

# PLANAR RECONFIGURABLE ANTENNAS

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## ABSTRACT

In this paper it is shown that planar reconfigurable antennas can cover a wide range of designs such as fractal antennas, triangular antennas, monopole, dipoles, log-periodic etc. Some of these designs can also be used to yield tunable electrically small antennas for miniature wireless device applications. In all cases RF MEMS switches are used to achieve reconfigurability and multi-functionality. Some of the challenges that the designer has to face in biasing and integrating switches with the antenna are presented and discussed.

## 1. INTRODUCTION

Re-configurable antennas, with the ability to radiate more than one pattern, at different frequencies, are necessary in radar and modern telecommunication systems. The requirements for increased functionality, such as direction finding, 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 [1-8].

Reconfigurable antennas have been used in the past 10 years for a variety of applications but almost all of them have made use of some kind of a switching mechanism. By combining low-loss, high-isolation RF MEMS switches with compatible antenna elements, we can physically reconfigure antennas and their feed structures providing frequency band and polarization diversity. RF MEMS or other switches are used to alternately connect or isolate sub-structures on a planar antenna element, creating a geometrically distinct radiator for each combination of switch positions.

Furthermore reconfigurable miniature systems can be constructed that have the ability to sense and/or transmit electromagnetic energy for communications or remote sensing. Microwave and millimeter-wave antennas can be fabricated monolithically with other electrical/mechanical components to yield a new class of reconfigurable antennas capable of multi-band operation, adaptive beamforming, jamming/interference mitigation, polarization diversity, low-observability, and direction of arrival estimation [9-10].

Although a reconfigurable antenna can actually take any shape, here we only cover planar reconfigurable

antennas and their design challenges. The antennas to be presented cover a wide range of designs such as fractal antennas, triangular antennas, monopoles, dipoles and log-periodic antennas. One can vary either the length or the width of the antenna (metallic parts) or its aperture. However, the presence of the switches themselves can have an adverse effect on the performance of the antenna. Biasing lines used to activate the switches can radiate themselves or they can alter the radiation pattern. Some of the challenges that the designer has to face in biasing and integrating these switches with the antenna are also presented and discussed.

It is expected that these antennas, once they are constructed and placed on a certain platform, they can be reconfigured remotely without having to reconstruct the antenna or the platform on which the antenna structure is placed on. It is expected that one day it will be possible to create antennas as part of a large reconfigurable systems that reconfigure themselves autonomously to adapt to environmental changes or operational requirements [11].

## 2. EXAMPLES

Here we present several examples of planar structures that can be used to create reconfigurable antennas.

### 2.1. X-band planar dipole

As a first example we show how one can change the length of a basic dipole antenna using a number of switches to change the operational frequency of the antenna. More specifically, in this particular example the goal is to design a reconfigurable dipole antenna that can operate on demand at any frequency in the X-band. As shown in Fig. 1, the arms of the dipole are connected with switches to additional patches. The basic function of the switches is to conductively couple the additional metallic patches thus extending on-demand each arm's length. When the switches are 'off' the patches couple capacitively to the main arms, thus they slightly increase the antenna's bandwidth. When the switches are 'on', the additional patches are connected to the antenna's arms via the continuous metallic path that each switch provides through its membrane. To avoid unnecessary discontinuities in the structure, the dipole is set to have the same width as the switches (110  $\mu\text{m}$ ). In

other words it can be considered as an extension of the switch's transmission line. Fig. 2 depicts the S11 performance of this antenna as the different switches go on and off. This is the most basic reconfigurable antenna configuration that one can have. However, care must be taken in placing the bias lines in such a way that they do not radiate or change the desired polarization of the antenna. Usually, the bias lines are fabricated using a high resistive material to reduce these effects. The antenna can cover the range of 8-12 GHz easily. So a narrow band antenna structure such as a printed dipole can actually be manipulated by switches to act as a multi-frequency antenna.

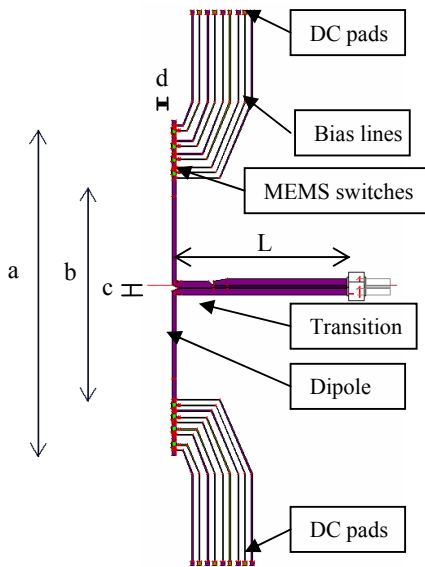


Figure 1. Topside view of the reconfigurable planar dipole antenna design

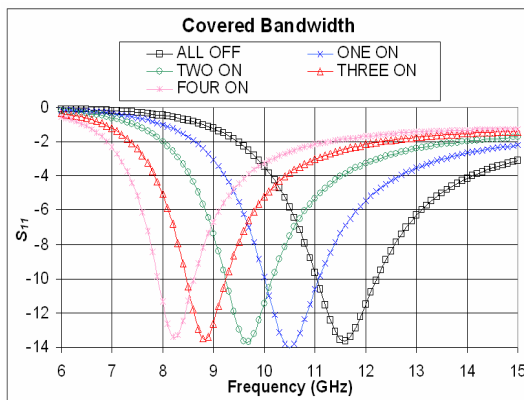


Figure 2. The S11 performance of the antenna antenna's performance for different configurations

