A Single-Pole, Eight-Throw, Radio-Frequency, MicroElectroMechanical Systems Switch for Multi-Band / Multi-Mode Front-End Module

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Abstract

This paper presents a single-pole eight-throw (SP8T) switch based on proposed a radio-frequency (RF) microelectromechanical systems (MEMS) switches. The proposed switch was driven by a double stop (DS) comb drive, with a lateral resistive contact. Additionally, the proposed switch was designed to have tapered signal line and bi-directionally actuated. A forward actuation connects between signal lines and contact part, and the output becomes on-state. A reverse actuation connects between ground lines and contact part, and the output becomes off-state. The SP8T switch of 3-stage tree topology was developed based on an arrangement of the proposed RF MEMS switches. The developed SP8T switch had an actuation voltage of 12 V, an insertion loss of 1.3 dB, a return loss of 15.1 dB, and an isolation of 31.4 dB at 6 GHz.

Keywords: MEMS, RF, SP8T, Switch

1. INTRODUCTION

Single-pole multi-throw (SPMT) switches, based on radio frequency (RF) microelectromechanical systems (MEMS) switches, are being researched to replace solid-state switches in switching systems, multi-band selectors, and filter banks[1]. Conventional SPMT switches actuated by electrostatic forces have several problems[2, 3]. SPMT switches containing thin metal films do not maintain mechanical reliability due to film deformation caused by heat or stress during complex fabrication processes[4]. Even if those conditions are optimal, insertion loss is large due to substrate loss and open-stub effects caused by multi-path fading[5]. Also, high drive voltage is required to generate essentially a large contact force for low insertion loss[6]. In order to solve these problems, we proposed the RF MEMS switch driven by a double stop (DS) comb drive, with a lateral resistive contact, and using single crystalline silicon (SCS)[7].

The previously presented switch had signal line of discrete sections type, it was hard to match the impedance between a signal line and contact part. And the switch remained between ground lines being disconnected when the switch was off-state. It is hard to remain same bias of ground lines. In this paper, by changing the signal line of tapered type, the proposed switch could have better insertion loss. The proposed switch using a bi-directional actuation has to not only connect the ground lines at off-state, but also fulfill good isolation characteristics. And we proposed a single-pole eight-throw (SP8T) switch of 3-stage tree topology which consists of proposed RF MEMS switches.

2. DESIGN

2.1 RF MEMS Switch Design

The proposed switch has a tapered signal line, and is driven by the bi-directional DS comb drive, with a lateral resistive contact, and using SCS on glass. A large contact force at low drive voltage can be achieved by electrostatic actuation of the DS comb drive. Good RF characteristics can be achieved by large contact force and a lateral resistive gold-to-gold (Au-to-Au) contact. Mechanical reliability can be achieved by using SCS, which has no residual stress as a structural material[7]. Better insertion loss characteristics can be obtained from the tapered signal lines. Bi-directional actuation of the DS comb drive has to not only connect the ground lines at off-state, but also...
fulfill good isolation characteristics.

The proposed RF MEMS switch is shown in Fig. 1. There was signal lines, ground lines, contact part, bias pads and DS comb drive. A forward actuation connects between signal lines and contact part, an output becomes on-state. A reverse actuation connects between ground lines and contact part, an output becomes off-state.

![Fig. 1. Schematic of the proposed RF MEMS switch and an bi-directional actuation of DS comb drive: (a) connected between signal lines and contact part by forward actuation, (b) connected between ground lines and contact part by reverse actuation.](image)

2.2 SP8T Switch Design

The SP8T RF MEMS switch was designed based on an arrangement of the single-pole single-throw (SPST) RF MEMS switches. Fig. 2 shows the topology of the 3-stage tree type SP8T switch. When one output is on-state, the others are off-state and open-stub. The SP8T switch was designed to be a 3-stage tree type to reduce the open-stub effect of off-state switch[8]. The 3-stage tree type switch was composed of seven single-pole double-throw (SPDT) switches. In addition, the signal lines were designed that the eight outputs had the same RF characteristics.

