Effect of parasitic capacitance on 'OFF/ON' ratio of RF MEMS capacitive switch

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Abstract— Figure of merit for the RF MEMS capacitive switch is decided by 'OFF/ON' capacitance ratio. There is number of methods reported in the literature to increase the 'OFF/ON' ratio of the switch. Floating metal concept is one among them. Theoretical ratio based on parallel plate calculations is claimed up to 2000. However parasitics capacitance plays a major role in 'ON' state capacitance and measured 'OFF/ON' ratio is less than 100. In present paper, LCR parameters for RF MEMS capacitive switch are extracted considering parasitics. Parasitics are independent from switch capacitance/overlap area. These are function of switch geometry and substrate material on which switch is fabricated.

Keywords: Capacitance ratio, LCR, Parasitics and RF MEMS switch.

1 Introduction

RF MEMS capacitive switches have superior performance as compared to solid state devices. In 'ON' state, RF signal is passed though solid metallic line which lower its insertion loss. Through, some leaky path between signals to ground exists through the capacitance. In 'ON' state, it is defined as 'ON' state capacitance and similarly 'OFF state capacitance. Insertion loss is affected by the 'UP' state capacitance which is function of area of overlap and parasitics [1]. Area of overlap is reduced significantly in the literature [2]–[4] using floating metal concept, however, calculations for parasitics are difficult and not included in the theoretical calculations [5], [6], [7]. Figure of merit for RF MEMS switch is calculated from its capacitance in 'ON' and 'OFF' states. With floating metal, theoretical 'ON' state capacitance is reduced up to 2 fF neglecting parasitics which leads to high (>2000) 'OFF/ON' ratio for the switch. However, experimental 'OFF/ON' ratio with parasitics is limited to 20-100 only. In the present paper, parasitics capacitance is extracted from its s-parameters.

2 Parametric extraction

RF MEMS switch equivalent to parallel resistor (R), capacitor (C) and inductor (L) network as shown in Fig 1. RF analysis of the switch is performed on High frequency Structure Simulator (HFSS). The switch down state capacitance is calculated from its parallel plate formula. In 'ON' state, impedance contributed by inductance and resistance are negligible [2], and capacitance is calculated from S11

$$|S_{11}|^2 = \frac{\omega^2 C_u^2 Z_o^2}{4} \quad \text{For s11<-10dB}$$

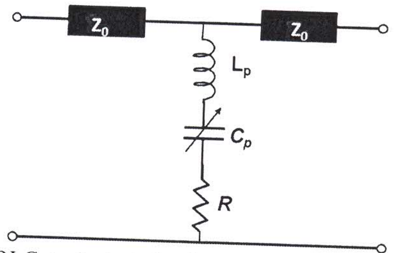

Fig 1. RLC equivalent circuit of the RF MEMS switch.

Knowing the resonance frequency and down state capacitance, inductance is calculated which is same in both 'ON' and 'OFF' states.

Switch response in 'OFF' state with the extracted LCR parameters in Advance Design System (ADS)© is compared with simulations in HFSS as shown in Fig. 2.

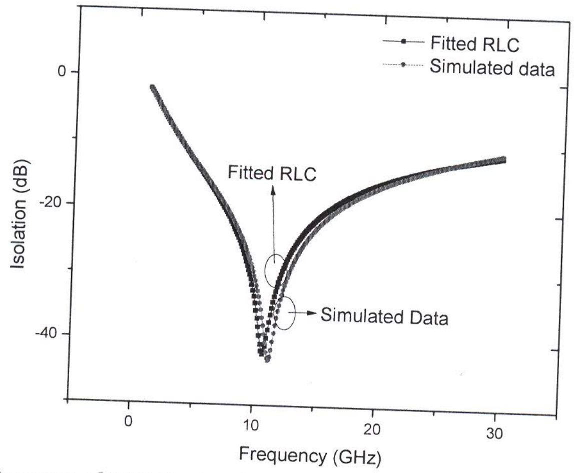

Fig. 2 Response of LCR fitted and simulated RF MEMS capacitive switch.

