Design Considerations of Reconfigurable Antennas using MEMS Switches

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ABSTRACT

In this paper, reconfigurable antenna design consideration is discussed. The antenna design constrains are base on the use of radio frequency microelectromechanical system (RF MEMS) switches. The design consideration includes practical issues in using the switches to either change the antenna feeding networks or change the antenna topologies. In the first design, a coplanar waveguide (CPW)-to-microstripline transition technique is used to integrate the small switches onto the antenna feeding networks to achieve beam steering. In the second design, the switches are used to change the antenna ground plane topology to achieve frequency switching. Both antennas are modeled using our Finite-Difference Time-Domain (FDTD) simulator. The beam steering antenna will be capable of more than 60° scanning angles and the frequency switching antenna can operate at 2.4GHz and 5.8 GHz for WLAN applications.

Keywords: reconfigurable antennas, MEMS, RF MEMS, beam steering, smart antennas

1. INTORDUCTION

Recently, many efforts have been carried out making antennas reconfigurable to improve performance and flexibility of wireless systems for applications such as high-capacity dynamic mobile communications, smart tracking systems and reconfigurable sensor networks. RF MEMS becomes one of the most promising RF switch technologies for this purpose over PIN diode and GaAs switches because of its low insertion loss, low power consumption and potentially low manufacturing costs. Thus, there is a great need in the antenna designs to accommodate RF MEMS uses. Currently, there are few commercial MEMS switches available in the market. Some of them are made by *Teravicta* [1], *Radant MEMS* [2] and *Dowkey Microwave* [3]. In general, as shown in Fig. 1, the overall size of the packaged switches is less than 5 mm with pad sizes less than 0.5 mm in diameter.

With limited commercial availability, they are not directly suitable for many antenna applications, either by putting them onto the antenna-radiating elements or in the feeding structures, because of the size and impedance mismatch. The antenna is designed to radiate electromagnetic waves efficiently, and therefore, the area of radiating element has certain sizes that may not be in the similar scales with the MEMS devices. The same situation is applied to the feeding structure as well, where the feeding line dimensions and impedance may not match with the switches.

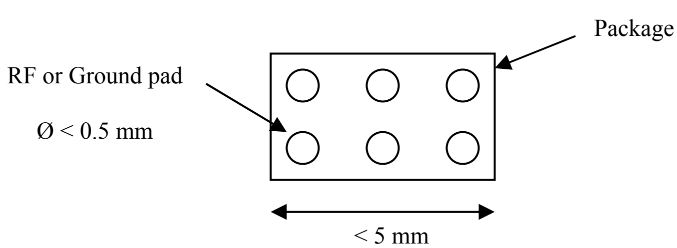

Figure 1. A possible package of RF MEMS switches.

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In the past, many reconfigurable antenna designs using RF MEMS switches have been proposed. However, due to the lack of commercially available MEMS switches, some designers [4-7] utilized the open or short circuit of a copper strip to emulate the ON or OFF status in the MEMS structures. In practical sense, the conductor in the antenna is usually much larger than the metal width in the MEMS switch. The transmission line impedance in the MEMS switch might not match with that of the antenna. Also for the same reason, if a MEMS switch is used in feeding networks, a transmission line transition technique is needed. Ideally, if RF MEMS devices are used, the performance of the antenna should not depend on the size of the devices or impedance dependent.

2. RECONFIGURABLE BEAM STEERING ANTENNAS

Phased-array antennas with phase shifters are a common means to achieve beam steering. A slot feed antenna array is used to demonstrate the beam steering capability. We design a 2-patch array antenna, as shown in Fig. 2, composing of 2 layers of *Rogers* RO4003C (ε_r = 3.38) 813-μm thick substrate, and 3 copper layers with a thickness of 35 μm each. The top layer has 2 patches of 15×15 mm and they couple the fields to the slots below. The slots isolate radiation interference from the feeding network to the patch antennas. The slots in the middle layer are 1.5×7 mm, and they are 1.75 mm from the edge of the patch to match the impedance of the patches and the feeding lines.

