Design of X-Band MEMS Microstrip Shunt Switches

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Abstract— **This paper presents the design and performance of X-band MEMS switches built in microstrip technology. The switches result in an insertion loss of less than 0.1 dB and a small isolation bandwidth, less than 10%, and are limited by the radial stubs bandwidths. The isolation value is also not dependent on the down-state capacitance of the switch. The isolation bandwidth (less than -20 dB isolation) is improved to 8-13 GHz with the use of a π-network and two MEMS switches. The up-state insertion loss of the π switch is less than 0.25 dB. The paper demonstrates that the performance of microstrip switch circuits *without* via-holes is dominated by the shorting (radial) stubs, and careful design must be done to result in an acceptable bandwidth of operation.**

Keywords—**MEMS, low-loss, micromachining, switches, microwave, millimeter-wave.**

I. INTRODUCTION

Micro-Electro-Mechanical-Systems (MEMS) electrostatically actuated reflective switches for low-loss microwave and mm-wave applications have been recently demonstrated [1], [2], [3], [4]. MEMS switches are composed of a thin metal membrane (or beam) which can be electrostatically actuated to the RF line using a DC bias voltage. The MEMS switch has very little DC power consumption (1-3 nJ during the switching process), allows for large down-state to up-state capacitance ratios (C_d/C_u = 20-100), has very low intermodulation products, and can be fabricated on almost any substrate. Several disadvantages include slow switching speeds (2-10 μs) and high actuation voltages (15-80 V).

This paper focuses on the design and measurement of microstrip shunt capacitive switches. This is a departure from the current literature which is on coplanar-waveguide (cpw) switches. The microstrip designs offer easier biasing of the individual switches, especially if a large number is used. However, it requires via-hole technology for obtaining a wideband short circuit to ground. This paper demonstrates that a single MEMS microstrip switch has a very small isolation bandwidth. However, it is possible to obtain wideband performance using two microstrip switches connected in a π configuration.

II. SINGLE MEMS SHUNT SWITCHES: DESIGN AND MEASUREMENTS

Fig. 1 shows a microstrip shunt capacitive MEMS switch which is connected to a $\lambda/4$ resonant stub. When the switch is in the up state position, the up-state capacitance is negligible (40-100 fF) and the switch has a very low insertion loss (less than 0.1 dB). When the switch is in the down-state position, the radial stub is connected to the microstrip line through the down-state capacitance (C_d =2-5 pF depending on the size of the switch) and the switch isolation is limited by the bandwidth of the radial stub.

The resonant frequency is dependent on the switch down-state capacitance and inductance values (Fig. 2). The response is very narrowband, and is given by the radial stub bandwidth. The switch inductance (10-20 pH) has a small effect since the stub inductance is around 400-500 pH. However, the switch down-state capacitance results in a considerable change in the resonant frequency for low capacitance values (1-3 pF) and in less change for high capacitance values (3-6 pF). This is expected due to the series combination between the down-state capacitance and the radial stub. Note that the isolation value is independent of the down-state capacitance and is limited to 35 dB by the series resistance of the switch and the radial stub (around 0.35 Ω).

In this design, the stub is 1,950 μm long and is designed to resonate at 8.3 GHz, with an equivalent series LC circuit of L=430 pH and C=850 fF (obtained using Libra). When the switch is connected to the stub with an expected capacitance of C_d=1.8 pF, the effective capacitance of the switch/stub combination decreases to 580 fF, resulting in a resonant frequency of 10 GHz.

The switches are fabricated on a 400 μm thick high-resistivity silicon wafer (2,000-3,000 Ω.cm). The microstrip lines are deposited using 2 μm thick gold and result in an attenuation of 0.5 dB/cm at 10 GHz. The MEMS bridge is fabricated using 1.5 μm sputtered gold layer and is suspended 1.5 μm above the microstrip line. The interlayer dielectric is 1500 Å of silicon nitride (ϵ_r = 7.6). The pull down voltage was more than 40 V since the MEMS bridges were slightly curved up.

