

Integrated MEM Antenna System for Wireless Communications

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Abstract — This paper presents the results on the fabrication and testing of a compact broadband antenna integrated with RF MEMS switches for wireless communications. The system consists of two individual broadband CPW fed antennas (having 50% bandwidth) sequentially addressed using low-loss RF-MEMS switches. The antennas, as well as, the RF-MEMS switches are fabricated on a glass substrate using surface micromachining batch processing method. The design and fabrication process of the system are outlined. The results showing the circuit and radiation characteristics are discussed in terms of radiation pattern reconfigurability and spatial and angular diversity capabilities.

I. INTRODUCTION

With the ongoing growth in wireless communications, more spectrum is needed to avoid interference and permit wider bandwidth signals. So the next-generation cellular networks deployment will require systems with broadband capabilities in order to transmit the high data rates (up to 20 Megabits per second) in high-mobility environments. This bandwidth is at the higher microwave frequencies (4-6 GHz). Circuits need to be small and physical structures must be precisely reproducible in manufacturing. One of the crucial breakthroughs towards miniaturization in size and cost, is the possibility of integrating all the radio modules, including the antenna, T/R switch, and RF circuits on a packaged module using a common monolithic batch fabrication process.

From the radiating element point of view compact planar geometries with broadband behavior are needed. In addition, for use in multi-element antenna geometries, mutual coupling between adjacent antenna elements must be minimized. For microwave applications, slot antennas fed by coplanar waveguide (CPW) [1] offer clear advantages including broader bandwidth, better impedance matching, lower radiation losses and mutual coupling, and easier integration with the microwave monolithic integrated circuits (MMICs).

The need to employ antenna diversity to improve receiver performance, and reconfigurability for beam shaping and steering requires the use of multi-element antenna geometries in today's communication systems in which switching is the critical operation. The excellent switching characteristics of RF MEMS switches, very low insertion loss (0.1-0.2 dB) in the on state (when signal is passed) and high isolation (25-35 dB) in the off state (when signal is rejected) over an extremely wide band (DC to 40 GHz) make them very attractive to be used in multi-element antenna systems. The low loss nature of MEMS switch also can eliminate the use of power amplifiers behind antenna elements, which is inevitable when pin diode or FETs are used as switching components, making the overall system cheaper and more robust.

In this work, we separately designed, fabricated and tested very broadband antennas and low loss RF MEMS switches. And as part of our ongoing efforts in creating a RF packaged chip module we integrated multi-element antenna geometries with RF MEMS switches. The antenna having such a structural geometry not only provides desired radiation and impedance characteristics (broad bandwidth, high gain, small mutual coupling and low copol. cross-pol. ratio) but also allows very easy integration with the RF MEMS switches by eliminating hybrid assembly otherwise necessary when the antenna structure is not compatible to RF MEMS switch structure. This monolithic batch fabrication dramatically reduces the overall system cost.

In section II of this paper, the antenna structure is introduced and its impedance and radiation behavior are characterized. Section III briefly describes the RF MEMS switch fabricated on a glass substrate using surface micromachining process techniques. The measured results showing the performance of the switch are provided. The measured results for the multi-element antenna system integrated with MEMS switches are finally given and discussed in section III.

II. ANTENNA STRUCTURE AND CHARACTERIZATION

The antenna structure (antenna 1) is depicted in Fig.1 It consists of an inductively coupled CPW slot antenna combined with capacitively coupled slot antenna through a triangular shaped CPW line. The inductively coupled slots are bent upward direction in order to achieve more compact and small antenna geometry to be used in multi-element antenna system. The resonant frequencies are determined by the slots lengths such that upper and lower resonant frequencies are designed to cover the frequency band of 4 to 6 GHz. This band was deliberately chosen to be compatible for the next generation wireless communications standards. In order to obtain optimum match covering the entire band of 4 to 6 GHz the slot widths and the dimensions of the triangular CPW line are optimized.

