RF-MEMS Capacitive Series Switches of CPW & MSL Configurations for Reconfigurable Antenna Application

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Abstract: The air-bridged RF-MEMS switches in single pole single through (SPST) transmission lines are presented for reconfigurable antenna application. The RF characteristics of capacitive series switches are analyzed, measured, and compared with microstrip line (MSL) and coplanar waveguide (CPW) structures. RF-MEMS series switches are monolithic fabricated in both transmission line structures on glass substrate of dielectric constant, $\varepsilon_r = 7.4$. The reconfigurable multi-beam spiral antenna ($\nu = 11$ GHz), which is monolithic integrated with RF-MEMS capacitive series switches on the same glass substrates is also presented as an example of the use of in-line MEMS series switches for reconfigurable antenna applications.

Introduction: The radio frequency-micro electro mechanical system (RF-MEMS) switches have been integrated for reconfigurable circuits in the past decades [1-2]. The reconfigurable antenna using RF-MEMS switches has been demonstrated with superior performances [3]. This reconfigurability has highlighted advantages of the RF-MEMS switches.

In this paper, RF-MEMS capacitive (metal-insulator-metal) series switches are fabricated in CPW and MSL transmission lines to investigate their RF-characteristics for reconfigurable antenna application. The series switches are monolithic fabricated on the same glass substrate with spiral antenna to configure multi-beam by changing spiral arm length. This technique has advantages of its low-cost by monolithic fabrication process and multi-beam forming in communication systems.

I. In-line RF-MEMS capacitive series switch:

A. Geometry and fabrication: Inline RF-MEMS capacitive series switches of fixed-fixed metal beam in SPST configuration are designed. Switches are configured in two types of transmission lines, coplanar waveguide (CPW: Fig.1 (a)) and microstripline (MSL: Fig.1 (b)). The RF-MEMS switches are fabricated on a rigid glass substrate (MICA: $\varepsilon_r = 7.4$) in order to measure their RF-performances. The thickness of the glass substrate is 1.2 mm. The metal layers are made of 0.1 $\mu$m-Ti, deposited on the glass substrate and 0.5 $\mu$m-Au, deposited on top of the Ti. The line length, $L$, is 3.5 mm for both CPW and MSL configuration. For the CPW transmission line configuration, signal line width is 500 $\mu$m and CPW gap (ground to signal line) is 150 $\mu$m to provide 50 $\Omega$-characteristic impedance. The MSL width, satisfying 50 $\Omega$-characteristic impedance, is about 1.7 mm. The schematic view of MEMS switch is shown in Fig.1 (c). The dimensions of RF-MEMS switch in both configurations are the same. The width of bottom electrode is 200 $\mu$m for both switches. A dielectric film (silicon nitride) of 2000 Å is deposited on the bottom electrode for the dielectric isolation. The thickness of metallic membrane (Al or Au) is 5000 Å, and length is fixed to 400 $\mu$m. Membrane width ($W$), which determines overlapping area ($A$) between bottom electrode and membrane, contributes most to the down capacitance and its width is 200 $\mu$m including releasing holes. Pull down voltage is 40 V.

B. Simulation and measurement results: The RF-MEMS capacitive series switch can be modeled by a series resonance circuit, constituted by a resistance ($R$), a capacitance ($C$), and an
inductance (L). RF measurements have been performed using a HP 8510C network analyzer connected to a cascade probe station. The simulated, measured isolation and insertion loss of inline RF-MEMS capacitive series switch of CPW and MSL configurations are shown in Fig. 2. Membrane height (H) from the bottom electrode is 5 µm in up-state. The up-state capacitance (C_u) of capacitive series switch is 4–5 times higher than that of resistive series switches [2]. Therefore, capacitive series switch has lower isolation than that of resistive series switch at the same frequency. The up-state capacitance (C_u) is 50 fF. Downstate capacitance (C_d) is ideally 7 pF in perfect contact between membrane and bottom electrode. The ratio of capacitance between up/down states is 140. In the simulation, the down-state capacitance has been 3 ~ 5 pF due to the presence of 20 nm ~ 50 nm gaps between metallic membrane and bottom electrode produced by the roughness of bottom electrode, dielectric material, and metallic membrane. The isolation (S_{21} of switched “off” state) decreases by increasing frequency as shown in Fig. 2. The measured isolation is −30.7 dB to −10.5 dB, and insertion loss is −0.18 dB to −0.31 dB at 1 to 10 GHz, in CPW configuration, respectively. The measured isolation is -29.3 dB to -9.7 dB, and insertion loss is – 0.07 dB to – 0.34 dB at 1 to 10 GHz, in MSL configuration, respectively. The measurement results are matched well with simulation. The isolation and insertion loss are slightly different between two structures, about 1 ~ 2 dB for isolation, and 0.01 ~ 0.2 dB for insertion loss at the same frequency band, due to the differences between geometric configurations of transmission lines (MSL and CPW).