2.1 Parasitic capacitance

Switch capacitance is adversely affected by fringing and parasitic effects. In 'ON' state, switch capacitance is very small (1-80 fF) [4], [5], [8]. Fringing/parasitic capacitance also lies in same range (20-90 fF). In 'OFF' state, capacitance is of the order of 1-10 pF and parasitic capacitance has negligible effect on it. Hence, extraction of parasitic is done in 'ON' state. In 'ON' state, capacitances based on parallel plate and equation (actual value) are extracted and verified.

Up state capacitance of the MEMS shunt switch using parallel plate formula is given by.

$$C_{pp} = \frac{\varepsilon_o A}{g + \frac{t_d}{\varepsilon_r}}$$

Here overlap area "A" is varied from minimum (with floating metal concept) to 90 x 150 μm^2 (full overlap) to increase the 'OFF/ON' ratio as shown in Fig 2. However, switch capacitance calculated from (parallel plate) and LCR parameters gives parasitic capacitance of 76-80 fF which degrades the desired 'OFF/ON' ratio as listed in Table 1. Two type of RF MEMS capacitive switch are designed and fabricated as shown in Fig. 3. First switch has area of overlap of 5 μm and second one has area of overlap of 90 μm.

The fabricated devices are characterized by CV measurements using Agilent LCR meter (E4980A) to confirm the parasitics capacitance and change in 'OFF/ON' ratio as shown in Fig. 3.

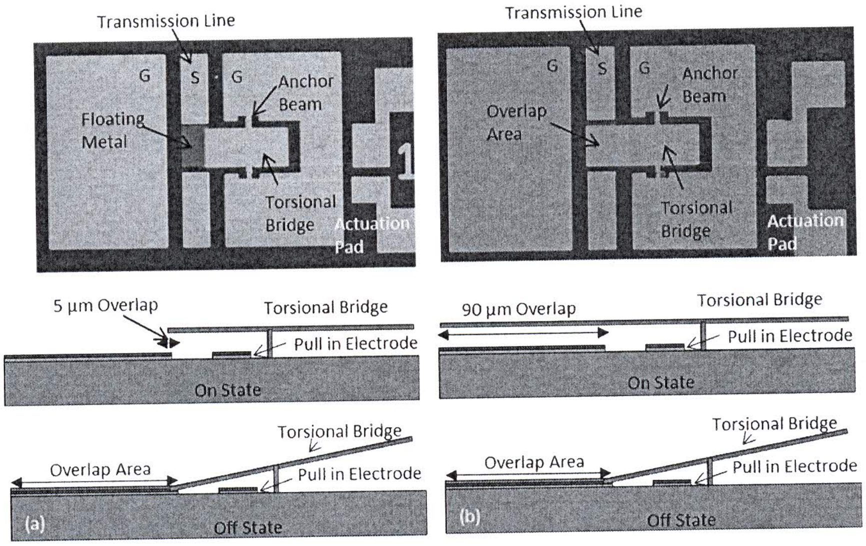

Fig. 3 SEM images of the RF MEMS capacitive switch with (a) 5 μm and (b) 90 μm overlaps.

Measured 'ON' state switch capacitance is 79 fF which closely matches with the simulated one. Parasitics capacitance lies in the range of 75-80 fF and independent from switch capacitance as listed in Table 1. 'OFF' state capacitance is 4.6 pF and has negligible effect of parasitics which reduces the practical 'OFF/ON' ratio to 58. On the other hand simulated results without considering parasitics, gives 'OFF/ON' ratio of 2091 which needs to be corrected.

Table 1 Calculation of parasitics capacitance by changing overlap area.

S.N.	Overlap Area (μm^2)	Gap (μm)	Parallel plate Capacitance (fF)	Simulated Capacitance (fF)	Parasitic Capacitance (fF)	OFF/ON ratio Simulated	
						Without parasitics	With parasitics
1	150x90	3	40	118.5	78.5	115	39
2	150x45	3	20	100	80	230	46
3	150x5	3	2.2	78	75.8	2091	59

Conclusion:

Parasitics plays an important role in 'ON' state and degrades the figure of merit. Parasitic capacitance for the fabricated RF MEMS switch is 75-80 fF which is independent from 'ON' state capacitance. 'OFF' state lies in the range of pico Farad and has negligible effect of parasitics. Extracted parameters match with simulated as well as fabricated results.

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