Silicon-etched Re-configurable Self-Similar Antenna with RF-MEMS Switches

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Abstract—Self-Similar antennas have been well known for their multiband characteristics. The use of series ohmic contact cantilever RF MEMS switches in coordination with a simple self-similar antenna is exploited. The compatibility of the designs and the fractal nature of the antenna can lead to large increases in antenna performance, since not only a wider selection of frequencies, but also several different radiation patterns can be radiated with a single antenna. In this paper, the design and the compatibility of the switches and simulated results are presented.

Index Terms *– Fractal antennas, Sierpinski, Re-configurable antennas, RF-MEMS*

I. INTRODUCTION

Multiband antennas, have the ability to radiate different patterns at different frequencies. Self-similar antennas on the other hand, radiate similar patterns at different frequencies, due to their fractal shape. Such types of antennas are used in radar and modern telecommunication systems [1-5]. The requirements for increased functionality, such as DoA estimation, radar, control and command, within a confined volume, place a greater burden in today's transmitting and receiving systems. A solution to this problem is the re-configurable antenna.

In this work, series ohmic contact cantilever RF MEMS switches are used in conjunction with a simple self-similar fractal antenna, also studied in [6], as the basis of a new re-configurable antenna approach. In the past, re-configurable antennas have been restricted to the use of non-fractal elements, such as printed dipoles or conventional microstrip antennas. Here the use of fractal shapes permits a dynamically reconfigurable structure where the current flows through different path lengths that lead in multiple frequency applications. The aim is to be able to activate or deactivate the current on each element and therefore alter the radiation pattern for the required frequency of operation and mission in general. Polarization is inherently linear. Still, circular polarization can be achieved with the use of a second separately-fed antenna at a 90 degrees angle [7]. Several examples and their results are presented herein.

II. RF MEMS Switches Design and Measurements

The switches will be used in the antenna design are cantilever ohmic contact switches. The membrane is made out of gold and is suspended 1-2 μm above the silicon substrate. The switch is electrostatically activated by applying a DC voltage at the probe pad that is connected to the pull-down electrode. The latter is isolated from the membrane via a thin layer of silicon nitride. The switch actuation voltage is between 20-30 V. A photo of the fabricated switch is shown in Fig. 1(a). The measured insertion loss of the switch and the associated transmission line in the ON and OFF states is shown in Fig. 1(b). When the switch is in the ON state the loss is around 0.4 dB at 15 GHz. It is estimated that around 0.2 dB of that loss is due to the transmission line. When the switch is not activated the isolation is around 18 dB at 14 GHz.

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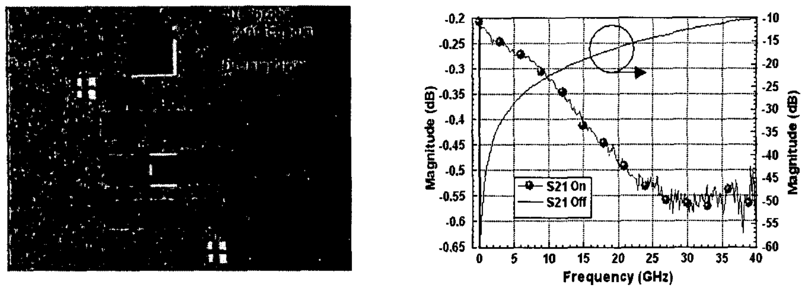

Figure 1(a,b). a) Photo of fabricated MEMS switch on silicon substrate and b) measured insertion loss of the switch in both states.

III. Antenna Design

By turning switches ON or OFF, different current paths are selected and therefore the antenna's size and shape are altered. Fractal antennas are generally placed as monopoles vertically over a ground plane. In this case, a self-similar antenna needs to be etched on the same layer with the series CPW RF-MEMS Switches. Therefore the antenna will be etched on a Silicon wafer. To achieve this, the self-similar Dipole antenna is etched on a silicon substrate with relative dielectric constant ε_r=11.9, like a printed dipole. For manufacturing purposes the antenna will fit in a quarter of a silicon wafer with a diameter of 4' inches.

This antenna has equilateral triangular patches with side-length of 10 mm. Also, a 140 μm gap is placed between each patch in order for the switch to be etched there. The diagonal gap's length is also exactly 140μm for this design. Eventhough a small change in any of these numbers will not affect much the antenna's behavior, apart from the fact that increasing the size of the antenna decreases its higher resonant frequency, accuracy is important as the behavior of the switches may be severely affected.

It is worth noting that a lossy dielectric layers such as Silicon, when thick, provide good matching in a very large range of frequencies (UWB/ bowtie antennas). On the other hand they are more lossy and most important, we need to comply with the manufacturing restrictions so the dielectric's thickness is that of the silicon wafer.

The antenna's characteristics are described next. Its total dimensions are 3.74 x 6.6 mm, and each element has 1.8 mm side-length and 1.55 mm vertical length (corner to edge). Silicon's dielectric permitivity is 11.9, but the effective ε_{r_eff}=1.8 since there is no ground plane. The Silicon wafer's thickness is 500 μm. The highest usuable resonant frequency is 13.4GHz, while the lowest is approximately 1.5GHz and that sets a low-limit for this antenna. The feeding gap between the 2 monopoles was made 0.49 mm although it may vary depending on the feed's characteristics. The antenna is fed using a CPW probe pad.

