DESIGN OF MEMS BASED TRIPLE BAND RECONFIGURABLE ANTENNA

Abstract: A reconfigurable triple-band antenna operating at 17.21, 23.54 and 29.27 GHz using MEMS switches is presented. The reconfigurable triple-band dipole is firstly designed assuming ideal switches (ON/OFF). The effects of the two MEMS switches on different cantilever bridge materials on the antenna performance are studied. The design is performed using the 3D electromagnetic simulator. Optimization of MEMS bridge materials is required to obtained low insertion loss.

Keywords: Microelectromechanical systems; MEMS; Reconfigurable, Antenna, Patch

1. INTRODUCTION

Radio frequency microelectrical mechanical systems (RF MEMS) is an emerging technology that promises the potential of revolutionizing RF and microwave system implementation for the next generation of telecommunication applications. Its low-power, excellent RF performance, large tuning range, and integration capability are the key characteristics enabling system implementation with potential improvements in size, cost, and increased functionality. An RF MEMS switch is one of the basic building blocks in an RF communication system. Switches operating at frequencies of up to 40 GHz, with very low insertion loss and high isolation, have been successfully demonstrated [1], [2]. In addition, they consume very little energy, and exhibit very linear characteristics with extremely low signal distortion, making them ideally suited for modern radar and communications applications [3]. Using RF MEMS switches, various RF circuits such as variable capacitors, tunable filters, on-chip inductors, and phase shifters have been demonstrated with superior performance over conventional semiconductor devices [4]–[7]. Typically, RF MEMS switches are classified into two types: resistive series and capacitive shunt switches. They are normally built on high-resistivity silicon wafers, gallium arsenide (GaAs) wafers, and quartz substrates using semiconductor microfabrication technology with a typical four-to six-mask level processing. [8]–[12]. Transfer process techniques to integrate MEMS onto RF compatible substrates on which direct MEMS fabrication is not feasible have also been proposed [13]–[15]. While RF MEMS switches have been successfully demonstrated to have outstanding RF performance as discrete components, their use in communication systems is still limited due to the high cost of packaging them and the high cost of RF matching requirements in module board implementation. Recently there has been tremendous interest in planner antennas capable of dynamically reconfiguring the radiation pattern to provide horizon-to-horizon scan coverage over a wide frequency range, through geometric configuration. These capabilities are possible through MEMS based switching and actuating devices or circuits. The MEMS devices offer the following advantages over semiconductor devices first, significant reduction in insertion loss. Second, they consume insignificant amount of power during operation. Third, higher linearity hence lower signal distortion. Typical example of MEMS based antenna are reported in [16]-[18]. In this paper, we proposed a triple band reconfigurable antenna using RF MEMS switches that can be fabricate in easy process steps. The effect of material used for MEMS switches is described.

2. RECONFIGURABLE MEMS ANTENNA DESIGN

The schematic diagram of the reconfigurable antenna is shown in Figure 1. It consists of three patches where the feeding configuration exists in the center patch. The patch antenna design was supported with a model built using a high frequency structure simulator (HFSS) based on finite elements modeling (FEM). A tool with 3D modeling capabilities was necessary due the fact that, for small ground planes, the antenna behavior depends on the ground size.

The two critical steps in designing the patch antenna were the definition of the patch dimensions and the feeding configuration. The patch dimensions have direct influence on the operating frequency and on the antenna gain. The difficulty to predict accurately the patch dimensions is related to the fringing fields together with the small size of the ground plane used.

The antenna feeding should be designed carefully since it must provide a correct impedance matching. At high-signal frequencies it is necessary to design a feeding line with specific characteristic impedance. Also, that line must be connected in a point of the antenna where the input impedance is the same than the feed-line characteristic impedance. The patch antenna was fed with a microstrip line connected to a point inside the patch where the input impedance is 50 Ω. The MEMS contacts are formed on alumina or Teflon or GaAs or SiN substrates which forms cantilever beam on the antenna surface.

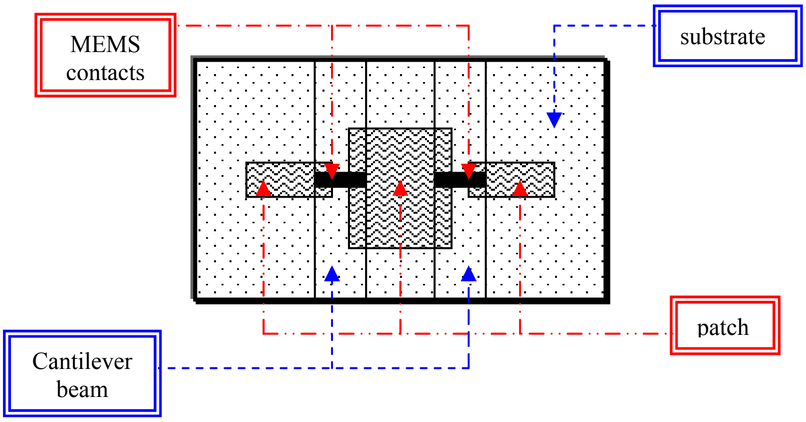

Figure 1. Schematic diagram of MEMS reconfigurable antenna.