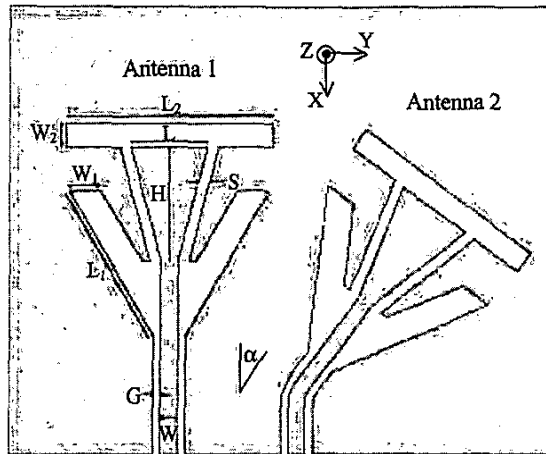


Fig. 1. Top view of the CPW fed antenna geometry and dimensions. $L_2=17.6\text{mm}$, $W_2=3.4\text{mm}$, $L_1=19.2\text{mm}$, $W_1=3.7\text{mm}$, $H=12\text{mm}$, $L=8\text{mm}$, $S=0.25\text{mm}$, $G=0.3\text{mm}$, $W=1.75\text{mm}$ α : orientation angle.

The designed antenna was fabricated on a glass substrate ($\epsilon_r=5.7$, loss tangent=0.0035) with the thickness of 1.51 mm. Firstly a 0.2 μm electron-beam Ti/Cu seed layer was deposited using e-beam evaporation and patterned to define the region of the antenna geometry. The patterned region was then Cu electroplated to a thickness of 5 μm . As it is shown in Fig. 2 the measured result agrees very well with the computed result and for a voltage standing wave ratio (VSWR) of 2:1 the bandwidth of 50% is achieved. Since the antenna element is intended to be used in multi-element antenna system we also investigated the interaction between two antenna elements by studying mutual coupling as a function of orientation angle α (see Fig. 1). In Fig. 3 the

measured mutual couplings of antenna pairs for different orientation angles are compared. It is observed that, although increasing orientation angle provides slightly lower mutual coupling, for any α orientation the coupling is small enough required by most of the communications application employing spatial and angular diversity techniques. This low mutual coupling provides us flexibility in locating antennas in a variety of spatial orientations.

The radiation characteristics of the antenna were also studied. The E- and H-plane measured and simulated radiation patterns for the operating frequency of 5.8 GHz are plotted in Fig. 4 showing good agreement in both co-polar and cross-polar components. Low cross-polarization radiation is observed in both planes. The measured and calculated average gain over the frequency band of interest is obtained to be 4.8dBi.

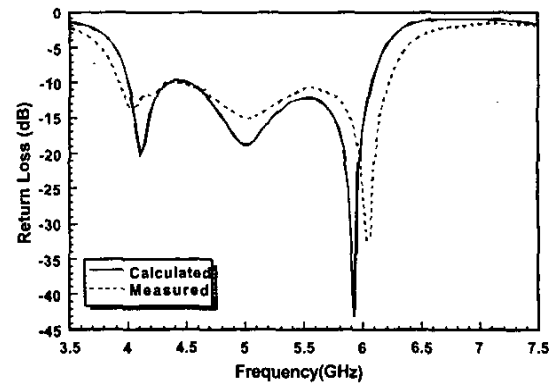


Fig. 2. Measured and calculated return loss of the antenna.

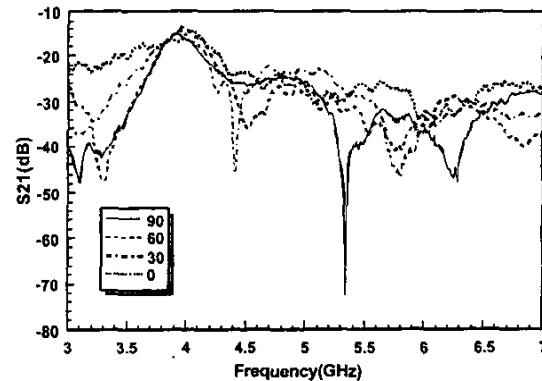


Fig. 3. Measured mutual coupling as a function of the orientation angle α , between two antenna elements

