RECONFIGURABLE RF MEMS DEVICES AND ANTENNAS

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Abstract

This paper presents the overview of RF MEMS (Radio Frequency-MicroElectroMechanical Systems) components and reconfigurable antennas designed and produced in Middle East Technical University (METU) using the in-house fabrication process. The design and measurement results of various components such as switches, impedance tuners, phase shifters, frequency tunable antennas, a phased array antenna with RF MEMS phase shifters, and a reflectarray design are summarized. It is shown that the fabricated RF MEMS components satisfy the design specifications and have better performance and reconfigurability capabilities compared to their conventional counterparts.

1. Introduction

MEMS technology is a powerful way of merging the functions of sensing and actuation with computation and communication to control physical parameters at the microscale. Present markets of MEMS technology are mainly in pressure and inertial sensors, inkjet print heads, and high-resolution digital displays. Future and emerging applications include tire pressure sensing, fiber optical components, fluid management and processing devices for chemical microanalysis, medical diagnostics, and drug delivery, and RF and wireless electronics, namely RF MEMS. The application of MEMS technology to RF systems enables production of components with low power consumption, high linearity, low insertion loss, and high isolation. RF MEMS components are particularly attractive for researchers due to their tunable properties. This technology is used to implement many tunable circuits and systems in a miniaturized way that has never been implemented before using any other technology [1].

This paper presents some of the RF MEMS components and reconfigurable antennas designed and produced in METU using the in-house fabrication process developed at the Microelectronics Facilities (METU MET). Section II gives the RF MEMS switch structures, which are the key element of technology. Section III and Section IV present the impedance tuner and reconfigurable antennas, respectively. Section V gives the monolithic phased array structure implemented with MEMS technology and the proposed reflectarray design.

2. RF MEMS Switches

Metal-to-Metal Contact RF MEMS Shunt Switch

RF MEMS switches are the key elements in the design of the complete systems hence the improvement in one switch can affect the whole system performance. We have designed a metal-to-metal contact switch operating at 1-6 GHz band to obtain a better performance than the existing ones. The switch, shown in Figure 1, consists of two cantilevers located on ground planes of a coplanar waveguide (CPW) transmission line [2]. With the help of actuation electrodes beneath the cantilevers, the switching of the RF signal is maintained. According to the measurement results shown in Figure 2, the switch has isolation better than 20 dB in the 1-6 GHz band and better than 10 dB in the 1-20 GHz band. Insertion loss of the structure is better than the 0.3 dB in the 1-20 GHz band. The switch has a measured actuation voltage of 7 V.

Capacitive Contact RF MEMS Shunt Switch

A capacitive contact RF MEMS shunt switch is designed as shown in Figure 3 (a). The switch has recessed sections on the ground plane of coplanar waveguide and the meanders supporting the bridge increase the series inductance of the bridge, which is used to tune the switch to operate at Ku-band [2]. The switch has a measured down-state capacitance of 2.08 pF which results in better than 20 dB measured isolation and better than 0.2 dB insertion loss for the 11-17 GHz band as shown in Figure 3 (b). The measured actuation voltage of the switch is 13 V.



Figure 1. Metal-to-metal contact RF MEMS shunt switch: (a) 3D schematic drawing and (b) SEM image of the fabricated device.



Figure 2. The measurement results of the metal-to-metal contact RF MEMS shunt switch: (a) downstate and (b) upstate.



Figure 3. (a) SEM image of capacitive contact RF MEMS shunt switch. (b) Measurement result.

3. Impedance Tuners

Reconfigurable double-stub and triple stub impedance tuners are designed and produced for X and Ku-band applications. These can be used for LNA matching, antenna matching, noise parameter, and load-pull measurements. One of the designs has a double-stub structure which has 10 CPW based MEMS switches distributed evenly on the two stubs forming a distributed structure [3]. Figure 4 (a) shows the schematic view of

this design. The capacitive MEMS switch used has a specific design which uses two variable capacitors between the signal and the ground of the CPW for discrete biasing requirements for each MEMS switch of the matcher. The design is capable of matching 25 different points on the Smith Chart with a maximum measured VSWR of 5.27 at 18 GHz when a single MEMS switch is actuated from each stub. The design can also be operated by actuating more than one MEMS switch resulting with $1024 (2^{10})$ combinations which has a maximum VSWR of 50.8 at 18 GHz. Figure 4 (b) shows the Smith Chart distribution of all possible states. It should be noted here that external SMT resistors were used for the DC biasing of the MEMS switches. Figure 5 shows the fabricated impedance matcher with the attached SMT resistors for DC biasing.



Figure 4. (a) The schematic of the designed MEMS impedance matcher. (b) The simulated Smith Chart distribution all possible states of the designed MEMS impedance matcher @ 18 GHz.



Figure 5. The photograph of the fabricated MEMS impedance matcher with external resistors and narrowed ground connections.