II. Reconfigurable antenna application:

A. Geometry and fabrication: We use RF-MEMS capacitive series switch integrated in a spiral antenna in order to turn the radiation beam direction by changing the length of the spiral antenna [4]. Two RF-MEMS series switches (M_1 and M_2) are monolithic integrated in spiral line on rigid glass substrate (\epsilon_r = 7.4 and thickness of 2.4 mm) as the same monolithic fabrication process with series switches in transmission lines as shown in Fig. 1. The dimension of RF-MEMS capacitive series switches, used in spiral line, is the same with that of series switches as shown in Fig. 1. Outer feeding using microstrip-feeding line is used as shown in Fig. 3. The winding direction of proposed antenna is left-handed. Therefore, antenna radiates left hand circular polarization (LHCP). We used two-switches to get three different beam directions by spiral arm length changes. The spiral arm lengths, L_1 (from S to M1), L_2 (from S to M2), and L_3 (from S to E), are determined as the distance from the feeding point, S, to the last RF-MEMS switch in the “off” state (M_1 and M_2) and ending point E for both substrates. The size of the substrate is 15 mm X 17.5 mm. Ground reflector backs both substrates. Spiral line width is 0.5 mm.

B. Simulation and measurement results: The operating frequency of the antenna is chosen to be 11 GHz (\lambda_o = 27.3 mm). The proposed antenna has three different maximum beam directions by three different spiral arm lengths, L_1 ~ L_3. The spiral arm lengths, L_1 ~ L_3, are determined from axial ratio and gain at the maximum beam direction of LHCP using full wave analysis, HFSS [4]. The spiral arm lengths is determined to L_1 = 0.23 \lambda_o, L_2 = 0.86 \lambda_o, and L_3 = 2.2 \lambda_o as shown in Fig. 3 (a). The maximum beam directions of spiral arm lengths, L_1 ~ L_3, are summarized in table 1. The variation of maximum beam directions is from 34° to 42° in its elevation angle (\theta) and from -29° to 14° in its azimuth angle (\phi) respectively. Axial ratio and gain at the maximum beam direction of LHCP is also summarized in table 1. Axial ratios of spiral arm lengths, L_1 ~ L_3, are under 3 dB. The antenna gain is achieved between 1.1 and 2.5 dBi. Measured return loss of the reconfigurable spiral antenna is shown in Fig. 4. Return losses of reconfigurable antenna is under −10 dB at operating frequency 11 GHz. Return loss shows the wide frequency band (> 3GHz) characteristic of the spiral antenna. The simulation and measurement results of CP radiation pattern are shown in Fig. 5. The radiation patterns of CP are plotted in elevation angle at the maximum azimuth (\phi) cut. The overall CP-radiations are matched well with simulation result as summarized in table 1.
**Conclusion:** The monolithic integrated RF-MEMS capacitive series switches are analyzed, measured, and compared with both microstrip line (MSL) and coplanar waveguide (CPW) structures. The isolation is $-30.7 \text{ dB}$ to $-10.5 \text{ dB}$, and insertion loss is $-0.18 \text{ dB}$ to $-0.31 \text{ dB}$ at 1 to 10 GHz, in CPW configuration. The isolation is $-29.3 \text{ dB}$ to $-9.7 \text{ dB}$, and insertion loss is $-0.07 \text{ dB}$ to $-0.34 \text{ dB}$ at 1 to 10 GHz, in MSL configuration. The reconfigurable multi-beam spiral antennas fabricated on rigid glass substrates are introduced for an example of the use of inline series switches. Reconfigurable spiral antenna radiates three different LHCP beams by three spiral arm lengths, $L_1$, $L_2$, and $L_3$.

**REFERENCES**


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**Fig. 1.** Geometry and microscopic picture of RF-MEMS capacitive series switches. (a) CPW configuration. (b) MSL configuration. (c) Top and side view of functional diagram.

**Fig. 2.** Simulated, measured isolation and insertion losses of RF-MEMS capacitive series switch in transmission lines. (a) CPW configuration. (b) MSL configuration.
<table>
<thead>
<tr>
<th>Antenna state</th>
<th>State of MEMS switch</th>
<th>Spiral arm length ($\lambda_o$)</th>
<th>Max. beam direction (degree)</th>
<th>Axial ratio (dB)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$</td>
<td>M1: off, M2: off</td>
<td>0.23</td>
<td>Theta: 42, Phi: -29</td>
<td>2.6</td>
<td>1.1</td>
</tr>
<tr>
<td>$L_2$</td>
<td>M1: on, M2: off</td>
<td>0.86</td>
<td>Theta: 38, Phi: -8</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$L_3$</td>
<td>M1: on, M2: on</td>
<td>2.2</td>
<td>Theta: 34, Phi: 14</td>
<td>1.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 1. The summary of maximum beam direction of LHCP, axial ratio, and gain.

Fig. 3. A reconfigurable multi-beam spiral antenna. (a) A fabricated reconfigurable antenna on glass substrate. (b) Microscopic view of a RF-MEMS capacitive series switch. (c) Up-state of metallic membrane.

Fig. 4. Measured return losses of the reconfigurable spiral antenna.

(a) $L_1$, \( \phi = -29^\circ \)  
(b) $L_2$, \( \phi = -8^\circ \)  
(c) $L_3$, \( \phi = 14^\circ \)  

Fig. 5. Measured and simulated radiation patterns of a reconfigurable multi-beam spiral antenna. (a) $L_1$, \( \phi = -29^\circ \), (b) $L_2$, \( \phi = -8^\circ \), and (c) $L_3$, \( \phi = 14^\circ \).