

BROADBAND DESIGN OF RF MEMS SPDT SWITCH

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ABSTRACT

This paper describes a broadband single pole double throw (SPDT) switch in the range of DC to 18 GHz. The switch consists of cascade cantilever type ohmic series switch connected through bias lines. Electrodes below the cantilever are used to toggle the switch between open and closed position. Simulated electromechanical response of the single switch and rf performance of the SPDT switch are presented. The SPDT switch provides an insertion loss -0.4 dB, return loss -16dB and isolation better than -39 dB over the full frequency band.

KEYWORDS: RF MEMS Switch, SPDT, SPST, Pull down, switching time

I. INTRODUCTION

The single-pole double-throw (SPDT) switches are an integral part of many microwave systems and have been extensively employed in the microwave and millimeter wave communication systems such as transceivers, where they are used to switch a device between receiver and transmitter modes, the switched-line phase shifters in phased array antennas and the wide-band tuning networks[1]. Traditionally, GaAs MESFETs and PIN diodes are integrated in the SPDT switching circuits. However, the performance of these semiconductor switches deteriorates with the increase of the frequency[2]. Now, RF MEMS switches have become an attractive alternative to solid state switches due to their low insertion loss, high isolation and low power consumption at microwave frequencies. These types of MEMS switches utilize electrostatic actuation to change the signal path and generally require two independent voltages to switch between the two ports. Various SPDT switch circuits have been developed using MEMS switches to replace the conventional semiconductor switches[3].

In this paper, a new SPDT switch circuit using broadside series switches is presented for the application of DC-18 GHz. In the design sequence, first a highly reliable SPST switch is realized, and then a highly reliable SPDT switch using these SPST switches is developed. The switches are implemented on a CPW transmission line and are actuated by electrostatic force. The analysis is based on the RF and electromechanical simulations using commercially available HFSS[4] and CoventorWare[5] softwares.

II. DESIGN AND ANALYSIS

2.1 Design of SPST switch

The SPST switch structure for use in the SPDT switch is shown in Fig 1. It consists of a cantilever which is suspended above the gap in the CPW transmission line. The cantilever beam is in the direction perpendicular to the signal line. It is anchored at one end while the other end is free. Below the free end of the cantilever there is a dimple which is used to short the input and output transmission lines i.e. close the gap when the bias is applied. The actuation of the switch is achieved by an electrostatic force between the top and bottom electrode. This voltage induced force bends the cantilever down and the dimple connects with the two parts of the transmission line and allows

transmission of the RF signal. Since this is a series ohmic switch, the UP position of the bridge corresponds to the OFF state, while the DOWN position will correspond to the ON state.

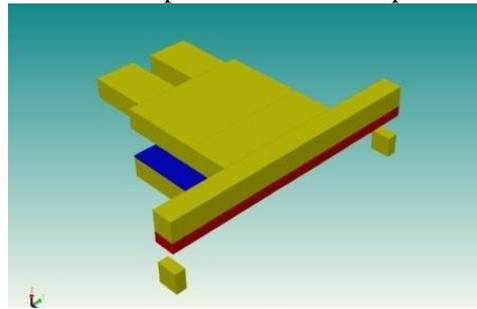


Fig 1 : Schematic of the SPST switch

The CPW dimensions are $G/W/G = 60/100/60 \mu\text{m}$ required for $Z_0=50\Omega$. The cantilever beam geometry, material and gap to CPW plane determine the activation voltage and signal transmission efficiency. The width of the center conductor has been reduced in the center i.e. around the switch to reduce the up-state capacitance and the fringing capacitance. Thickness of the cantilever has been chosen as $1.0\mu\text{m}$. The pull-down voltage and switching time have been investigated in terms of beam structure and suspension height using CoventorWare software and is shown in fig 2. Simulated results are summarized in Table 1. It is found that height of $1.8 \mu\text{m}$ is most appropriate as at this value coupling between signal line and dimple is avoided in OFF position and actuation voltage is also within a reasonable value.

