PROCEEDINGS OF ISAP2000, FUKUOKA, JAPAN

Reconfigurable Antenna Elements Using RF MEMS Switches

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1. INTRODUCTION

These days it seems that every research institution has a program to develop MEMS components; sensors, switches, optics, or fluidics. Some of these components are already finding their way into the marketplace, and MEMS/microelectronic systems-on-a-chip are already being designed. HRL Laboratories, LLC, as been building RF MEMS switches for the last three years. [1,2] The design and fabrication of metal-metal contact cantilever switches on GaAs substrates, and the measured performance of the switches will be presented, including switching speed, insertion loss, and isolation. Some examples of how these switches can be integrated into simple filters and antenna elements will be exhibited to show the potential for MEMS applications in electronic systems

Microwave and millimeter wave phased-array antennas typically operate over a narrow bandwidth, but for many applications multiple frequency operation would be highly desirable. This would require either a tunable antenna element with a multiband feed network or a multiband antenna array and the tunable feed network. PIN diodes and ferrites have been used for decades as tuning devices for antennas [3,4]. Recently, optoelectronically tunable antennas have been reported [5-7] where photoconductive switches are used to connect dipole segments for frequency tuning or beam scanning. With the advent of MEMS processing, new RF switch structures are possible, and have the advantages over the other tuning techniques in simplicity, ultra-low insertion loss, high isolation, power efficiency, and compactness.

Two canonical RF MEMS switch structures are being actively developed, the capacitive switch and the contacting switch. The capacitive switch uses a metal membrane that is physically in contact with the ground electrode of a planar transmission line. A DC voltage causes opposite charges to be induced between the membrane and the ground electrode, which in turn results in an attractive force which pulls the membrane toward the oppositely charged electrode. A thin dielectric insulator (on the order of a few microns) prevents the switch from shorting. The effective RF capacitance of this switch increases from the switch "off" state to the switch "on: state, with an on-off capacitance ratio up to the order of 100 [8].

Reliable contacts are essential for the metal-contact RF MEMS switch, which depends on the making and breaking of an actual metal-to-metal joint, a feat complicated by the low forces available from microactuation. In the force regime of tens to hundreds of micronewtons, surface states, adsorbed contaminants, and nanometer-depth material properties dominate the properties of metallic contact, and limited information has been available to the MEMS switch designer. Recent studies into this phenomenon by [9] have determined useful design criteria for pure gold contacts electroplated from sodium sulfite solution. Based on this work and other recent low-force contact studies [10,11], switch designs were developed to provide 200 µN of contact force per contact and maximal-heat sinking to the substrate.

During the past three years, HRL Laboratories has developed a metal-contact RF MEMS switch for operation up through 40 GHz, and beyond. The design and fabrication of the switches will be presented in this paper. In addition, the performance of this switch, including some limited lifetime data and power handling capability, will be provided. Finally, examples of the integration of these switches into frequency tuned filters and antennas will demonstrate the potential application of these switches to subsystem components.

2. CANTILEVER RF MEMS SWITCH CONFIGURATION AND PERFORMANCE

The RF MEMS switch, shown in figure 1, has a suspended cantilever trilayer structure of metal sandwiched between insulating layers to improve the thermal stability of the devices and reduce the effect of as-fabricated stress mismatch between the layers. A microphotograph of the switch is shown in figure 2. The cantilever beam includes the top actuation electrode and the RF switch. The actuation electrodes are isolated from the RF transmission line, thus no bias circuit is required for this switch. In addition, the switch actuation, being electrostatic, does not draw any DC current (there is a very small transient capacitance charging current), thus the required power for applications where arrays of switches are needed can remain reasonable.

The RF MEMS switches have been demonstrated on GaAs substrates, although the process is compatible with other substrate materials such as InP or high resistivity silicon. The microstrip line is fabricated by evaporation of gold, followed by a sacrificial PECVD silicon dioxide. The cantilever is formed by a PECVD nitride - plated gold – PECVD nitride trilayer. A hole is etched in the nitride structural layer, resulting in a gold dimple that contacts the microstrip. The sacrificial layer is removed with HF, followed by a critical point dry.

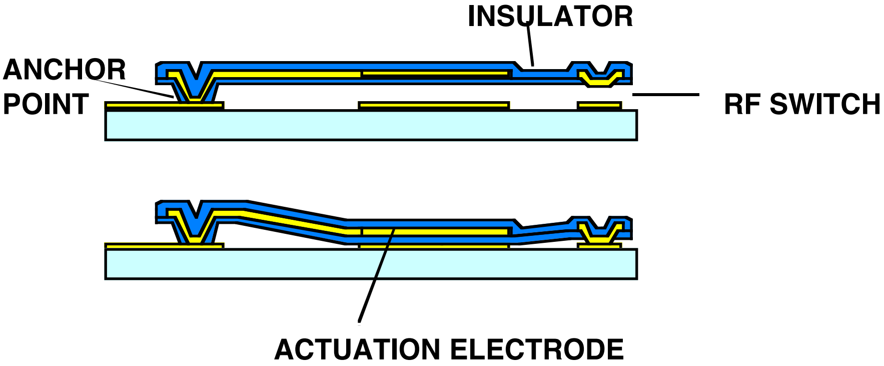

Figure 1. Side view of metal contacting cantilever RF MEMS switch in the off and on states.