Fig. 3 presents measurements done on a single microstrip switch in the up and down-state position. The reflection coefficient in the up-state is less than -25 dB from 8 to 12 GHz equivalent to an up-state capacitance of 40 fF. In fact, the switch is matched by the small sections of narrow microstrip line under the bridge which acts like an inductance. The down-state resonance occurs at 9.5 GHz for a stub length of 1,950 μm and a down-capacitance of 2.5 pF (L = 10 pH), and results in a 10 % isolation bandwidth at -20 dB. The measured loss in the up-state position is less than 0.1 dB at 10 GHz. The reference planes are 250 μm away from the bridge. Also the isolation bandwidth can be increased by using two stubs connected to the two edges of the MEMS bridge. In this case the -20 dB isolation bandwidth is increased to 18 %. The penalty paid is an increase in the size of the switch on the Si/GaAs wafer.

III. π MEMS SHUNT SWITCHES: DESIGN AND MEASUREMENTS

The bandwidth of the MEMS microstrip switch can be significantly improved if a π-circuit is used (Fig. 4) . The circuit consists of two MEMS switches connected by a *short* high-impedance transmission line. The π-circuit does two functions: First, it provides a good match in the up-state position ($S_{11} \leq$ -20 dB) over a wide bandwidth. Second, one can design the stub lengths so as to result in a wide isolation bandwidth. Fig. 5 shows the response of two π designs, with C_u=40 fF, L= 10 pH, C_d=1.8 pF, and with either equal stub lengths on both switches (1,950 μm) or with different stub lengths (1,800 μm and 2,300 μm). The mid-section impedance is 60 Ω with a length of 1,000 μm. The different stub lengths result in an "elliptic" low-pass filter response with a ripple of less than -30 dB over 8.5-11.3 GHz bandwidth.

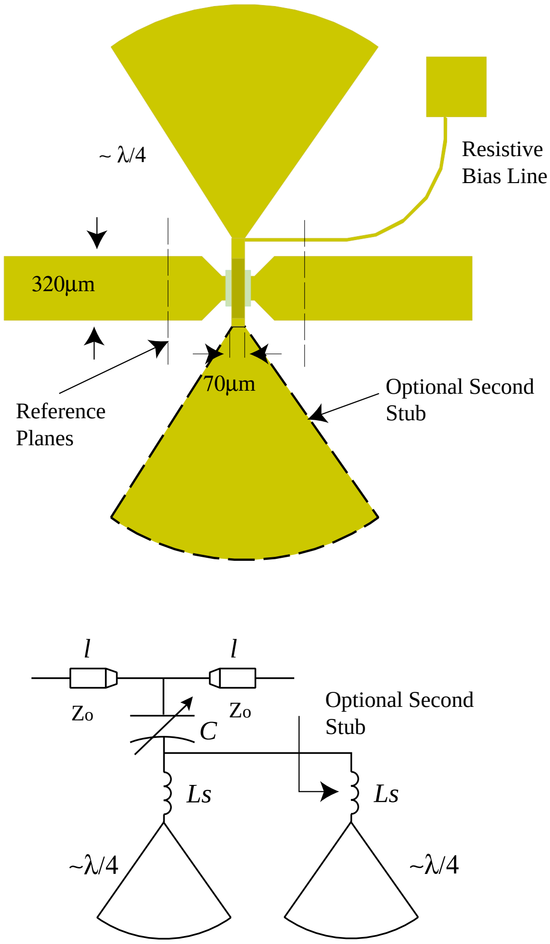
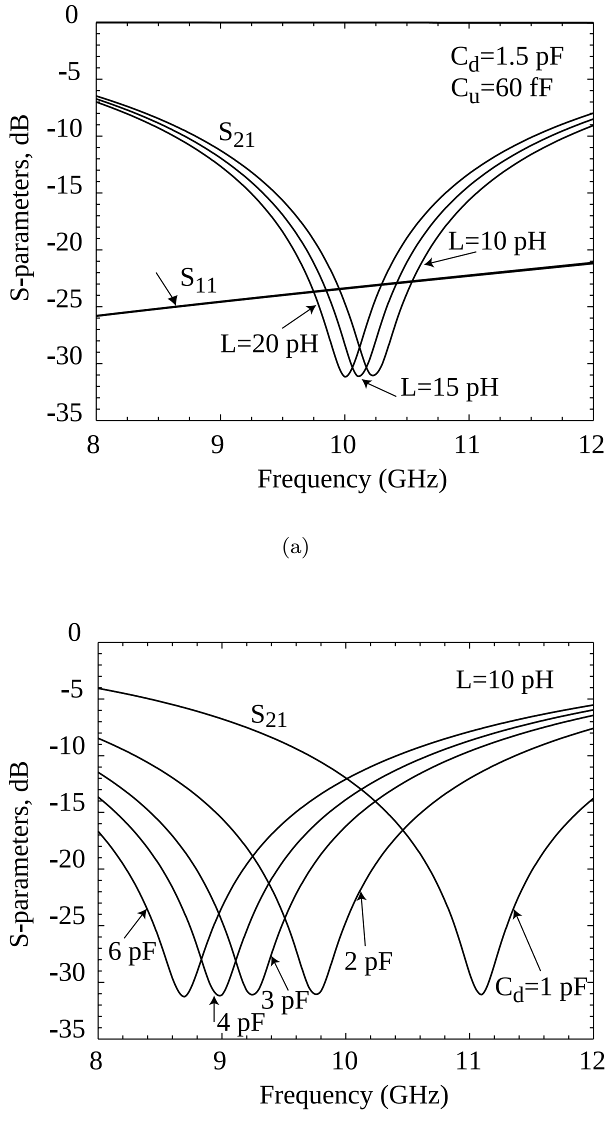