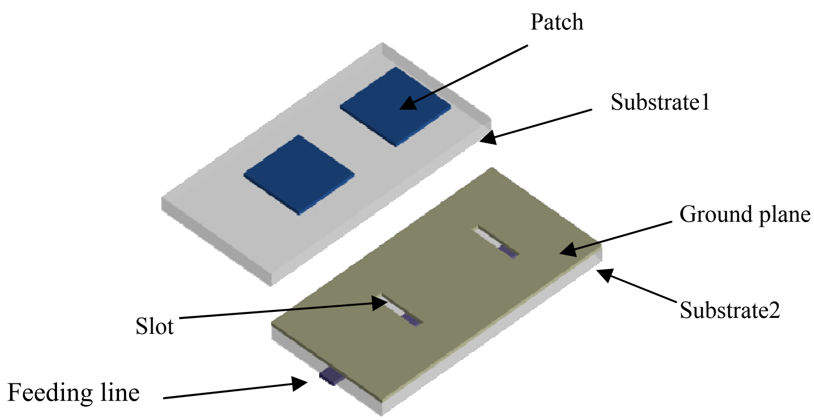


Figure 2. Slot feed patch array antenna array.

Most of the commercially available MEMS switches are designed to have a 50-Ω impedance. The transmission line connected to the switch should have a characteristic impedance of 50 Ω as well. Therefore, the feeding line on the bottom layer is chosen to be 1.8 mm wide microstripline, which has an impedance of 50 Ω. The spacing between the patches is design to be one wavelength, which is 29.5 mm at 5 GHz. The total size of the antenna is 6.3×5.6cm^2.

With in-phase feeding to the slot feed antennas, the beam direction of the array is perpendicular to the substrate (0°). To achieve beam steering, MEMS switches are used to reconfigure the delay feeding line between the patches. The packaged MEMS switches have contact pads of less than 0.5 mm width, much smaller than the 1.8-mm width of the microstrip feeding line, it is difficult to attach the switches onto the feeding line directly. Both sizes and impedance transition between these 2 elements need to be considered. One of the transmission line architecture that can achieve a 50-Ω impedance with such a small size is the coplanar waveguide (CPW). The CPW-to-microstrip transition [8, 9] is thus used to match the feeding line and the switch.

2.1. CPW to microstrip transition

A typical CPW-to-microstrip transition structure is shown in Fig. 3. The ground plane continues from under the microstripline to under the CPW line, and it becomes a conductor back CPW (CPWG). The characteristic impedance of the CPWG can be considered as two characteristic impedances of CPW and microstripline [8, 9] in parallel. A two-step

CPWG is designed with a center conductor width of 500 µm and 500-µm ground spacing in the first section, where the MEMS switch will be connected. The second section has a center conductor of 800 µm, and a ground spacing of 2.55 mm, which connects to a 1.8-mm wide microstrip feeding line. Both sections of CPWG achieve 50-Ω impedance and the junction reflection is minimized. The 50-Ω-1.8-mm wide feeding line is then transformed to a 50-Ω-500-µm one that is physically compatible to connect to the MEMS switch. The same technique can be used with any size of the switches.

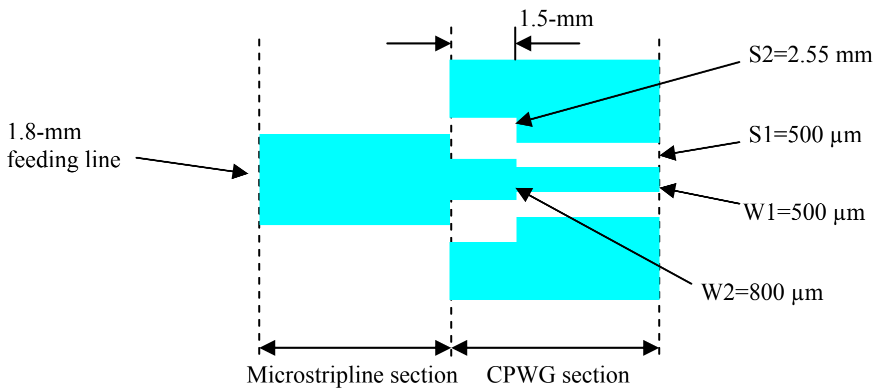


Figure 3. The CPW-to-microstrip transition.