The antenna's layout is shown in Fig. 2(a,b). By placing the switches on the antenna and numbering their positions as 1,2,3.,...6, the switches position can be represented as a 6-digit binary number. The placement of the switches is shown in Fig. 2(c). Setting the switches ON or OFF, we obtain different antenna shapes. First the simple bowtie antenna shown dark-shaded in Fig. 3(a) is obtained. Setting 0 for the OFF and 1 for the ON state of each switch this switch state can be represented with the binary number 000-000. Its dipole-like radiation pattern is shown in Fig. 3(b).

When all the switches are connected (ON-state 111-111), the antenna functions with its full-size, and it resonates in different frequencies, and particularly at 7.6GHz as shown in Fig. 4.

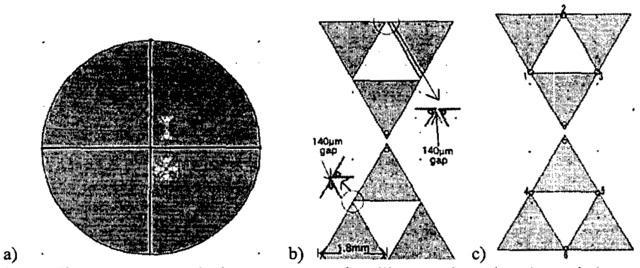

Figure 2(a,b). a) The antenna as etched on a quarter of a silicon wafer. Also shown below a design for circular polarization. b) The antenna's shape and dimensions. c) The switch positions and numbering

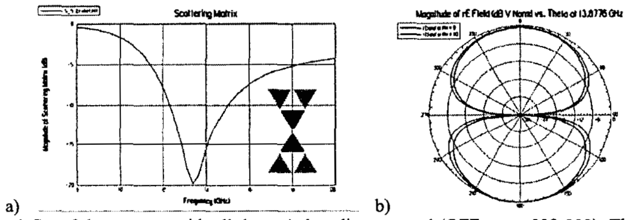

Figure 3(a,b). a) S_{11} of the antenna with all the switches disconnected (OFF, state 000-000). The antenna functions as a 13.8 GHz printed bowtie on a Silicon layer. b) Radiation pattern at around 13.8GHz.

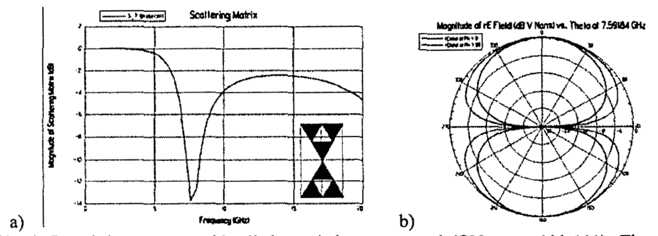

Figure 4(a,b). a) S_{11} of the antenna with all the switches connected (ON, state 111-111). The antenna functions at around 7.6GHz as expected. b) Radiation pattern at 7.6 GHz.

Several assymetric configurations can be exploited as well. When one diagonal switch is turned off, the currents are directed to follow a certain, longer, path resulting in a lower resonance, but with similar radiation pattern (state 011-011). Resonances now occur at 6 GHz, 13 GHz and 18 GHz. The results are shown in Fig. 5.

As a final case, when the antenna has only one diagonal switch actived, its radiation patterns are similar as before but the frequencies differ. The resonant frequencies have decreased, as the lengt of the current has been maximized. It seems that the antenna has maintained the characteristics of its previous radiation patterns. The results are shown in Fig. 6.

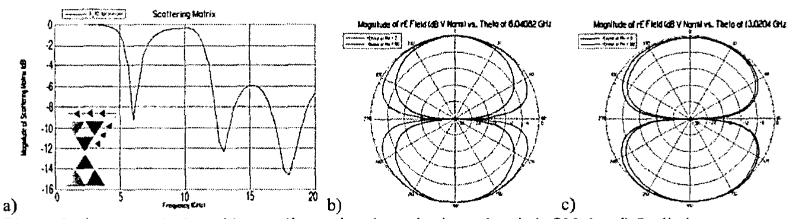

Figure 5. a) Antenna's S_{11} with one diagonal and one horizontal switch ON. b,c,d) Radiation patterns at 6.04 GHz and 13.02 GHz.

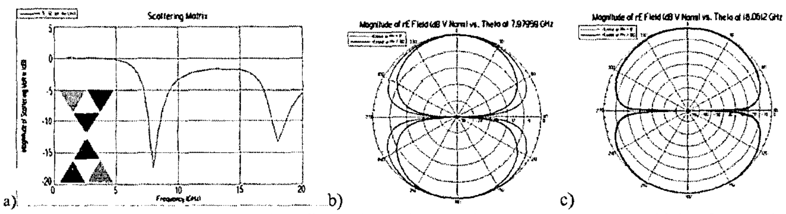

Figure 5. a) Antenna's S_{11} with one(x2) diagonal switch ON only. Antenna resonates at higher frequencies (8 GHz and 18 GHz) due to its reduced physical size. b,c) Radiation patterns at 8 GHz and 18 GHz.

IV. CONCLUSIONS

The first self-similar antenna with RF-MEMS switches was been studied. The structure of the series ohmic contact cantilever RF MEMS switches permit the interconnection of the antenna's patches and therefore this exceptionally multiband performance. Furthermore, more complex self-similar antennas such as high-iterations Sierpinski Gaskets or other structures can be examined and the results are expected to show resopnances in many frequency bands with both dipole-like and steered dipole-like radiation patterns. Future work will investigate the function of this antenna on the whole 10-14 GHz bandwidth, as well as both at 35 GHz and 14 GHz, for communication or military applications.

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