![Fig. 2. Topology of the proposed SP8T switch.](image)

Fig. 3 shows electromagnetic simulation model of the proposed SP8T switch. The electromagnetic simulation results of the SP8T switch are shown in Fig. 4. The output of 1, 3, 6, 8 for the SP8T switch showed insertion loss of 2.85 dB, return loss of 8.62 dB and isolation of 34.7 dB at 6 GHz, whereas the output of 2, 4, 5, 7 for the SP8T switch showed insertion loss of 3.71 dB, return loss of 6.42 dB, and isolation of 34.4 dB at 6 GHz.

![Fig. 3. The electromagnetic simulation model of the proposed SP8T switch.](image)

![Fig. 4. The electromagnetic simulation results of the SP8T switch: (a) outputs 1, 3, 6, 8, (b) outputs 2, 4, 5, 7.](image)
3. FABRICATION

3.1 Process Flow

The process flow of proposed switch was reported previously[7]. Four photo masks were used in the process. The SCS wafer was etched 10 μm to create an air gap between the glass wafer and the SCS switch structure. The SCS wafer was bonded to the glass wafer with anodic bonding and thinned to 45 μm thickness with chemical mechanical polishing(CMP). This was done to accommodate the 35 μm thick SCS switch structure and the 10 μm thick air gap. For the DS comb drive to interdigitate in the lateral direction, 2 Åm tetraethyl orthosilicate(TEOS) was deposited and patterned by dry etching. The TEOS acts as an etch mask and insulation between the SCS wafer and the CPW. Cr/Au seed layers were deposited by a metal sputter. The CPW and the contact part were formed by 2 Åm Au electroplating process. TEOS was again patterned by wet etching using the Au and photo resist mask to minimize alignment error between the signal line and contact metal. Finally, the silicon wafer was etched by deep silicon etching process.

3.2 Fabrication Results

Scanning electron microscope(SEM) images of the fabricated SPST RF MEMS switch are shown in Fig. 5. It shows a fabricated RF MEMS switch, DS comb drive for bi-directional actuation, and contact part. An optical image of the fabricated SP8T switch was shown in Fig. 6. The optical image was that five optical images of the fabricated SP8T switch were overlapped. There was one input and eight outputs. The switch was composed of seven SPDT switches.

Fig. 5. SEM images of (a) the fabricated RF MEMS switch, (b) DS comb drive, and (c) contact part.

Fig. 6. Optical images of the fabricated SP8T switch.

4. MEASUREMENT RESULTS

The RF characteristics of the fabricated switch were measured with an RF signal of 10 mW and a drive voltage of 12 V using the Hewlett Packard 8510C network analyzer and on-wafer probe station(Hewlett-Packard Co., Palo Alto, CA, USA). Fig. 7 shows the equipment setup for measurement of the fabricated SP8T switch. The SP8T switch was measured with a 2-port network analyzer,
leaving the rest of ports open. An actuation voltage of average 12.5 V with a standard deviation of 0.218 V was applied for actuation of the switch.

A measurement setup of the SP8T switch is shown in Fig. 7. The measurement setup consists of a function generator (Agilent 33120A), an electronic amplifier, a DC power supply (Agilent E3640A), an oscilloscope (LeCroy L1344ML), and a network analyzer (Hewlett-Packard 8510C).

Fig. 8(a) shows measurement results of outputs 1, 3, 6, 8 of the fabricated SP8T switch. The insertion loss was on average 1.4 dB with a standard deviation of 0.0665 dB at 6 GHz. Return loss was on average 14.13 dB with a standard deviation of 1.127 dB at 6 GHz. The isolation characteristic was on average 36.7 dB with a standard deviation of 3.93 dB at 6 GHz. Fig. 8(b) shows measurement results of outputs 2, 4, 5, 7 of the fabricated SP8T switch. The insertion loss was on average 1.2 dB with a standard deviation of 0.119 dB at 6 GHz. Return loss was on average 12.08 dB with a standard deviation of 0.896 dB at 6 GHz. The isolation characteristic was on average 35.8 dB with a standard deviation of 3.32 dB at 6 GHz.

5. CONCLUSIONS

The RF characteristics of the proposed switch were improved with tapered signal lines and connected ground lines by bi-directional actuation of the DS comb drive. Revised RF MEMS switch provided better RF characteristics. The 3-stage tree type SP8T switch was fabricated based on revised RF MEMS switches. At 6 GHz, the 3-stage tree type SP8T switch has insertion loss of 1.3 dB, return loss of 15.1 dB, and isolation of 31.4 dB.

REFERENCES

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