2.2. MEMS switch phase shifter

The delay line architecture is used to realize phase shifting by changing the path length in the feeding line. The switch functionality is emulated by shorting or opening the center conductor of the CPWG. Three beam steering conditions are simulated with FDTD with three delay paths, as shown in Fig. 4. The switching between paths can be carried out by two single-pole-three-throw (SP3T) switches. The feeding line is designed to give the best performance for the center path, which results in a total length of 5.1 cm. The performance of the antenna is shown in Fig. 5. In Fig. 5 (a), the s_{11} is lower than –30 dB when the antenna operates with the switch connecting the center path. However the s_{11} degrades to about -6 dB when the switch feeds the lower path. This is mainly due to the total length in the feeding line does not match the resonant length at the 5 GHz. To improve s_{11}, we reduce the length of the feeding line by 2.5 mm to change the reactance. The s_{11} improves to about -15 dB, as shown in Fig. 5(b). Therefore, in a reconfigurable antenna using the similar delay lines, one extra switch is needed to adjust the total length of the feeding line in order to reach better performance.

The E-plane radiation patterns of the antenna are shown in Fig. 6. The beam peaks are at 0°, -30°and +30°. The scanning ability of the antenna array is 60° with three delay paths.

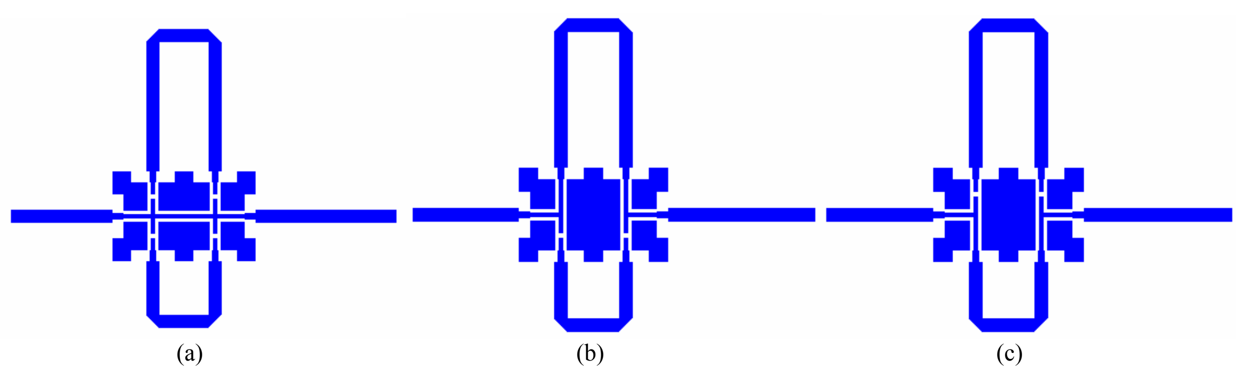
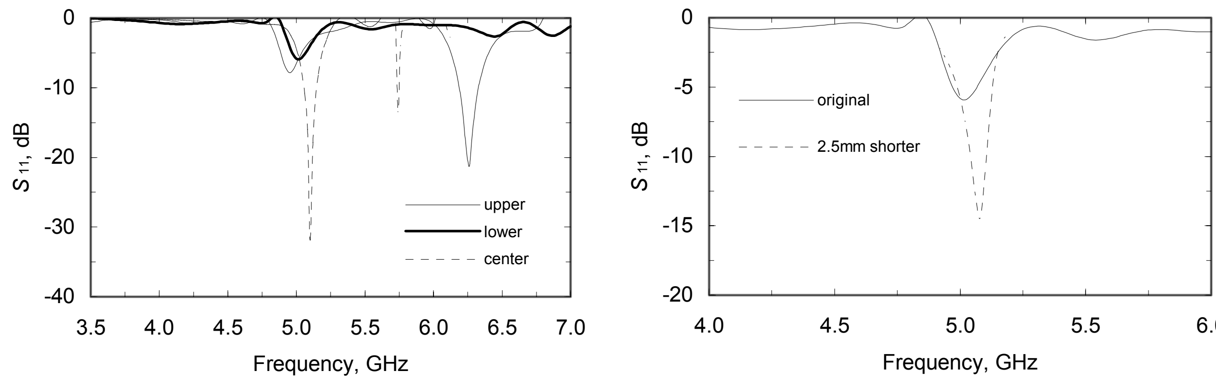
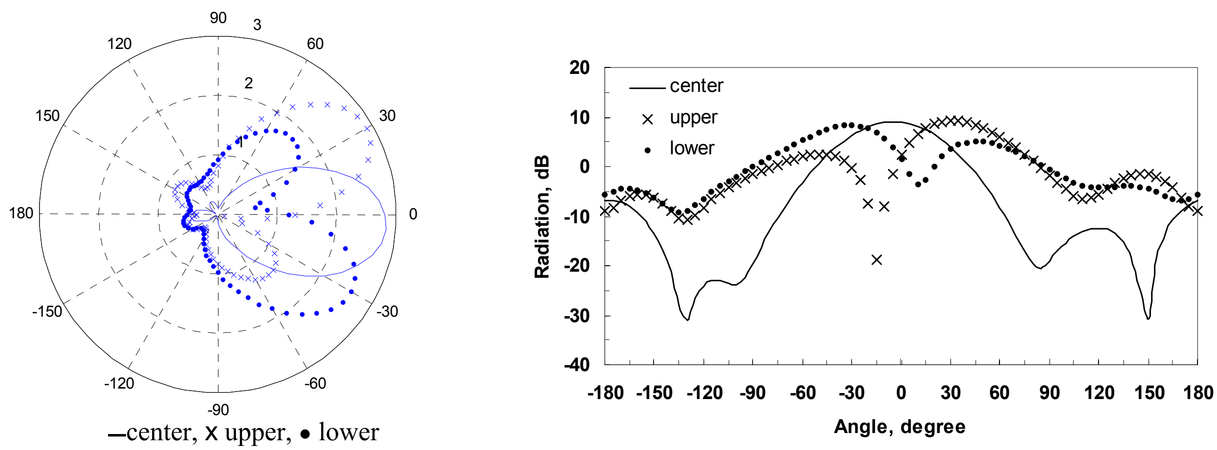