2.1 Antenna Modeling

The center patch antenna was first designed based on the equations from the transmission line model (TLM) approximation [19]. That approximation states that the operating frequency of patch antenna is given by :

$$f_r = \frac{1}{2(L+\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_o \varepsilon_o}} \qquad (1)$$

where L is the length of the antenna, ε_0 and μ_0 are the free space dielectric permittivity and permeability respectively, ε_{eff} is the effective dielectric permittivity given as

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

wher ε_r and *h* are the relative dielectric permittivity and thickness of the substrate and *W* is the width of the patch. Because of the fringing effects, the antenna looks larger than its physical dimensions. ΔL takes this effect in account and can be computed from:

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(W/h + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(W/h + 0.8\right)} \tag{3}$$

In order to facilate its characterization, the antenna was designed to have a 50 Ω input impedance as mentioned earlier. The input impedance of the antenna can be adapted by choosing the right position for the feeding point [19]. Its value is maximum at the patch border and decreases as we move inside according to:

$$Z_{in} = Z_{\max}\cos^2\left(y\frac{\pi}{L}\right) \tag{4}$$

where $Z_{\max}$ is the impedance at y=0. Because the antenna was to be feed with a microstrip, the connection to a point inside the metal match requires the use of wire bonding or an inset. Using the values given by the TLM approximation, a model for the antenna was built in HFSS. The model was used to trim the antenna dimensions for the desired frequency. The two wing patches were designed by choosing the same length of the centre patch and then optimized the width of the patch.

3. RESULTS AND DISCUSSIONS

Reconfigurable antenna structure has been designed with choosing length of 18 mm, width of 10 mm and depth of 0.32 mm. The centre patch is optimized and designed based on the centre resonant frequency of operation. The performance of the antenna is analyzed by changing the material of MEMS bridge.

3.1 Effect of MEMS bridges Materials

In order to study the effect of cantilever beam materials which acts as a MEMS bridge for switching, various dielectric constant materials were chosen by considering substrate material as Rogers. The dimension of the wing patches were maintained as 5x2 mm after optimization. Here, the comparison of the results will be analyzed for various MEMS bridge materials when both switches are either ON or OFF.

3.1.1 *Alumina as a MEMS bridge material*

MEMS bridges were designed by choosing alumina material with permittivity 9.4. It is observed that there are three resonant frequencies depending on the MEMS switches states, both switches either ON or OFF as shown in Figure 2. The figure shows that when both switches are OFF, there are three frequency bands. The lower frequency at 17.21 GHz with return loss -12.04 dB, the centre frequency response at 23.54 GHz with -19.37 dB return loss and the upper frequency at 29.27 GHz with return loss of -17.34 dB. On the other hand, when the both switches are ON, the antenna behaves like a single patch antenna with resonant frequency at 23.54 GHz and return loss -20.85. It is found that there is no shift of resonant frequency which occurs at 23.54 GHz irrespective of switches states.

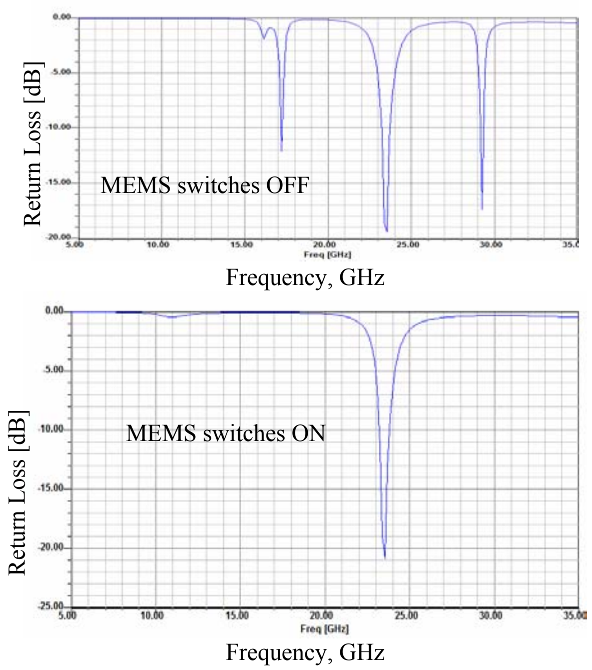

Figure 2. Return loss of the antenna for alumina as MEMS bridge material.

3.1.2 *Teflon as a MEMS bridge material*

MEMS bridges were also designed by choosing Teflon material with permittivity 2.1.In this case, there are also there are no changes of resonant frequency when the switches are either ON or OFF. However, lower return losses are observed for lower and centre resonant frequencies as shown in Figure 3. The return losses are -14.67, -23.07 and -11.48 dB at 17.21, 23.54 and 29.27 GHz respectively when both the switches are OFF. For both switches ON, the return loss is -23.61 dB.

