Meander based RF MEMS capacitive switch for Mobile Front End Terminal Antenna support

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ABSTRACT

Future network's main requirements are compact size, support to heterogeneous network which drive the requirements for multiband support. Self-similar shaped structure have useful applications in cellular telephone and microwave communications etc. Video conferencing, streaming video are main applications that are included in future networks and requirements for these applications are high data rates which require to have high bandwidth. But our aim to derive an antenna which works on large band of frequencies while having compact size. As size of antenna reduces bandwidth supported by the antenna. So it is required to have small size with high bandwidth. In this paper we propose meander based RF MEMS capacitive switch for mobile front end terminal antenna support for next generation networks. Different number of iteration is performed for its support to different bands. Re-configurability in antenna is another important concept and in this work this reconfigurability is achieved by using RF MEMS switches.

Keywords: meander, RF MEMS switch, reconfigurable antenna, fractal antenna

1. INTRODUCTION

Rapid developments in wireless communication industry continue to drive the requirements for small, compatible, and affordable reconfigurable antennas and antenna arrays. Reconfigurable multiband antennas are attractive for many satellites, military and commercial applications where it is desirable to have a single antenna that can be dynamically reconfigured to transmit and/or receive on multiple frequency bands. Such antennas find applications in space-based radar, unmanned aerial vehicles, communication satellites, electronic intelligence aircraft and many other communications and sensing applications. The technology of design and fabrication of MEMS for RF circuits had a major positive impact on reconfigurable antennas[1, 2]. Next generation network aims at high data rates requires wide bandwidth. High efficiency is expected from antenna performance in today's era of communication system.But today's miniaturization technologies need antennas size to be less as well. Both requirements at a time first for small size and wider bandwidth can be fulfilled by using antenna fractal shape. Re-configurable antenna can be further use to improve overall system performance Pattern-reconfigurable antennas can either increase capacity or extend radio coverage by increasing the carrier-to-interference ratio.

Puente et al. [3,4]introduces Fractal multiband antenna based on theSierpinski gasket. Reconfigurablity to these fractal antennas will enhance the performance and this reconfigurability is achieved by using RF MEMS. Anagnostou et al.[5] defines an RF MEMS based Self similar shaped reconfigurable antenna which has potential of multiband antenna with small size and reconfigurablity. In this paper proposed meander based RF MEMS capacitive switch support shows an improvement in characteristics at higher frequenciesoffered bySerpentine flexure beam as compared to fixed-fixed beam [6]. In this paper we propose a switch which uses meander shape beam rather cantilever beam so that improvement in scattering parameters. It has wide potential with multiband support for different applications like K and K_a band which is to be sight for different satellite communication. It is also supposed to support next generation mobile terminal applications.

2. Antenna and RF MEMS Switch Design

As discussed in above section, reconfigurablity in antennas offer us tunability of frequency for which we can use our antenna, so that we can use same antenna for large range of frequencies. While electric switching proved useful in assuring re-configurability so that frequency tuning in antenna can be achieved. But MEMS advantages over electric switches leads us use of MEMS in this paper to achieve frequency tuning of antenna. As size and bandwidth requirement is achieved by fractal shape, we propose here Fractal shaped reconfigurable antenna which is reconfigured by RF MEMS switch and it supports bands including K, Ka and Q band.

2.1 RF MEMS Switch

MEMS are the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology. The micro-fabrication process normally involves a lithography-based micromachining, fabricated on batch basis, which offers great advantages of low cost when manufacturing in large volume. MEMS are also built on high-resistivity Gallium Arsenide (GaAs) wafers, and quartz substrates using semiconductor micro fabrication technology. From a mechanical point of view, MEMS switches can be a thin metal cantilever, air bridge, or diaphragm, from RF circuit configuration point of view, it can be series connected or parallel connected with an RF transmission line [8,9]. The contact condition can be capacitive (metal–insulator–metal) or resistive (metal-to-metal), polar ceramics such as (Ba,Sr)TiO3 - BST and designed to open the line or shunt it to ground upon actuation of the MEMS switch. Each type of switch has certain advantages in performance or manufacturability. Tunable ferroelectrics have great potential applications in tunable microwave devices [10,11]. Main mechanical operations of RF MEMS switches depends mainly on spring constant of material used i.e. k. We always require to have less k i.e. less stiff material because the deflection of beam depends on spring constant k and we need more deflection with given force for an given RF MEMS Switch. In this paper we have used Serpentine flexure type meander shape to lower the k value [8,9]. Calculation for spring constant for meander shaped beam is given below.