Figure 4. Feeding line with CPW-to-microstrip transition. (a) Center path. (b) Upper path. (c) Lower path.



(a) (b)

Figure 5. Reflection coefficient s_{11} of the antenna with the feeding lines in Fig. 4. (a) When operating with different paths and (b) the improvement of s_{11} by reducing the length of feeding line in lower path.



(a) (b)

Figure 6. Radiation patterns of the antenna in (a) a polar plot and (b) a dB plot.

3. FREQUENCY RECONFIGURABLE ANTENNAS

Frequency switching is another potential application of the reconfigurable antenna. Using RF MEMS switches on a transmission line faces issues and consideration in both size and impedance mismatch. Due to the lack of standardized MEMS packages, the entire system dimensions needs to be redesigned for different switches. For different antenna or feeding line dimensions, antenna resonant frequencies and patterns vary. Instead of using the switch on the signal path, we proposed to use the switch on the ground plane to avoid changing the feeding line dimensions directly. In this case, the change in the switch (or package) dimensions will not affect the antenna performance.

We design a CPW feed slot dipole antenna operated at 2.4 GHz as shown in Fig. 7. The substrate is RO4003C with ε_r = 3.38 and a 813-μm thickness. The CPW feed is chosen to be 50 Ω with the dimensions of W1=3mm and S1=300 μm, which fits to a typical SMA connector. The CPW dimension is expanded to W2=6.4 mm, S2=640 μm with g=460 μm and l=1.95 mm to feed the slot of 4.18 mm x 4.01 cm. Fig. 7(a) shows the position of switches s1, s2 and s3. Two switches (s1, s2) are put in the slot to vary the slot length and operating frequency. Another switch (s3) is placed near the center conductor to extend the ground plane and adjust the impedance of the feeding line to match the slot impedance at different configurations. The switches are emulated by a metal connection with a 500-µm width in the ON state. The OFF state is emulated by a 400-µm gap. When s1, s2 are OFF, and s3 is ON, the slot length is 4.01 cm and the antenna operates at 2.4GHz. When s1, s2 are ON, and s3 is OFF, the slot length reduces to 1.68 cm, and the antenna operating frequency increases to 5.8 GHz. Fig. 7(b) and (c) show the antenna structure when operating at 2.4 GHz and 5.8 GHz, respectively. The simulation results of s_{11} are shown in Fig. 8 where the reflections are less than -15 dB in both cases. The radiation patterns are shown in Fig. 9. The patterns do not vary significantly with different operating frequencies.