Table 2 : Varying gap with Fixed Dimple thickness

Dimple thickness (um)	Gap between upper and lower electrode (um)	Pull down voltage (V)	Switching time (us)	Settling time (us)
1	1.6	14	12.57	889
1	1.7	15	14.49	885
1	1.8	17	16.64	887
1	1.9	18	19.15	890
1	2.0	19	21.95	896
1	2.5	27	unstable	unstable

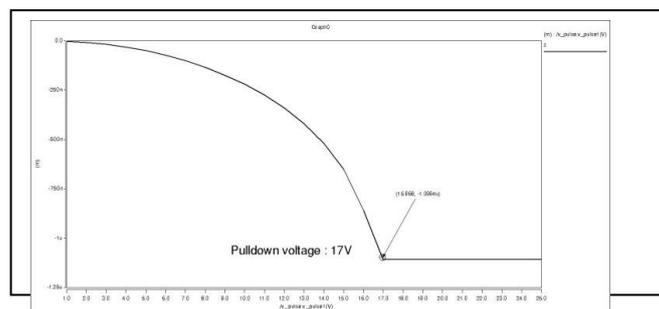


Fig 2 (a) : Pull down vs displacement

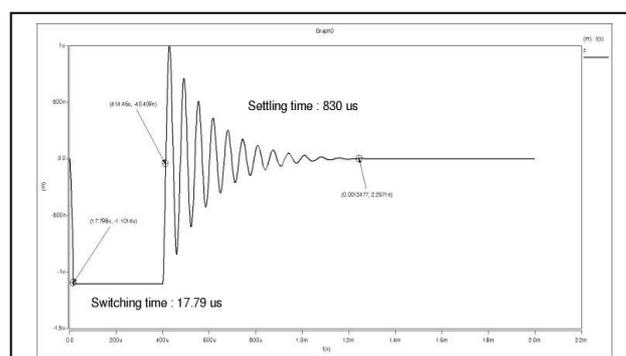


Fig 2 (b) : Transient response of the SPST switch

In general, higher the resonant frequency, lower is the switching time. The switch has resonant frequency of 16.76 kHz which is in desirable range for MEMS devices.

2.2 Design of SPDT switch

The schematic diagram of the SPDT switch circuit is shown in Fig.3. To achieve a SPDT switch with good RF performance, circuit topology plays an important role. The circuit consists of a T-junction with two identical SPST MEMS switches located at each of the output arms. Two switches in each arm enable high isolation. In all four cantilever based series switches sw1, sw2, sw3 and sw4 as designed in the previous section are used. The signal can therefore be routed to the two different output ports with one switched off and the other switched on.

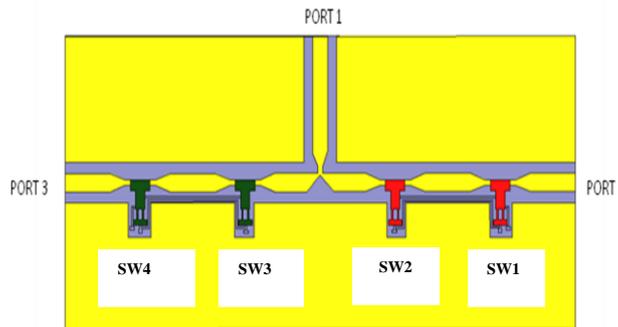


Fig 3 : Schematic of the SPDT Switch

When the bias voltage is applied to the switches sw1 and sw2, then both will be in ON state and the signal flows from port 1 to port 2 and port 3 is isolated. Similarly signal flows from port 1 to 3 by actuating the switches sw3 and sw4. Since the switches are same they can be actuated simultaneously. However the biasing arrangement is such that only one arm is actuated while the other is cut-off. Due to the discontinuity of the CPW ground plane at the T junction, the RF power can be converted from the desired CPW mode to the parasitic coupled mode. To avoid such a mode bond wires should be used at the discontinuity.

The bias lines of 0.075um thickness and of 10um width are used. The lower electrode and the anchors of both the switches sw1, sw2 are connected with each other. Similarly the lower electrodes and anchors are connected for sw3 and sw4. The design is then simulated for rf performance using HFSS software. The insertion loss and the return loss of the SPDT switch are determined by S21 and S11 respectively through the input and output branch that contains the actuated switch while the switch in the other output branch is in the off state. The isolation of the SPDT switch is characterized by S21 along the signal line with the switch in the off-state, while the input signal is routed to the branch containing the actuated switch.