Fig. 3a shows the schematic of an RF-MEMS series cantilever switches, with a 3  $\mu\text{m}$  thick membrane made of gold for greater flexibility. The biasing is achieved with 9-pin GSG probe pads that provide the necessary 17 Volts potential difference between the pull-down electrode and the membrane. The switches have been designed and fabricated at the Georgia Institute of Technology [12]. They demonstrated a high isolation (-15dB) and low insertion loss (-0.3 dB) for frequencies up to 40 GHz.

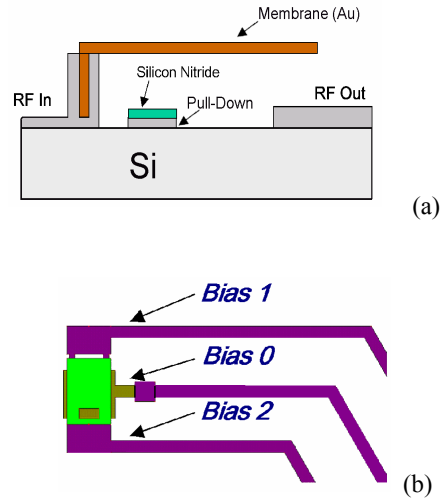


Figure 3. a) Schematic cross-section of the switch. b). The switch with its bias lines

The bias lines, shown in Fig. 3b, are made of high-resistive material. Sheet resistance  $R_s = 10\text{K}\Omega/\text{sq}$ , and each line is more than 20 squares long causing the currents to attenuate rapidly on them. The lines end in 150-pitched biasing pads, placed  $3000\ \mu\text{m}$  from the top and bottom of the structure, in order to minimize interference with the bulky metallic probe heads. Finally, the antenna's RF feed is achieved with CPW probes, through a wideband CPS to CPW transition [12] designed specifically to make possible the feed of any planar dipole-like antenna up to 40 GHz.

## 2.2. Monopole with attached sleeves

Here we show how a standard monopole fed with a coplanar waveguide (CPW) feed can be converted to a reconfigurable antenna structure by attaching sleeves to its side. A planar monopole has been considered as an attractive printed antenna for wireless communications, because of its simple structure and omni-directional radiation pattern. The idea here is to maintain its omni-directional radiation properties when additional components or sleeves are attached to it. This is where optimization techniques can help figure out which way the additional conductive strips or other parts have to be placed and what shape they should have. In most cases this is done by a trial and error approach. This

particular structure, shown in Fig. 4, is very compatible with monolithic microwave integrated circuits (MMICs) and has small radiation losses.

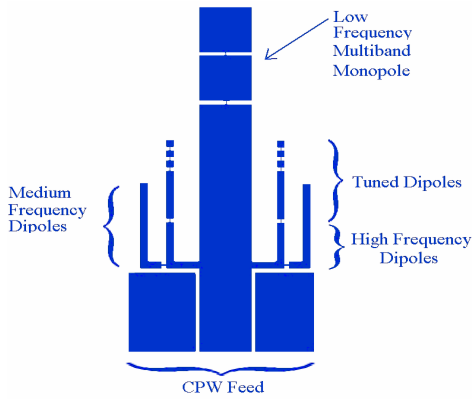


Figure 4. Layout of a cactus-like shape reconfigurable antenna

Figure 5 shows the dimensions of an antenna with one sleeve on each side of the monopole. The antenna is printed on a Rogers RO 3203 substrate with a thickness of 1.524 mm and relative permittivity  $\epsilon_r=3.02$ . A 12 mm long sleeve is attached to each side of the monopole. Switches are used to connect two additional patches of area 1 mm x 1 mm to each sleeve. An extra patch of length 12 mm is also connected to the monopole via a switch to vary its length. This arrangement produces frequency agility since the obtained resonant frequencies will vary depending on the states of the monopole and the sleeve switches as shown in Figs. 6 and 7. Figure 8 depicts the radiation patterns that one gets from such an antenna.