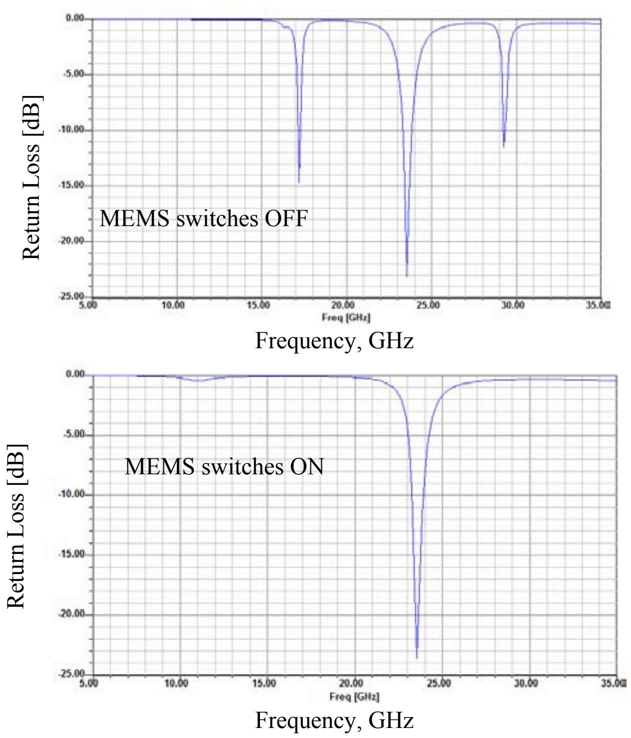

Figure 3. Return loss of the antenna for Teflon as MEMS bridge material.

3.1.3 *Comparison of different MEMS bridge material*

Figure 4 shows the variation of return loss of the antenna at resonant frequencies for different types of materials as a MEMS bridge when both the switches are OFF. It is observed that there are three resonant frequencies for all the materials. The lower, centre and higher resonant occurs almost of the same points irrespective of the materials used which proves that the MEMS bridge material types does not influence the frequency of operation. However, the insertion losses are different. The alumina gives better performance compared to other materials for all the frequency range.

Return loss and resonant frequency of the antenna for different types of MEMS bridge materials are shown in Figure 5 when both the switches are ON. Teflon gives lower insertion loss.

Alumina has been chosen as the best materials for MEMS bridge compared to Teflon, Si and GaAS considering both the switches ON or OFF.

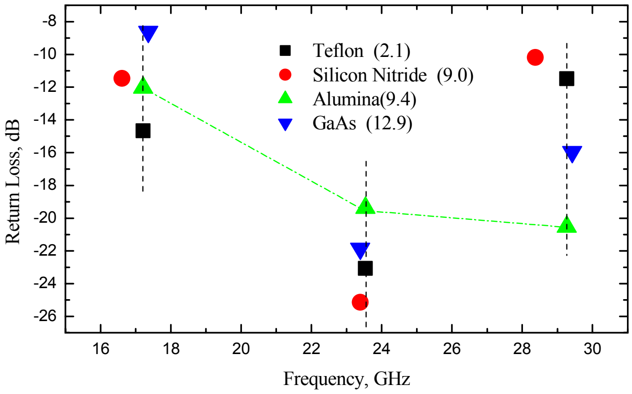

Figure 4. Return loss of the antenna for different types of MEMS bridge materials when the switches are OFF.

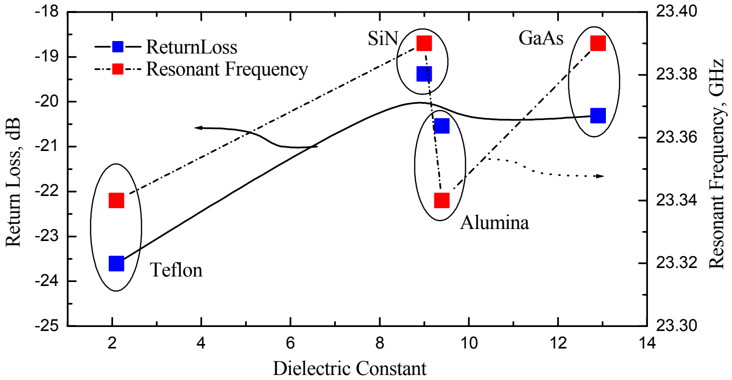

Figure 5. Return loss and resonant of the antenna for different types of MEMS bridge materials when the switches are ON.

4. CONCLUSION

A reconfigurable triple-band antenna operating at 17.21, 23.54 and 29.27 GHz using MEMS switches is presented. Single resonant frequency occurred when both the MEMS switches are ON confirmed that the antenna behaves like a single patch antenna. The resonant frequencies do not depend on the cantilever beam which acts as a MEMS bridge for switch. Careful selection of cantilever beam is required for low insertion loss. The proposed reconfigurable antenna can be implemented in easy fabrication process steps by sandwich methods.

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