The open line presents a stub loading to the selected path (OFF arm) this length is tuned using the parametric analyser. The mid line is tapered for a length from 10um to 90 um and it is found that on increasing the taper length the return loss improves from a value of -11db to -16db. The simulated results are shown in fig 4 and fig 5.

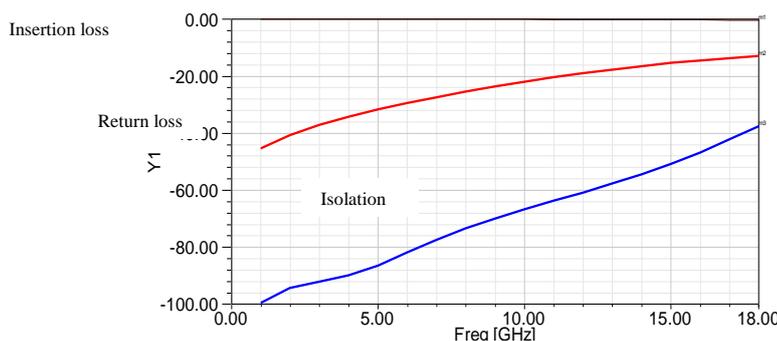


Fig 4 : Insertion loss, Return loss and Isolation for the SPDT switch

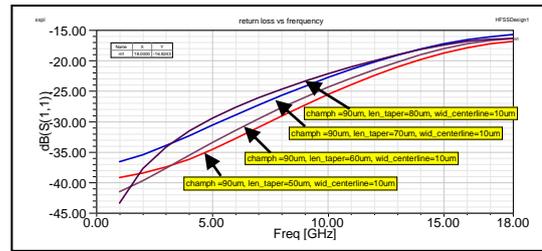


Fig 5 : Return loss response

The distance between the center of the switch sw2 and sw3 is 870um. The sw1, sw2 and sw3, sw4 are separated at a distance of 570um from each other. The successive gap at the signal line is 110um so as to have better isolation. The total length of the SPDT switch is 3400um.

Initially the structure has been analyzed when the distance of the switch sw2 and sw3 from the center line is $\lambda/4$ [6-9]. By doing so it is observed that the return loss gets better for a frequency band of DC-10GHz but poor for the 10 GHz to 12 GHz. The discontinuity at the center finally helps in the structure to improve the return loss. It was observed that when a notch was made at the center line and chamfered upto 90um, the return loss improves tremendously between this frequency range. The fig 3 shows the layout of the SPDT structure and fig 4 shows the insertion loss, return loss and isolation where the return loss in red color shows that it is smaller than -16db at 18 GHz. The curve in blue shows the isolation, which is -60db upto 12 GHz and better than -39db from 12 GHz to 18GHz. The insertion loss is better than -0.43dB throughout the band. Efforts have been made to improve the return loss by changing the taper length and the width of the center line. The taper length is varied from a length of 50um to 80um and width of the center line from 10um to 40um. As the taper length reduces to a length of 50um for a fixed center line signal width of 10 um, the return loss gets smaller. On increasing the chamfer length at the notch, it is seen that return loss can be further improved. The best results are achieved at a taper length of 50um, signal line center width of 10um and chamfer of 90um at the center of the SPDT structure.

III. CONCLUSION

A SPDT switch with bias lines has been designed by integrating a pair of SPST switches in each arm. An isolation better than -39dB, a return loss of -16dB and an insertion loss of -0.42 dB has been achieved throughout the frequency band. Electromechanical results of SPST switch indicate a pull down voltage of 17 volts and switching time of 17.79 micro second. The electromagnetic simulation results indicate high isolation and low insertion loss. The switch is expected to provide low loss, high reliability, compact design, easy fabrication, and high yield.

ACKNOWLEDGEMENT

Authors thank Director SSPL for his kind permission to publish this work.

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