Reconfigurable Dual-Band Dipole Antenna on Silicon using Series MEMS Switches

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Abstract
This paper presents a reconfigurable dual-band 4.86 and 8.98 GHz dipole antenna on silicon using series MEMS switches. The effects of series MEMS switches on the antenna performance are studied. The design is performed using the 3D electromagnetic simulator HFSS®. Using the designed series MEMS switches, the obtained antenna return loss is –10.2dB and –21.6dB, at the lower and upper frequencies, respectively. However, comparable to the case of ideal switches, a frequency shift of 0.4% and of 2.8% at the lower and upper frequencies, respectively, is observed. The antenna, including the MEMS switches, has bandwidth of 1.9% and 13.6% at the lower and upper frequencies, respectively. The antenna directivity is 2 dB at the lower frequency, and is 3 dB at the upper frequency.

I. Introduction

Reconfigurable multi-band antennas are attractive for many military and commercial applications where it is required to have a single antenna that can be dynamically reconfigured to transmit or receive on multiple frequency bands. Such common-aperture antennas result in considerable savings in size, weight and coast. They find application in space-based radar, communication satellites, electronic intelligence, aircraft and many other communications and sensing applications. The reconfigurable antenna can be envisioned as an array of elements that are resonant at the highest operation frequency f_{max}, and that can be connected together using switches to form groups of elements that are resonant at several lower frequencies f_{max}/n, where n is a scale factor related to the element groupings [1].

A critical component of the reconfigurable antenna is the switches or the relays used to interconnect the antenna elements. The insertion loss and the isolation of the switches used will dictate the performance of the overall reconfigurable antenna array. In this paper, the design and simulation details of a prototype reconfigurable dual-band (n=2) dipole antenna using series MEMS switches, is presented [2]. MEMS switches have advantages of wide bandwidth, low insertion loss (< 0.2 dB), and high isolation.

II. Design Procedure

A. Dual-Band Dipole (Ideal Switches)

The dual-band dipole antenna configuration is presented in figure 1. It consists of a High Resistivity Silicon (HRS) substrate (525µm) over which two layers of silicon dioxide and nitride are deposited SiO_2/Si_3N_4 (0.8µm/0.6µm). The dipole antenna is patterned on the topside of the wafer using 0.2µm gold electroplating technique [3].

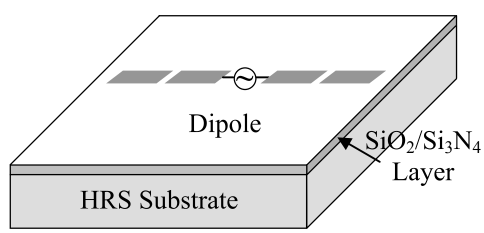

Figure 1: Dual-band dipole antenna

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To achieve the dual-band operation, a gap in each dipole arm is used. In addition, an ideal switch (ON/OFF) in the gap location is inserted. The short dipole (corresponding to the OFF state of the switch) resonates at the higher frequency band. On the other hand, the long dipole (corresponding to the ON state of the switch) resonates at the lower one.

B. Series MEMS Switch Design

A broadside high-isolation series MEMS switch is designed [2]. The switch configuration is presented in figure 2. The series switch is composed of an all-metal gold bridge suspended 1.5 µm over the dipole arm in the gap location. A gap of 80 µm is defined in the line. The bridge length is 300 µm, thickness 0.9 µm, and width 120 µm (thus insuring a 20 µm overlap with the line from each side). The bridge is anchored at both sides. Two pull-down electrodes are defined near both anchors of the switch. Figures 3 and 4 show the switch in the up and down states, respectively. When the switch is pulled down, it makes a metal-to-metal contact between the two sections of the dipole arm. The pull-down electrode area is 55x120 μm^2. In order to insure that the bridge makes good contacts with the line, the line is made 0.4 µm thicker than the pull-down electrode. The insertion of the narrow line (30 µm) reduces the up-state capacitance, due to fringing fields between the edges of the two main lines, and also provides better contact in the down state position.

