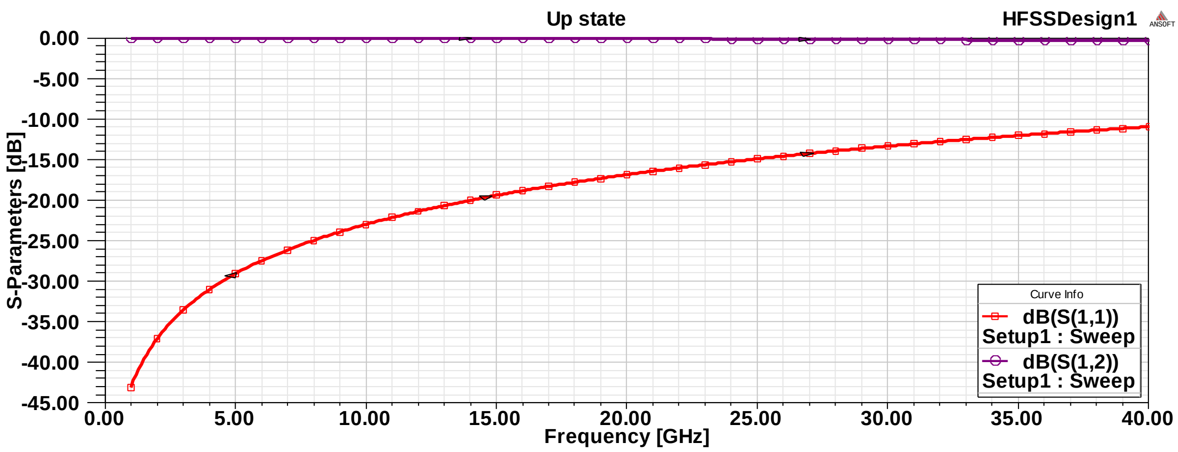


Fig. 6. S-Parameters of Crab-leg in up state

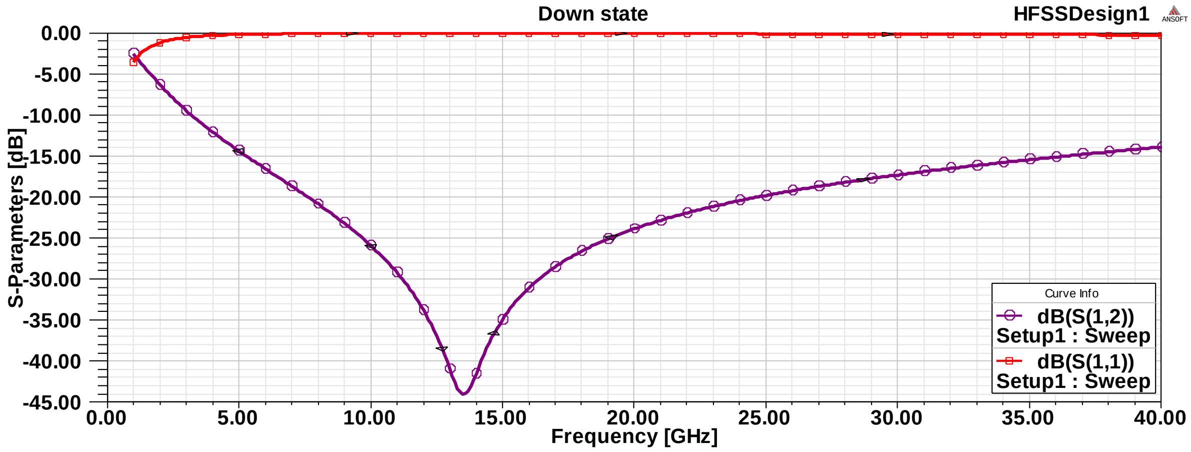


Fig. 7. S-Parameters of Crab-leg in down state

IV. CONCLUSION

The RF MEMS switch with crab-leg connection beam structure is designed and analyzed electrical and mechanical model. Finite element method was employed for the analysis of RF MEMS switch. RF characterization of the switch is carried out from 1 to 40 GHz. The switch has insertion loss of -0.04 dB and pull-in voltage is 17.5V. The switch has an isolation of -2.52 to -13.91dB at 1 to 40GHz that makes it suitable for various Ku band applications.

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