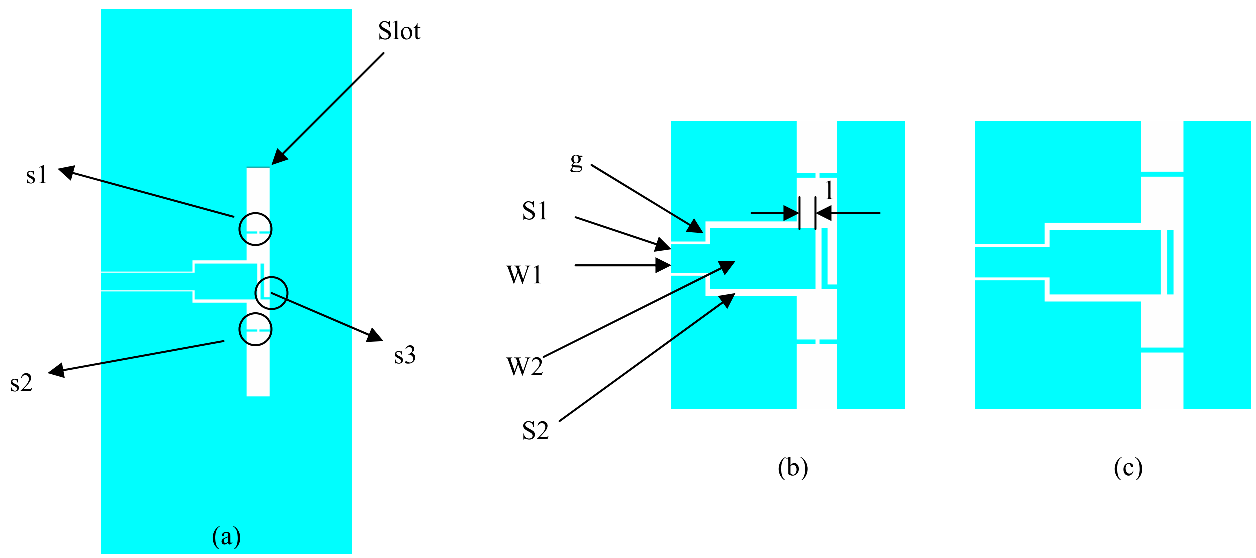


Figure 7. Configurations for the reconfigurable antenna. (a) Physical layout. (b) When operating at 2.4GHz and (c) when operating at 5.8 GHz.

We reduce the width of the MEMS switch from 500 µm to 250 µm to investigate the effects of MEMS device dimensions in our designs. The results in Fig. 10(a) show that the operating frequencies for the conductor width of 250 µm is about 200MHz or 3.5% lower than that of the 500-µm wide switch. Fig. 10(b) shows that there is almost no change in the antenna radiation pattern. This means the size of the switch has relatively little effect on the antenna performance.

