کارگاه های آموزشی مرکز اطلاعات علمی جهاد دانشگاهی

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کارگاه آنلاین با باکیفیت های اطلاعات علمی بین المللی و ترفندهای جستجو
A Fixed Central Bridge RF MEMS Switch for Multiband Applications

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Abstract
Micro Electro Mechanical Systems have been introduced during past three decades. Based on MEMS technology, vast variety of nonelectrical elements like mechanical, chemical, magnetic and optical parts can be miniaturized to micrometer scales in order to be fabricated on small areas. RF MEMS switches are a category of RF MEMS devices which have been developed for communication applications. RF switches may be used for connecting or disconnecting an RF signal. They may be useful for implementation of modulators, filters and phase shifters, too. In this paper a new RF MEMS switch structure is proposed which can be actuated by two electrostatic electrodes. It consists of two unsimilar bridges which are held near to a microstrip passing RF signal. Simulation results show larger band width and lower actuation voltage for proposed structure in comparison with conventional structure and some novel structures which have been introduced recently.

Keywords: RF MEMS switch - Low voltage actuation - Spring-structure

1. Introduction
RF MEMS switches have low-loss consumption, large bandwidth and good isolation. Electromechanical switches have linear properties. MEMS switches are used widely in tune circuits, antennas, filters and phase shifters [1-3]. The insertion loss, isolation and return loss are measured to evaluate RF performance of MEMS switches. MEMS switches are usually actuated by mechanisms such as electrostatic, electromagnetic, piezoelectric and electrothermal. The electrostatic mechanism is faster than others and has a low switching time. Also, power consumption is very low in this mechanism that could provide a small force between 50 to 200μN[4]. Up to now most of MEMS switches that have been presented, activated by electrostatic mechanism. In fact, they use electrostatic force in order to pull down bridges. These switches usually require a high actuation voltage, more than 20 volts [5, 6]. Actuation voltage is one of the most important issues in designing and fabrication of RF MEMS switches.

RF MEMS switches usually have a high actuation voltage. One of the methods to reduce actuation voltage is using a spring structure for suspending the bridge. The less spring constant leads to the less actuation voltage [7-9]. In 2016 a new RF MEMS switch is provided with a spring structure that can be activated with an actuation voltage about 2.9 volts [7].

An important problem of spring structure is sensitivity to mechanical forces such as acceleration and vibration. Another problem is that reducing the voltage would eliminates the electrostatic force applied to moving parts of switch and it reduces switching speed[10].

Electrical charges usually produce problems in RF MEMS capacitive elements and reduce the reliability of RF MEMS switches. Ya and et al in 2016 have presented a new method based on finite element method which analyzes the electrical charge effect on pull down voltage.[11] Different materials can be used as a dielectric layer in RF MEMS switches. Better isolation and loss could be achieved by a higher dielectric constant. In 2014, Mahesh and et al presented an RF MEMS switch which used HfO₂ as dielectric layer [8]. Therefore the switch has lower power loss and higher isolation. Also, due to spring structure of the switch, the actuation voltage is small. Various materials have been used as dielectric material such as Al₂O₃, SrTiO₃, Si₃N₄ [10].

Another important aspect of designing an RF MEMS switch is frequency bandwidth. In some applications, combinational switches have been used as series or parallel switches to increase frequency bandwidth. However, these switches have large insertion loss and also have a large cross-sectional area. In 2015 Bhattacharjee and et al have presented an RF MEMS switch which consists of two parallel capacitive bridges that can be used in higher frequency bands[12].

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In this paper, an RF MEMS switch is proposed which has fixed center connected the signal line. Dielectric in the proposed switch is Si$_3$N$_4$ and both sides of the switch are asymmetric to each other. The bridges have designed based on meanders to reduce the actuation voltages. In the following, simulations are presented for the proposed switch, conventional switch and the switch presented in [13].

2. Switch structure

Fig. 1.a shows a conventional switch that has a bridge with four flexures. The substrate has made of silicon. Also, the material of the proposed switch is gold which has been designed on a CPW line with demotions of 50-90-50. When no voltage applied to the electrodes, because of the large gap, the capacitance is very low. Therefore high-frequency signal transmitted through the transmission line. When an appropriate actuation voltage is applied to the electrodes, the bridge is pulled down, due to electrostatic force, thus the capacitance between switching plate and transmission line increases. As a result, radio frequency signal transmits to the ground through coupled capacitors. In this case, the switch changes to OFF state. If the applied voltage is removed, the bridge mechanical stress returns it to its original state and thus RF signal can be transmitted through the transmission line. Fig. 1.b shows the structure of the switch that has been proposed by Ya and et al [11]. Middle of the bridge is fixed on the transmission line. Both sides of the bridge are similar to each other. When one side of the bridge is pulled down, the capacitance is less than the situation which both sides of the bridge are pulled down. So minimum of isolation values occurs at higher frequencies. This switch can be used for wider frequency band [11].