Fig. 1. Microstrip shunt capacitive MEMS switch and its equivalent circuit.

Fig. 6 presents measurements for a π-circuit with stub lengths of 1,800 and 2,300 μm. The -20 dB isolation bandwidth is from 7.8 GHz to 13.1 GHz, and is much wider than the single stub measurements. The up-state reflection coefficient is around -20 dB over the entire frequency range 7-15 GHz. The measured loss is less than 0.25 dB. The reference planes are 250 μm away from the bridge. The measurements, while still excellent, do not agree with the model probably due to different down-state capacitance values.

REFERENCES

[1] C. Goldsmith and J. Randall and S. Eshelman and T. H. Lin and D. Dennistor and S. Chen and B. Norvell, "Char-



(a)

(b)

Fig. 2. Modeled microstrip shunt switch response: (a) effect of L (b) effect of C_d. S_{11} in the up-state position, S_{21} in the down-state position.

acteristics of Micromachined Switches at Microwave Frequencies," *1996 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1141–1144, San Francisco, CA, June 1996.

[2] Yao, J. J. and M. F. Chang, "A Surface Micromachined Miniature Switch for Telecommunications Applications with Signal Frequencies From DC up to 4 GHz," *1996 Int. Conf. On Solid-State Sensors and Acutators Dig.*, pp. 384-387, Stockholm, Sweden, June 1996.

[3] J. B. Muldavin and G. M. Rebeiz, "High isolation MEMS shunt switches; Part 1: Modeling," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 1045-1052, June 2000.

[4] J. B. Muldavin and G. M. Rebeiz, "High isolation MEMS shunt switches; Part 2: Design," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 1053-1056, June 2000.

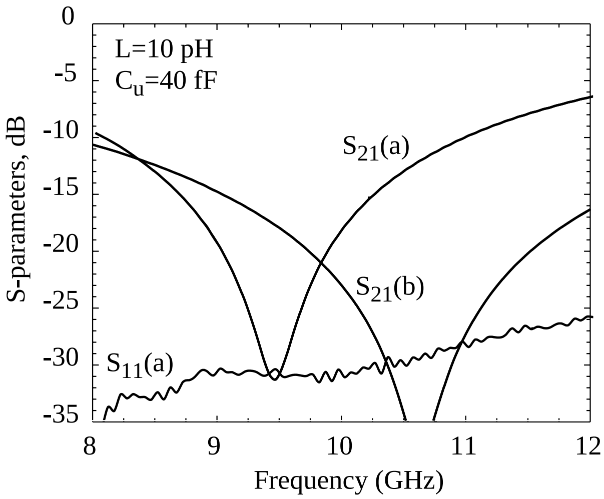


Fig. 3. Measured S-parameters of a single microstrip switch: (a) with one radial stub of 1,950 μm in up and down-state positions (C_d=2.5 pF) (b) two radial stubs of 2,400 μm in the down position (C_d=1.4 pF).