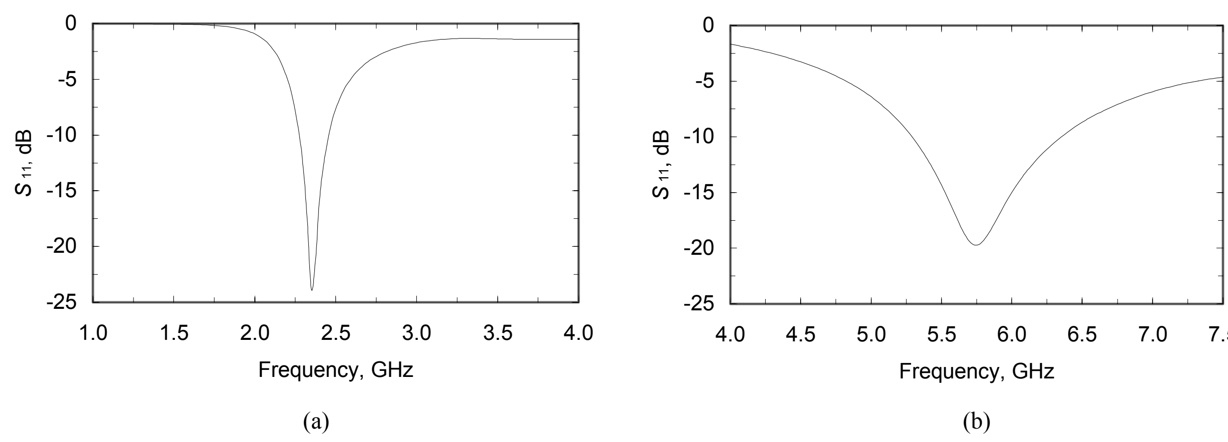
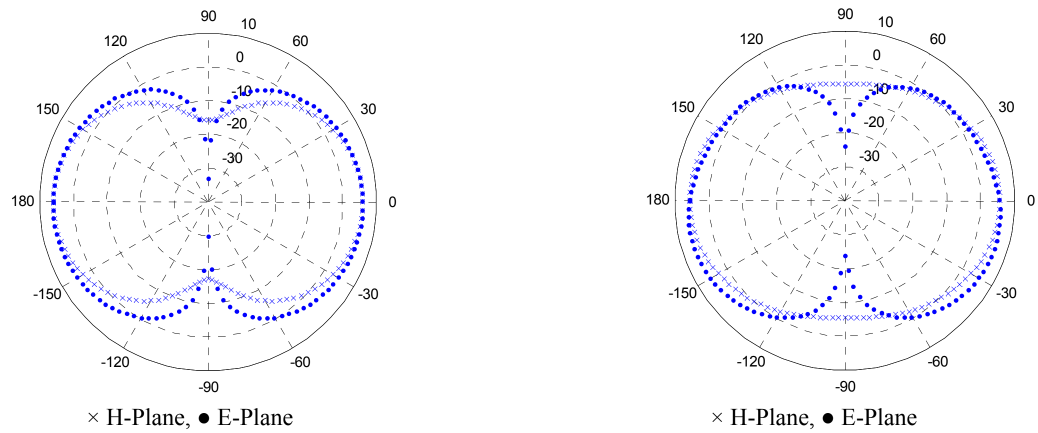
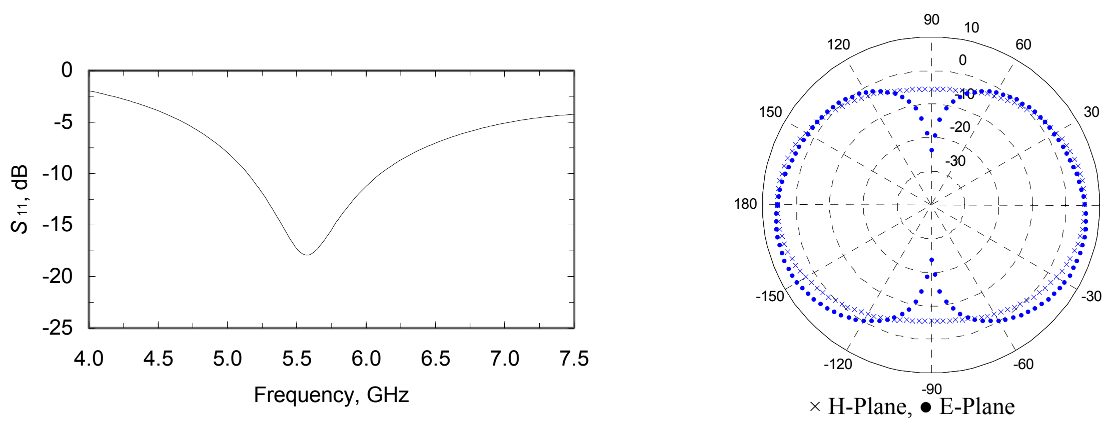


Figure 8. Reflection coefficient s_{11} results of the frequency reconfigurable antenna (a) at 2.4 GHz and (b) 5.8 GHz configurations.