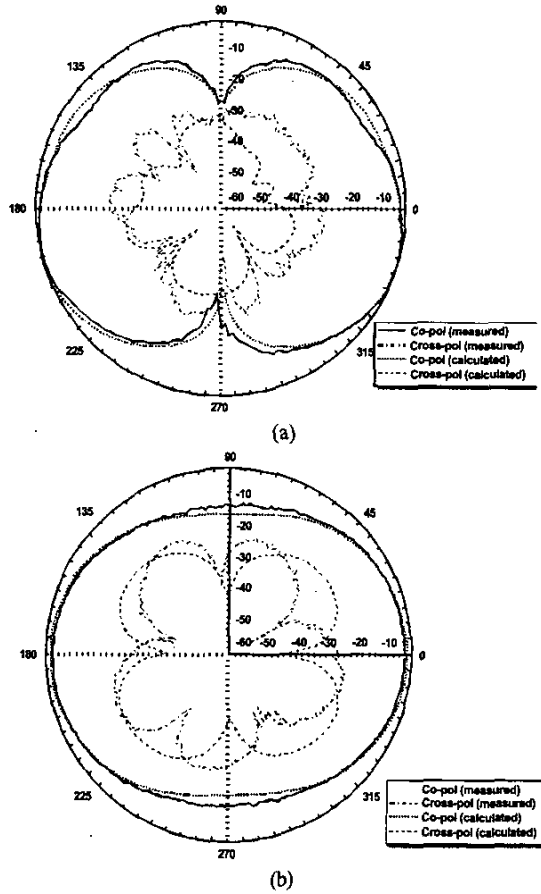


Fig. 4. Calculated and measured radiation patterns in the (a) x-z plane (E-plane) and (b) y-z plane (H-plane) for the antenna at 5.8 GHz.

III. RF MEMS SWITCH AND INTEGRATED ANTENNA SYSTEM

A. RF MEMS Switch

The RF MEMS switches here used is similar to the one presented in the paper of Yao, et al [2]. It consists of a CPW transmission line with a metallic membrane suspended on top of a signal electrode and it is fixed at both ends to the ground plane. The 4-mask fabrication includes the process steps of electron-beam metal deposition, Cu electroplating, low temperature PECVD silicon nitride deposition, reactive ion etching and selective wet etching. It is worth nothing that, although the structure of the switch is similar to the one described in [2] our MEMS switch is fabricated based on very low temperature PECVD process (90 °C) [3], which is a novel patent-pending technology, providing a higher quality

nitride layer to enhance the RF performance of the switch. A more detailed discussion on the design, fabrication and performance analysis of a similar RF MEMS switch can be found in [4].

Figs.5a and 5b illustrate the measured S-parameters of the switch in up (on) and down positions (off), respectively. In the on state (without bias), it shows approximately 0 to 0.15 dB of loss over the frequency range from DC to 20 GHz and the return loss is better than 20 dB. By applying DC bias voltage (30-35V) the membrane snaps down on the signal electrode shorting signal line to the ground plane. As it is seen from Fig. 5b, in the off state the isolation performance is very good to switch RF signal. In order to obtain a better isolation at the off-state the resonant frequency can be shifted into the frequencies at which the system is operated by changing the membrane dimensions.