Serpentine flexure

$$k \approx \frac{48GJ}{l_a^2\left(\frac{GJ}{EI_x}l_a + l_b\right)n^3} \quad \text{for} \quad n >> \frac{3l_b}{\frac{GJ}{EI_x}l_a + l_b} \qquad (1)$$

Where n is the number of meanders in the serpentine flexure, $G = E/2(1+\nu)$ is the torsion modulus, $I_x = wt^3/12$ is the moment of inertia, and the torsion constant is given by

$$J = \frac{1}{3}t^3 w\left(1 - \frac{192}{\pi^5}\frac{t}{w}\sum_{i=1,i\,odd}^{\infty}\frac{1}{i^5}\tanh\left(\frac{i\pi w}{2t}\right)\right) \qquad (2)$$

For the case where $l_a >> l_b$, the spring constant of the serpentine flexure becomes

$$k \approx 4Ew\left(t/(nl_a)^3\right) \qquad (3)$$

2.1.1 Design of a Coplanar Waveguide

Coplanar waveguide (CPW) is a one-sided three-conductor transmission line. Coplanar waveguide have two grounds in the same plane of center conductor, reducing the coupling effects and allows for easy inclusion of series and shunt elements. Since microwave integrated circuits are basically coplanar in structure, coplanar waveguide lines are used widely as circuit elements and as interconnecting lines. At millimeter-wave frequencies, coplanar waveguide offers the potential of lower conductor and radiation losses as compared to microstrip lines. Coplanar waveguide also allows for varying the dimensions of the transmission line without changing the characteristic impedance.

An approximate formula [12], for the characteristic impedance of the coplanar waveguide, assuming t is small, $0<k<1$, and h>>w, is

$$Z_o = \frac{30\pi^2}{\sqrt{(\varepsilon_r+1)/2}}\left[\ln\left(2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right)\right]^{-1} \text{ohms} \qquad (4)$$

Where $k = \frac{w}{w+2s}$ and w = center strip width; s = slot width; ε_{re} = relative dielectric constant of the dielectric substrate.

An empirical equation for effective relative dielectric constant ε_{re} of Eq. 4.1 is

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2}\left[\tanh\left(1.785\log\left(\frac{h}{w}+1.75\right) + \frac{kw}{h}\left(0.04-0.7k+(1-0.1\varepsilon_r)\frac{(0.25+k)}{100}\right)\right)\right] \qquad (5)$$

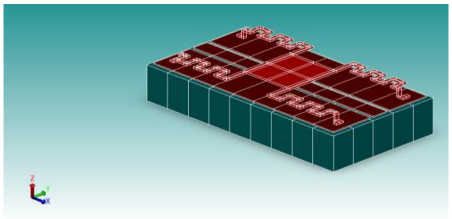


Figure 1 Serpentine flexure beam based RF MEMS switch

As shown in Figure 1, the Silicon substrate of ε_r = 11.8 was chosen, and CPW center conductor width w = 2µm and ground spacing s = 0.8 µm, nearly thickness is 0.5 mm and nearly infinite compared to width.The outer CPW ground wave conductor width is 14µm The effective dielectric constant is 4.4. Microwave parameters that should be optimized for any RF switch are the insertion loss, isolation, and switching frequency and return loss. The insertion loss is due to mismatch the characteristic impedance of the line and switch. The contact resistance and beam metallization loss will also contribute to the insertion loss. Switch influence on these microwave parameters will be discussed later.

2.1.2 Activation Mechanism for Electrostatic Actuation

When the voltage is applied between a fixed-fixed or cantilever beam and the pull down electrode, an electrostatic force is induced on the beam. The electrostatic force applied to the beam is found by considering the power delivered to a time-dependent capacitance and is given by

$$F_e = \frac{1}{2}V^2\frac{dC(g)}{dg} = -\frac{1}{2}\frac{\varepsilon o W w V^2}{g^2} \qquad (6)$$

where V is the voltage applied between the beam and electrode. Ww is the electrode area.
The electrostatic force is approximated as being distributed evenly across the beam section above the electrode. Equating the applied electrostatic force with the mechanical restoring force due to the stiffness of the beam (F= Kx),

$$\frac{1}{2}\frac{\epsilon_0 W w V^2}{g^2} = k(g_0 - g) \qquad (7)$$

Where g_0 is the zero-bias bridge height. At ($2/3g_0$), the increase in the electrostatic force is greater than the increase in the restoring force, resulting in the beam position becoming unstable and collapse of the bam to the down-state position. The pull-down (also called pull-in) voltage is found to be

$$V_p(V) = V\left(\frac{2g_o}{3}\right) = \sqrt{\frac{8k}{27\epsilon_0 W.w}go^3} = \sqrt{\frac{8k}{27\epsilon_0 A}go^3} \qquad (8)$$

As shown in Eq. (3-5), the pull down voltage depends on the spring constant of beam structure, and, beam gap g0 and electrode area A. To reduce the actuation voltage, the key is beam structure of low spring constant k. The pull-in voltage was investigated in terms of beam structure (different k), beam thickness, gap and beam materials.