(a) (b)

Figure 9. Radiation patterns of the frequency reconfigurable antenna (a) at 2.4 GHz and (b) at 5.8 GHz configurations.

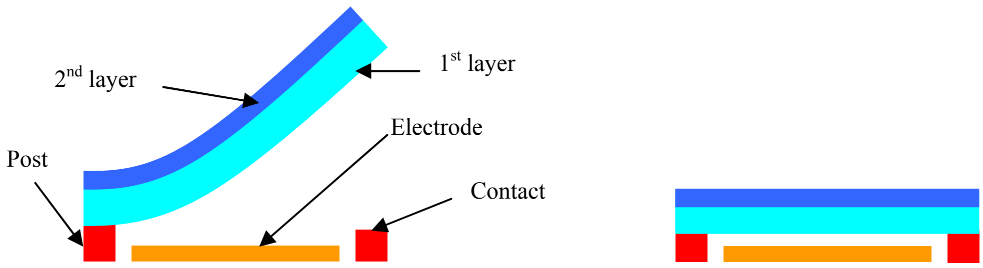


(a) (b)

Figure 10. Effect of the conductor width in the emulated switch when changed from 500 µm to 250 µm at 5.8 GHz. (a) s_{11} result and (b) radiation patterns.

4. MEMS SWITCHES

We designed and fabricated a bi-layer curled MEMS switch [10] that is suitable for our antenna designs. The switch structures compose of a movable cantilever and a fixed electrode. The cantilever is fabricated by 2 materials with different thermal expansion coefficients. After annealing, the residue stress in the materials pulls the cantilever up and provides the OFF state as shown in Fig. 11(a). By applying a DC voltage between the switch and the electrode, the switch will be pulled down by electrostatic forces, as shown in Fig. 11(b), and results in the ON state. Fig. 12 shows a photo of our switches fabricated by surface micromachining processes. The switch has a 1.5-µm thick silicon and a 0.5-µm thick metal. The bottom electrode is a layer of conductive polysilicon. The size of the switches is 300×1500 µm, which is a compatible size to be placed on the slot antenna to change the operating frequency. We will be investigating the integration issues of the MEMS switches on our antenna designs.



(a) (b)

Figure 11. Operation of a bi-layer curled MEMS switch. (a) OFF state and (b) ON state.

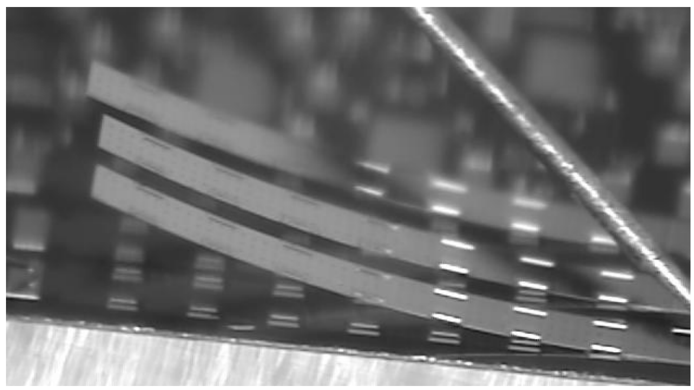


Figure 12. A photograph of the fabricated MEMS switches.

5. CONCLUSIONS

In this paper, we investigated the practical issues in using RF MEMS switch on the antenna structures. In the design of beam steering antennas, the size and the impedance issues can be accomplished by our CPW-to-microstrip transition technique. The simulation results show good matching at 5 GHz for all configurations of beam steering antenna with ±30° scanning. In our design for frequency reconfigurable antenna, the antenna performance does not depend on the switch size. The antenna can operate at 2.4 GHz and 5.8 GHz with s_{11} less than -15dB for both states. We designed and fabricated the bi-layer curled MEMS switches for the antenna. The preliminary results show that the DC voltage to pull the switch down is about 12 V. For the future work, the switches will be integrated onto the antennas.

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