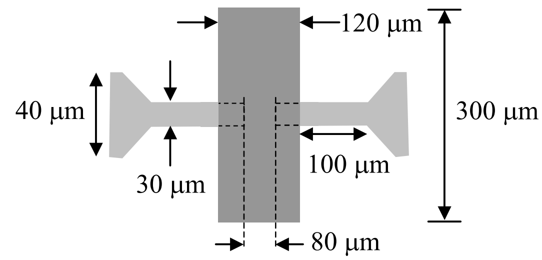

Figure 2: Broadside series MEMS switch

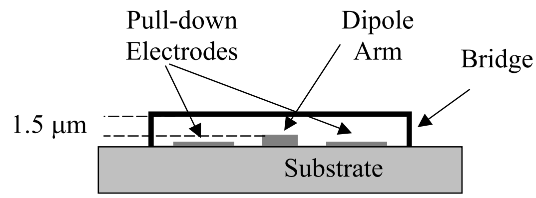

Figure 3: Switch in the up state

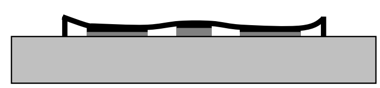

Figure 4: Switch in the down state

C. Dual-Band Dipole Antenna using MEMS Switches

The designed series MEMS switch is then used instead of the ideal switch to provide the dual-band reconfiguration. Firstly, the simulation of a series MEMS switch is performed to obtain its scattering parameters in the frequency range corresponding to the antenna resonance frequencies. Subsequently, the whole structure, including the two MEMS switches and the dipole arms, is simulated in both the up and the down states.

III. Results and Discussions

For reference purpose, the dual-band dipole antenna using ideal switches is studied. The dipole has the following dimensions: short arm case (OFF state) 7 mm, long arm case (ON state) 16 mm, arm width 40 µm, and metal thickness 2 µm. The dipole is fed at its center using 50Ω differential inputs. Return loss of -10.3dB at 4.88 GHz and of -23.8 dB at 9.24 GHz, are obtained. The bandwidth is 2.3% at the lower frequency band, and is 13% at the upper frequency band.

A separate series MEMS switch is designed and the simulation of its performance is carried out in the whole frequency range covering the two antenna resonance frequencies. Figures 5 and 6 show the scattering parameters of the switch in both the down and up states, respectively. In up state, isolation better than –25dB is observed over the entire frequency band 2-10 GHz. On the other hand, in the down state, the return loss is better than –15 dB over the entire frequency band 2-10 GHz and the insertion loss is less than 0.4 dB which agrees well with published data [2].

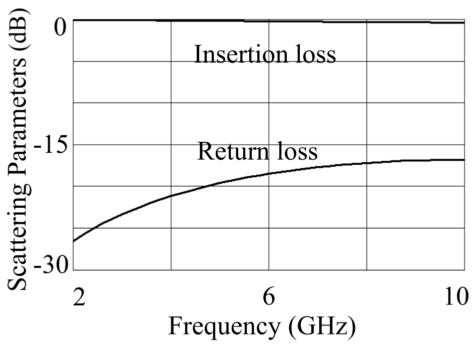

Figure 5: Switch scattering parameter (Down state)

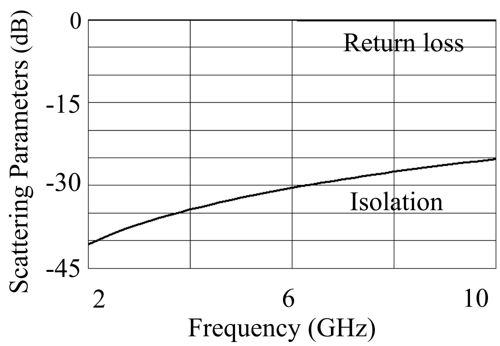

Figure 6: Switch scattering parameters (Up state)

Based on the results of the designed MEMS switch, the dual-band dipole antenna including two series MEMS switches is studied and compared to the case of ideal switches. The return loss of the dual-band dipole antenna with either two ideal switches or two MEMS switches in the up and down states, are shown in figures 7 and 8, respectively.