Fig.1.c shows the structure of the proposed switch. Middle of the bridge is fixed on the signal line. Two sides of the proposed switch are designed based on meanders and are asymmetric to each other. As a result, different capacitances are created on each side of the bridge. Ergo, each side of the bridge can be used for different frequency bands. Fig. 2.a illustrates the spring structure of the proposed switch which has designed based on meanders structure. $a$, $b$ and $w$ are primary meander, length of the secondary meander and width of the bridges, respectively. Since the switch has a serpentine structure, it has lower spring constant. As a result, the actuation voltage is smaller than other structures presented in Fig.1.

Fig. 2.b shows a cross-section of the proposed switch. The electrodes have made of aluminum. Silicon nitrate is used as the dielectric material. Since the amount of $\varepsilon_r$ for silicon nitrate is almost twice as

### Table 1: Demotions of the designed switches

<table>
<thead>
<tr>
<th>Demotions</th>
<th>value(um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CPW</td>
<td>55-90-55</td>
</tr>
<tr>
<td>2 substrate</td>
<td>200</td>
</tr>
<tr>
<td>3 Length of a in left switch</td>
<td>50</td>
</tr>
<tr>
<td>4 Length of b in left switch</td>
<td>100</td>
</tr>
<tr>
<td>5 Width of w in left switch</td>
<td>10</td>
</tr>
<tr>
<td>6 Length of a in left switch</td>
<td>60</td>
</tr>
<tr>
<td>7 Length of b in left switch</td>
<td>120</td>
</tr>
<tr>
<td>8 Width of w in left switch</td>
<td>20</td>
</tr>
<tr>
<td>9 Thickness of gold</td>
<td>2</td>
</tr>
<tr>
<td>10 Gap</td>
<td>2</td>
</tr>
<tr>
<td>11 Thickness of Si$_3$N$_4$</td>
<td>0.1</td>
</tr>
</tbody>
</table>
silicon dioxide, insertion loss has improved in comparison to a conventional switch that usually uses the silicon dioxide as a dielectric material. Table 1 shows the dimensions of the proposed switch.

3. Pulling voltage
When no voltage is applied to the electrode, the switch is in up-state and so the signal passes through the transmission line. If an electrostatic voltage is applied to an electrode that has been located under one of the bridges, the bridge is pulled down. Pulling down voltage can be obtained as follow [4]:

$$V_m = \left(\frac{2}{3} s_0 + \frac{t_{e'}}{\varepsilon_r} \right) \sqrt{\frac{2k\varepsilon_0}{3s_0A}}$$  \hspace{1cm} (1)

As it is apparent from Eq. (1), increase in spring constant causes increment in required electrostatic actuation voltage. Since the proposed switch has lower spring constant, actuation voltage has been reduced compared to conventional switch. Also, $\varepsilon_r$ for silicon nitrate is almost twice as silicon dioxide so the actuation voltage has decreased.

The proposed switch is activated by an electrostatic voltage. Fig. 3 shows the curve of displacement in terms of voltage changes for the conventional switch, and the proposed switch. When the air gap is reduced to 0.33 $\mu$m, the electrostatic force will be more effective than increasing restore force and thus beams reach into an unstable position and switch changes to OFF state. As is observed from Fig.3 actuation voltage for the left bridge, right bridge and the conventional switch are 4.1, 4.8 and 10.6 volts, respectively.

Also displacement equation in terms of time is simulated with MATLAB for the proposed switch and the conventional switch. Fig. 4 shows results of the simulation. Normally with increasing in actuation voltage switching time reduces. Switching time for the conventional switch, right bridge and the left bridge is 6 $\mu$s, 13 $\mu$s and 16 $\mu$s respectively.