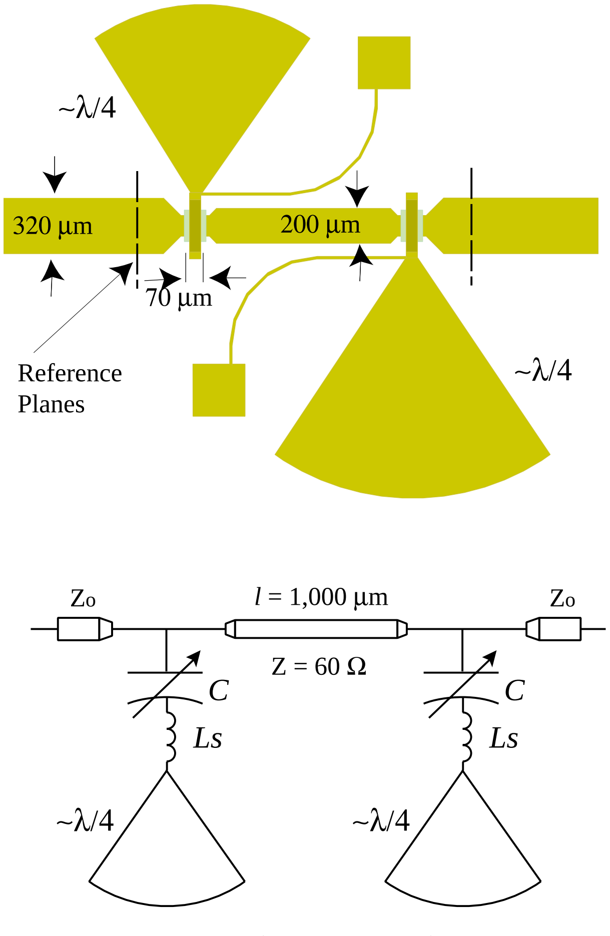


Fig. 4. π-circuit with microstrip shunt capacitive MEMS switches, and its equivalent circuit.

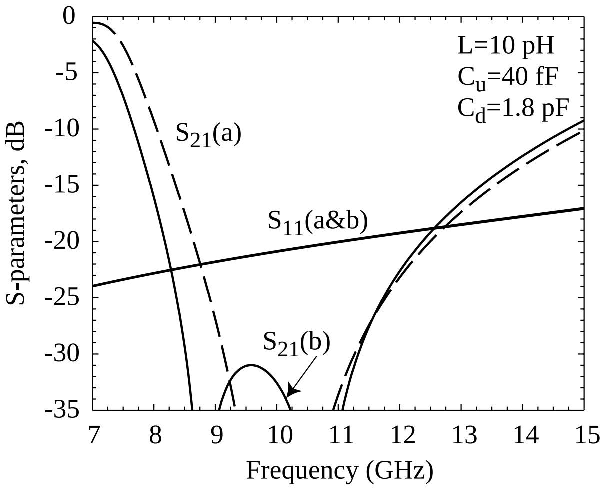


Fig. 5. Modeled π-circuit shunt switches with (a) two stubs of 1,950 μm and, (b) one stub of 1,800 μm and one stub of 2,300 μm.

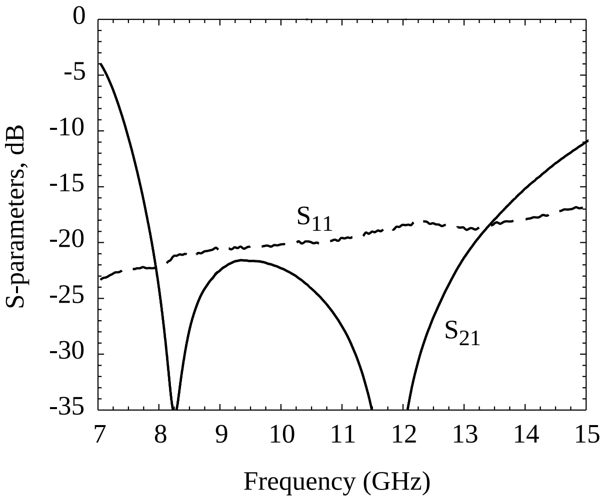


Fig. 6. Measured S-parameters π-circuit in up and down positions for stub lengths of 1,800 μm and 2,300 μm.