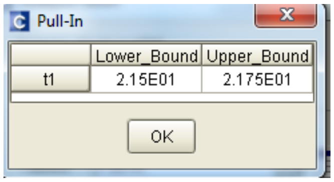
3. Results

3.1 RF MEMS Design and Analysis

Table 1 shows the various parameters calculated and measured for meander based RF MEMS switch. Since Coventorware software [14] could synthesize the multiply factors, such as electrostatic-forces, pull-down voltages, Young's modulus, and other vector values could are obtained, and the result is intuitionistic. So, we also used Coventore software to know the relationship shape, material and actuated voltage of switch. Fig 2 shows the Pull-in voltage for RF MEMS switch which ranges from 21.5V to 21.7V. Variation of displacement i.e. from maximum z-direction to minimum z-direction w.r.t. voltage is shown next in figure 3, when the switch is electrostatically actuated. The next graph (in fig 4) shows change in capacitance value with different values of voltages. In off - state its value is 509.09µF and at pull-in voltage i.e. in on-state comes out to be 467.9µF.

Parameter	Value	Parameter	Value
Length [µm]	160	Actuation Area [µm2]	20 * 80
Width [µm]	80	Actuation voltage [V]	21.5 V (20-30 V)
Height [µm]	2	Switch time [µs]	
Membrane Type	Aluminium (film)	Cd [pF]	50
Thickness [µm]	0.5	Poision Ratio	3.0e-001
Residual stress [MPa]	0	Young's Modulus	7.7e+004
Spring Constant [Nm]	10-50	Isolation [dB] > 20GHZ	20 dB
Holes [µm]	No	Isolation [dB] 20 GHz- 55 GHz	35 dB
Sacrificial Layer	BPSG (2 µm)	Loss [dB] (0.2-55 GHz)	0.2-0.4
Dielectric (Å)	SiN (0.2 µm)		

Table I. Parameters for Meander based RF MEMS switch



	Lower_Bound	Upper_Bound
t1	2.15E01	2.175E01

Fig 2: Pull-in voltage for capacitive MEMS switch

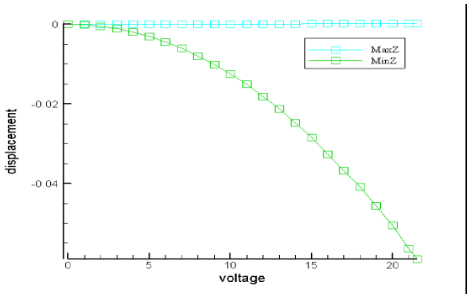


Fig 3: Displacement versus Voltage Graph for capacitive MEMS switch.

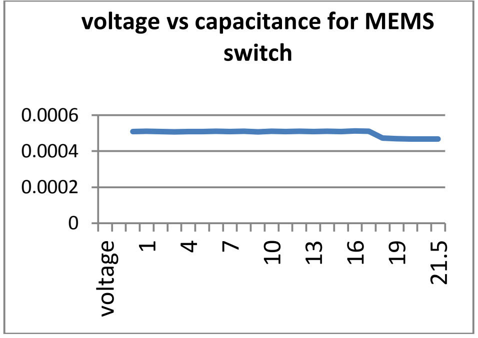


Fig 4. Voltage Vs Capacitiance graph for meander based RF MEMS switch.

4. Conclusion

In this paper, meander based RF MEMS switches designed and simulated fora multiple-frequency fractal antenna is presented which shows the frequency tunability by the reconfiguring of the antenna electronically or changing the order/iteration. By using MEMS switches, the losses are kept to a minimum. This is very important to obtain high reconfigurability and because the connection/ disconnection of a switch may lead to mismatched systems. Also, the integration of the switches to the antenna imposes restrictions on the system design. The antenna structure should be compatible with the switch structure and made with specific materials. The dimensions of the switches often cannot be altered and thus put a low-bound in the size of the antenna system and a high-bound in the power the system can handle. This technology can be applied to many other devices, including tunable filters, other antenna geometries, signal splitters or military applications.

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