The insertion loss and transmission isolation of one switch with an actuation voltage of 20 V is shown in figure 3. The insertion loss is less than 0.2 dB from DC through 40 GHz when the switch is closed. The DC resistance across the bonded switch of figure 3 in its closed position is 1.6 Ω, switches with contact resistances of 0.5 Ω have now been fabricated. The switch isolation, that is determined by the 2 µm gap between the metal switch dimple and the transmission line of an open switch, is larger than 50 dB at low frequencies, and decreases slowly to 27 dB at 40 GHz. The tiny resonance at 8 GHz is caused by a parasitic capacitive coupling to the electrostatic electrodes.

The switching speed for this switch is approximately 50 µsec. Limited studies on lifetime contact characteristics have shown robust actuation over a billion cycles with hot-switching lifetimes of over million cycles at 1 kHz with loads of 10 mA DC and 50% duty cycles. The RF power handling capability of this switch has been measured up to 1 W in a 50 Ω line.

3. ANTENNAS WITH RF MEMS SWITCHES

The insertion of these RF MEMS switches into new applications is opening up a whole new range of functions for high frequency systems.

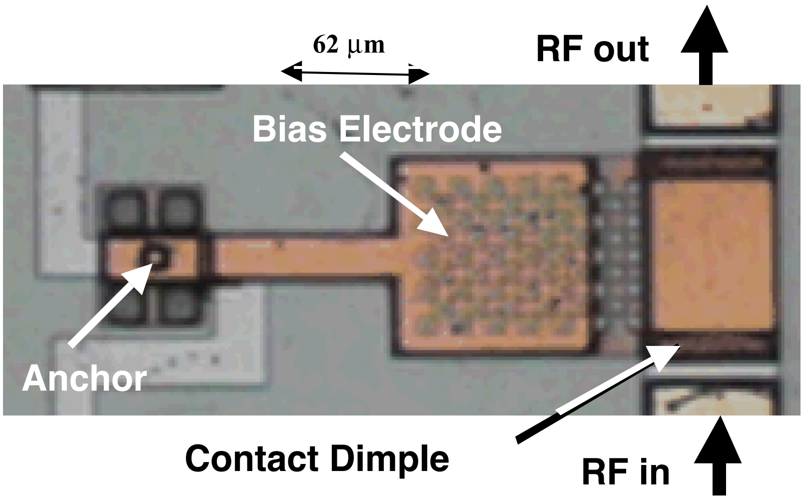

**Figure 2. Microphotograph of the RF MEMS contacting switch.
RF transmission line is 50 Ω on a 0.004" GaAs substrate.**

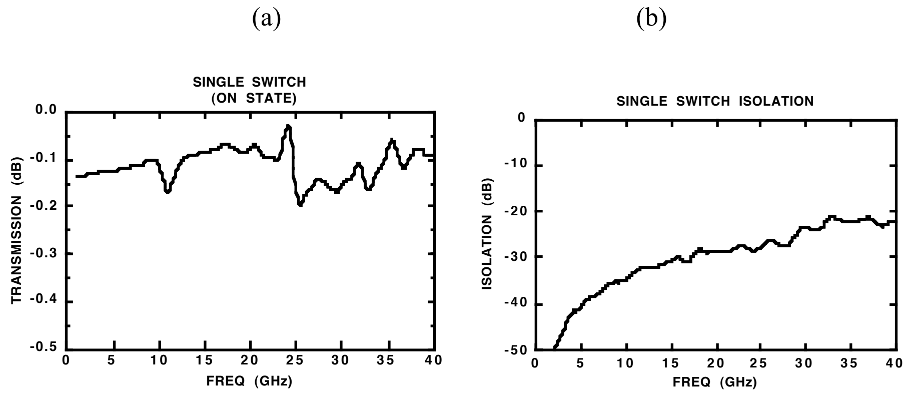

Figure 3. (a) RF insertion loss and of a closed RF MEMS switch. (b) Transmission isolation of an open RF MEMS switch.