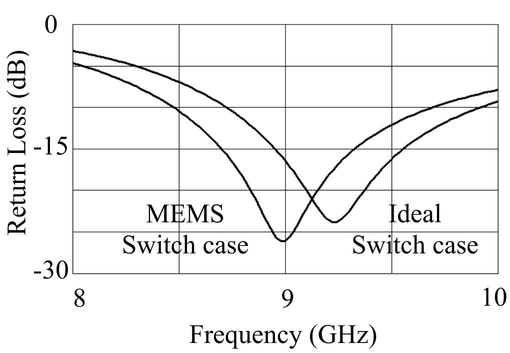

Figure 7: Antenna return loss (MEMS Switch in the up state, corresponding to 8.98 GHz)

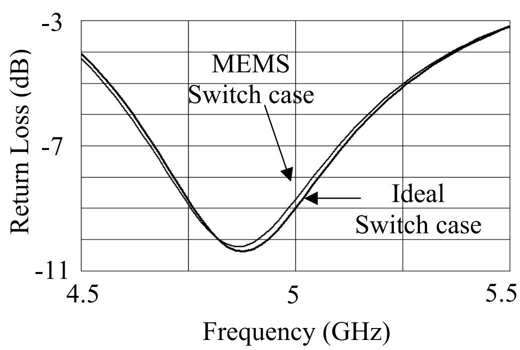

Figure 8: Antenna return loss (MEMS Switch in the down state, corresponding to 4.86 GHz)

The antenna has a return loss of -26.1 dB at 8.98 GHz and of -10.2 dB at 4.86 GHz, corresponding to the up and down states of the MEMS switches, respectively. The bandwidth of the antenna is 1.9% at the lower frequency band, and is 13.6 % at the upper frequency band. However, compared to the ideal switch case, a shift in the antenna resonance frequencies is observed. At the lower frequency band, where the performance of the MEMS switch is comparable to an ideal one, the shift in the resonance frequency is negligible and is equal to 0.4% with respect to the case of ideal switch. On the other hand, due to the MEMS up state capacitance, the shift in the resonance frequency at the higher frequency band is more significant and is equal to 2.8 % with respect to the case of ideal switch. The radiation pattern of the dipole antenna, including the MEMS switches, is presented in figures 9 and 10. The antenna directivity is 2 dB at the lower frequency band, and is 3 dB at the upper frequency band. The E-plane 3-dB beamwidth is 84 degrees at the lower frequency, and is 60 degrees at the higher frequency.

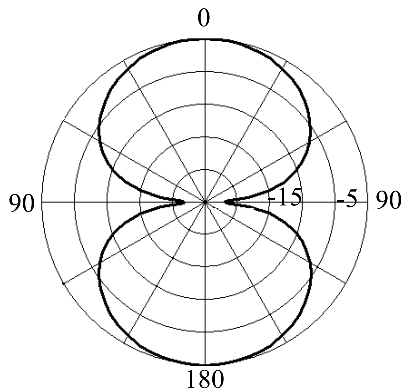

Figure 9: E-plane normalized (dB) radiation pattern (MEMS Switch in the down state)

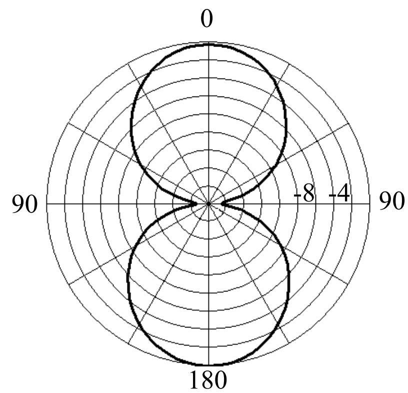

Figure 10: E-plane normalized (dB) radiation pattern (MEMS Switch in the down state)

IV. Conclusions

A reconfigurable dual-band dipole antenna operating at 4.86 and 8.98 GHz using MEMS switches over a HRS substrate is presented. The total substrate area is 1.6 cm^2, however this can be additionally reduced if the dipole arms are folded. The use of MEMS switches result in frequency shift at both frequencies. However, care must be taken especially at the high frequency band, where the effect of MEMS switch is more significant. The antenna, including the MEMS switches, has bandwidth of 1.9% and 13.6% at the lower and upper frequencies, respectively. The antenna radiation efficiency is 86% at the lower band, and 94% at the higher one. The dipole antenna has directivity of 2 dB and of 3 dB and at the lower and upper frequencies, respectively. The E-plane 3-dB beamwidth is wide and equals to 84 degrees at the low frequency, and to 60 degrees at the high frequency.

V. Acknowledgment

The authors would like to thank MEMScAP for their financial support of this work.

VI. References

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