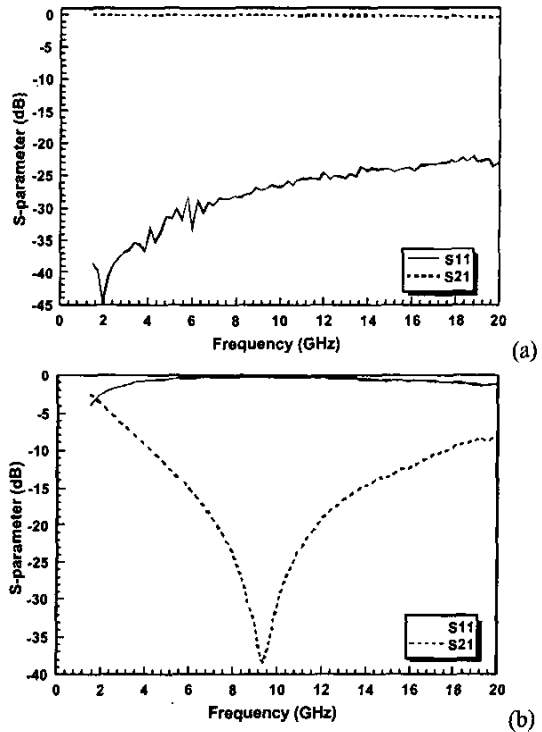


Fig. 5. Measured S-parameters for RF MEMS switch. (a) up-state, (b) down-state.

B. Integrated Antenna system

Having studied the antenna and RF MEMS switch individually, we integrated them together, using monolithic batch fabrication, to construct the integrated antenna system on glass substrate. The fabrication

process for the integrated system is exactly the same with individual MEMS switch fabrication. The only difference was made in one of the masks (Cu electroplating mask) such that it includes the geometry of the antenna structure. Sketch of the integrated system is given in Fig. 6 Two MEMS switches located on CPW feed lines enable to select either antenna element or operate them together. Antennas are located by orientation angle, $\alpha = 90^\circ$, so that by operating either antenna orthogonal radiation patterns are obtained. Selecting the ON and OFF states of the switches (S1 and S2) we can either activate a particular single antenna (A1 or A2) for spatial or angular diversity purposes, or create a superposition radiation pattern for coverage reconfigurability purposes. Fig.7 illustrates the measured y-z plane V-pol and H-pol radiation patterns corresponding to the simultaneous activation of both antennas (A1+A2). With the appropriate activation of one of the different coverages (single or combined antennas) angular discrimination of a useful weak signal from an unwanted strong interference can be performed in multipath scenarios.

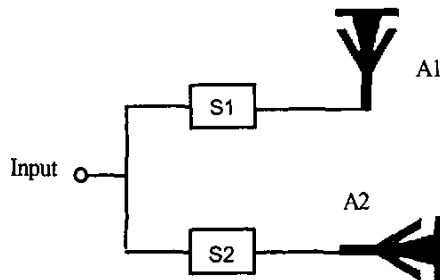


Fig. 6. Sketch of the RF MEMS switch-integrated antenna. S1, S2: RF MEMS switches, A1, A2: Antennas

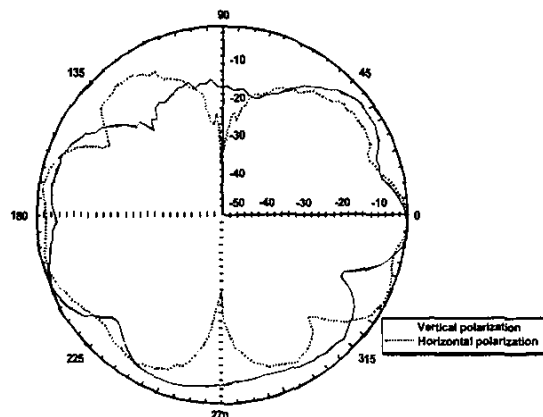


Fig. 7. Measured radiation patterns in the y-z plane when both switches are in the on state.

V. CONCLUSION

RF MEMS switches have been monolithically integrated with compact antenna elements to construct a broadband reconfigurable antenna system for use in next generation wireless applications. Switching between antenna elements generates different spatial radiation patterns that can be employed for spatial or angular diversity techniques to increase receiver performance of the communication system. Although the integrated system presented here consists of only two antenna elements and two MEMS switches the compatible structures of the RF MEMS switch and antenna, as well as, antenna's impedance characteristics (low mutual coupling) allows to extend it including many antenna elements and switches through monolithic batch fabrication. Such a system would be capable to provide larger number of beams having better chance of eliminating and mitigating the effects of multipath fading, which is a common problem in wireless communications.

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