We demonstrated was RF MEMS switches integrated into a dual-band dipole antenna. A diagram of the antenna, which was aperture coupled, is shown in figure 4. The dipole radiating efficiency is a maximum when the antenna element is resonant (that is the feed input impedance is real), and the resonance frequency is determined by the length of the dipole arms. Placement of RF MEMS switches along the arms of the dipole allows selection of different arm lengths and hence different resonant frequencies. In the dipole of figure 4, there are two alternative dipole lengths for selection between two operating frequency bands. Switching between frequency bands was accomplished by either turning both switches "on" (conducting, for the lower frequency band) or turning both switches "off" (non-conducting, for the upper band). The dipole was fed by a microstrip transmission line on a separate substrate that was bonded to the backside of the antenna board, and the coupling between the microstrip and the antenna occured through an aperture in the common ground plane that was sandwiched between the boards. An open circuited quarter-wavelength stub was needed to maximize the field in the coupling slot. Thus, for dual band operation, a Y-junction was used to provide open circuited stubs whose lengths were chosen such that the impedance of the line at the edge of the slot was nearly a short circuit at each operational frequency. This structure can be extended to additional operating frequencies by adding more stubs in the feedline, appropriately filtered for minimal cross-coupling, and additional switches in the dipole. Vertical interconnecting vias were used to bring the control lines to the top surface, upon which the dipole was printed.

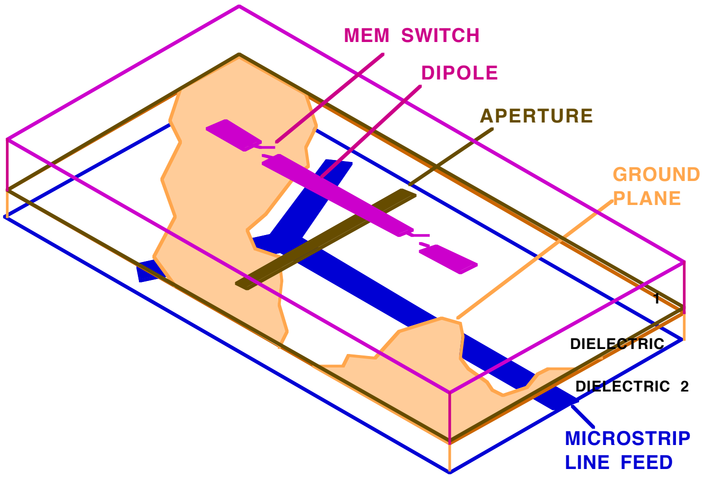

Figure 4. A diagram of the dual frequency aperture-coupled dipole antenna.

A comparison between the antenna gains of the switched printed circuit dipole element with the RF MEMS switches open and closed is shown in figure 5. The red curves are for the case when the switches are closed, while the blue curves are for the case when the switches are open. Figures 5(a) and (b) show the radiation patterns at 11 GHz and 18 GHz, respectively. When the switches are closed, the dipole appears longer, and therefore radiates at a lower frequency. When they are closed, it appears shorter, and radiates at a higher frequency. Thus, by actuating the switches, we have reconfigured the antenna to operate in a different band.

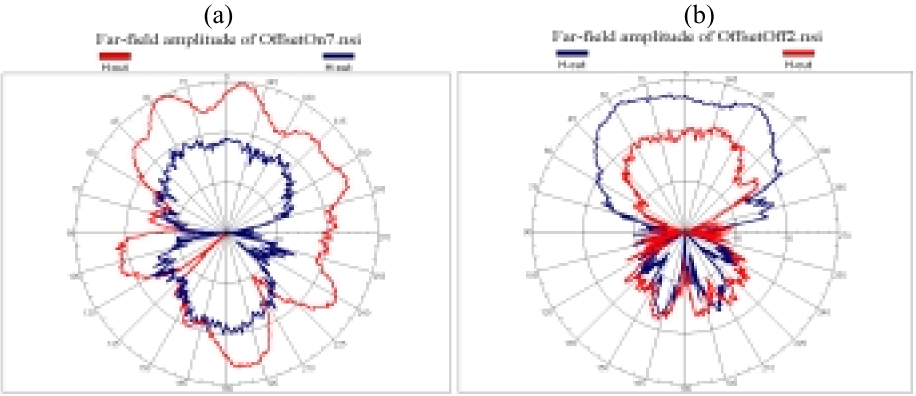

Figure 5. Measured antenna radiation pattern with open and closed RF MEMS switches at 11 GHz (a) and 18 GHz. (b) In both cases, the red curve corresponds to closed switches and the blue curve corresponds to open switches. Opening or closing the switches changes the operating band of the antenna.

The design, fabrication, and performance of metal-contact RF MEMS switches were presented in this paper. While only a few microwave components with integrated switches were demonstrated, the potential application of these switches to a variety of miniature systems should be apparent. As work continues to bring the reliability of MEMS devices on par with other electronic components, and new applications for these devices are invented, the creation of systems-on-a-chip are not to far off in the future.

Having demonstrated the reconfiguration of antenna elements using RF MEMS, we will present in this conference a diversity antenna on a periodic high impedance ground plane for which RF MEMS switches can be used as a selector.

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