4. Reconfigurable antennas

RF MEMS components have tunable characteristics; thus the integration of these components with radiators may vield several advantages such as reconfigurability in polarization, frequency, and radiation pattern. One of the reconfigurable antenna structure designed and fabricated is a tunable frequency CPW fed rectangular slot antenna [4]. In order to achieve a shift in the resonant frequency, a short circuited stub with RF-MEMS capacitors is inserted opposite to the feeding transmission line as shown in Figure 6 (a). Measured reflection coefficient characteristics for different actuation voltages are shown in Figure 6 (b). It is observed that the resonant frequencies can be shifted from 8.7 GHz to 7.7 GHz, and from 10.57 GHz to 10.22 GHz by changing the actuation voltage, -hence the height of the MEMS capacitors-, from 0 to 16 volts. The measurement results are in a good agreement with the simulations. The antenna radiates broadside for all of the four resonances and increasing the capacitance by lowering down the bridges does not cause any adverse effect on the radiation patterns. The other reconfigurable antenna structure employs the idea of loading a microstrip patch antenna with a stub on which MEMS capacitors are placed periodically as shown in Figure 7 (a) [5]. MEMS capacitors are electrostatically actuated with a low tuning voltage in the range of 0-11.9 V. The antenna resonant frequency can continuously be shifted from 16.05 GHz down to 15.75 GHz as the actuation voltage is increased from 0 to 11.9 V. These measurement results are in good agreement with the simulation results obtained with Ansoft HFSS as given in Figure 7 (b).



Figure 6. (a) The photograph of the rectangular slot antenna loaded with MEMS capacitors. (b) The measurement results of the slot antenna for different actuation voltages.



Figure 7. (a) The photograph of the patch antenna loaded with MEMS capacitors. (b) The measurement results of the patch antenna for different actuation voltages.

5. Phased arrays

This section presents the phased array system designed at 15 GHz employing 3-bit DMTL type phase shifters which are monolithically integrated with the feed network of the system and the radiating elements on the same substrate [6]. The phase shifter can give 0°-360° phase shift with 45° steps at 15 GHz which is used to obtain various combinations of progressive phase shift in the excitation of radiating elements. The phased array is composed of four linearly placed microstrip patch antennas. Figure 8 (a) shows the photograph of the phased array fabricated on a glass substrate. The digital phase shifter used in the system is composed of a periodically loaded high-impedance transmission line (> 50 Ω) with MEMS bridges in series with lumped capacitors, forming a DMTL. Figure 9 (a) and (b) shows the unit cell of the fabricated DMTL phase shifter and its circuit model []. Measured inserted phase shifts for different states are shown in Figure 9 (c). Figure 8 (b) shows the measured radiation pattern results for different progressive phase shift. The main beam can be steered by 4°, 14° as the phase shifter states are adjusted accordingly.



Figure 8. (a) Photograph of the fabricated phased array. Total chip size is about 6 cm \times 5 cm. (b) Radiation pattern of the array for different progressive phase shift values.



Figure 9. (a) Photograph of the unit cell of a phase shifter (b) Circuit model of a unit cell of phase shifter (c) Phase shift vs. frequency plot obtained for 8 states of the 3-bit RF MEMS phase shifter.

Another application of the MEMS technology is to use MEMS components in reflectarrays to scan the beam. In this work, in order to control the phase of the wave reflected from each element of reflectarray, the lengths of the microstrip lines are changed using RF MEMS series switches [7]. Thus, progressive phase shift between the elements are changed and reflectarray with reconfigurable main beam is obtained by the help of MEMS technology. In the proposed design, the patch antenna at 26.5GHz is printed on a glass substrate bonded to another glass substrate which contains the transmission lines with MEMS switches. Transmission line with series RF-MEMS switch is shown in Figure 10 (a). Transmission lines are coupled to the patch antenna by means of a slot in the ground layer between the two glass substrates as shown in Figure 10 (a) and (b). Control of the reflection phase from each unit element is achieved by the help of phase design curve obtained from infinite

array simulations in HFSS. The phase design curve shown in Figure 10 (c) indicates the dependence of the reflection phase on the transmission line length. Required transmission line lengths are chosen from this phase design curve. To switch the beam from broadside to 40°, two sets of lengths have been chosen by the ON-OFF states of RF MEMS switch. HFSS simulations have also been performed for transmission line with RF MEMS switch for further tuning of the phase.



Figure 10. The back view (a) and cross section (b) of the slot coupled patch antenna. (c) Phase design curve at 26.5 GHz.

6. Conclusions

This paper reviews some examples of RF MEMS components and antennas designed and fabricated in the facilities of METU. It is shown by the measurement results that the fabricated components satisfy the design specifications. More components, as well as production, modeling and packaging studies will be presented and discussed during the presentation in the conference.

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