4. Frequency response
In parallel capacitor Switch, frequency response is a function of up-state capacitance to down-state capacitance that can be obtained as follow:

$$C_{\text{ratio}} = \frac{C_{\text{down}}}{C_{\text{up}}} = \frac{\varepsilon_r A_{\text{down}}}{t_{e'} A_{\text{up}}}$$  \hspace{1cm} (2)

Where $A_{\text{up}}$ and $A_{\text{down}}$ are capacitance overlap area in upstate and downstate respectively. The more value for $C_{\text{ratio}}$ ends up to the better frequency response. In the conventional switch, silicon dioxide has been used as the dielectric material with $\varepsilon_r = 3.9$ whereas in the proposed switch silicon nitrate has been used with $\varepsilon_r = 7.6$. Due to the fact that $\varepsilon_r$ is directly related to $C_{\text{ratio}}$, it’s expected that frequency response improves in proposed switch in comparison with the conventional switch. To illustrate the frequency response of the switches, the simulations in HFSS are presented in next parts.

4.1. ON state
When no voltage applied to the electrodes both of the bridges are in upstate and so the RF signal can be transmitted through the transmission line. In this case, insertion loss value can be defined for evaluation of the switch performance. The value is equal to the amount of transmitted power to submitted power. Fig. 5 illustrates the insertion loss graphs for the conventional switches and proposed switches. As is clear, insertion loss value between 0 and -2.55dB is observed for the conventional switch and some values between 0 to -1.5dB for the proposed switch. Also, return loss is defined to evaluate the performance of the switch in the upstate that is equal to the amount of returned power to the submitted power. Fig. 6 shows the amount of return loss for the proposed switches and the
conventional switch. It is a value between -0.9dB to -27.5dB for the conventional switch while it is -6dB to -30dB for the proposed switch.

4.2. OFF state
By applying an electrostatic voltage to one of the electrodes, the bridge is pulled down and therefore capacitance increases. In the situation that both of the bridges are down, capacitance is much greater than the state which one of the bridge is down. Frequency response is a function of capacitance and inductance values so minimum values for isolation occurs at higher frequencies. Similarly, when the right bridge is actuated, minimum value happens at higher frequencies in comparison with the case that left bridge is actuated. This feature makes the switch suitable to use in different frequency bands.

Fig. 7 illustrate isolation graph for the conventional switch and the proposed switch. When both of the bridges are down, the minimum of isolation is -46dB at 15.5GHz while it is -40dB at 14.8GHz for the conventional structure. And also for the case that the left bridge or the right bridge is down, the minimum of isolation is equal to -29dB and -30dB in 8.4GHz and 9.6GHz, respectively. In addition to applications in different frequency bands, isolation has been improved in the proposed switch rather than conventional switch because, in the proposed switch, silicon nitrate has been used as the dielectric material. Another parameter which is used to evaluate RF switch performance, is return loss. Fig. 8 shows the return loss for the switches. Minimum of return loss happens in frequency that insertion loss is max. It can be seen that return loss graph for the conventional switch and the proposed switches is nearly coincident. Less return loss means that better RF performance is achieved. So in the state that both of the bridge are down, capacitance is larger and RF performance is better than the state which the left bridge or the right bridge is down.

4.3. Bandwidth
Usually, for calculation of bandwidth, a maximum value of 0.2dB is considered for insertion loss. Similarly, a minimum value of 20dB is considered for isolation. According to Fig. 7, a value between 10.4GHz to 19.2GHz is observed for the conventional switch bandwidth and 7.6GHz to 20GHz for the proposed switch that is approximately 1.4 times larger than the conventional switch bandwidth. The switch structure which introduced by Ya et al has been simulated in Fig. 9 and Fig. 10. Fig. 9 shows isolation diagrams of the switches whenever the left bridges are down in both proposed and Ya et al structures. Similarly, Fig. 10 shows isolation for the state that right bridges are down. Since the two sides of the switches which presented by Ya are symmetrical to each other, isolation diagram for the states that left bridge or right bridge are pulled down are the same. In comparison, both sides of the proposed switch are
asymmetrical and three different capacitance values can be achieved by actuating each or both of the bridges. Briefly, proposed structure can be implemented for larger band width in comparison with conventional switch and the structure introduced by Ya et al.

5. Concluding Remarks
In this paper an RF MEMS switch is presented which consists of two unsimilar bridges. There are two individual electrodes which are actuated by electrostatic forces. Serpentine springs connect the bridges to anchors in order to suspend them near to ground microstrip with a 2 micron gap. Spring constants can be tuned well, using serpentine structure. Regarding to some fabrication limitation, serpentine springs would be better than cantilever structures. In addition dissimilarity between two bridges would increase switch band width. The simulation results show that proposed structure can reduce actuating voltage to half in comparison with conventional switch structure. In addition, band width increases 1.4 times more than conventional switch structure. Regarding to another work which has been proposed recently, the bandwidth has been improved.

6. References
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