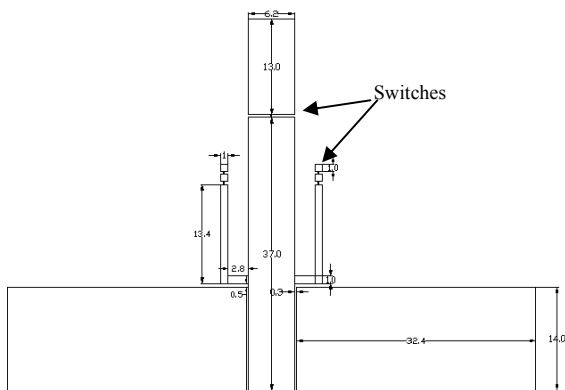


Figure 5. Layout of a monopole antenna with two attached sleeves

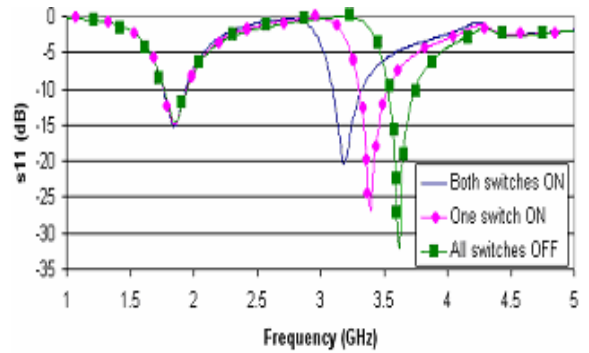


Figure 6. Simulated results of  $S_{11}$  vs. frequency for different sleeve switch states when monopole switch ON

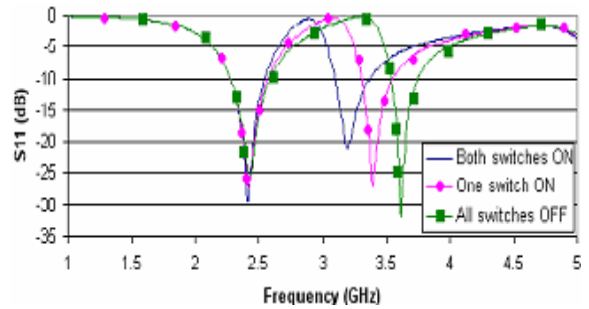


Figure 7. Simulated results of  $S_{11}$  vs. frequency for different sleeve switch states when monopole switch OFF

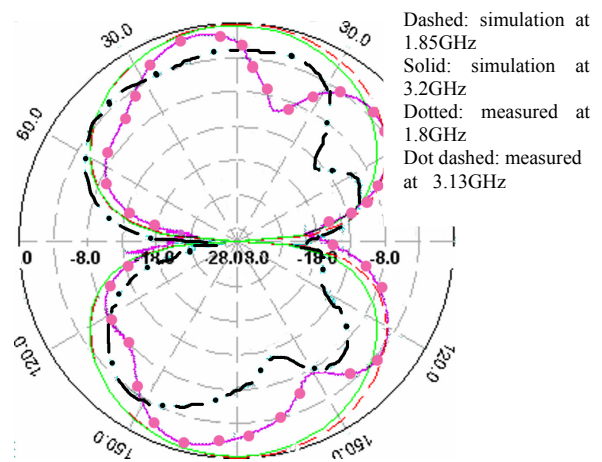


Fig. 8 Simulated and measured radiation patterns in the E-plane for the one-sleeve antenna when the monopole switch and both sleeve switches are ON

One can add several sleeves on each side of the monopole to achieve not only frequency agility but also radiation pattern diversity.

### 2.3. Reconfigurable aperture coupled microstrip patch

Another reconfigurable planar structure using RF MEMS to vary its frequency and modes of excitation in triangular patch is shown in Fig. 9. This antenna fabricated at Sandia National Labs [10] uses  $80\ \mu\text{m}$  by  $200\ \mu\text{m}$  capacitive RF MEMS switches to bridge two symmetric slots on the triangular radiating element. The slots are positioned perpendicular to the direction of RF current flow in order to vary the dominant operating mode of the antenna. The switches control the length of this perturbing slot which determines the direction of RF current flow along the patch. When all of the switches are closed the antenna behaves essentially as if there were no slot present on the patch. When all the switches are open, the slot reaches its full length and the resonant RF current is forced to travel a substantially longer distance producing a 30% lower resonant frequency as shown in Fig. 10. This antenna has 5 different states. Each state is determined by the action of two symmetric switches on each slot.

The switch positions and slot dimensions are optimized with the rest of the feed and coupling structure to provide near- contiguous coverage across the 32 to 39GHz band. Fig. 11 depicts the return loss for the 5 different states.

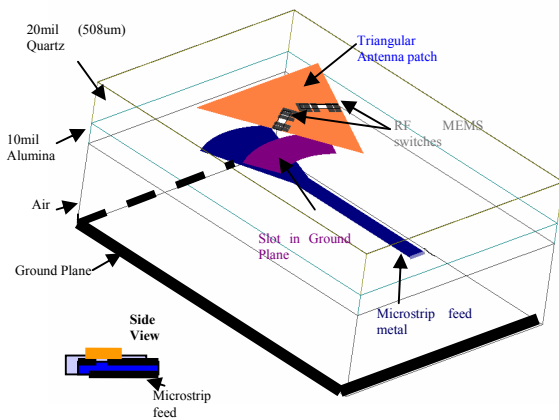


Figure 9. Layout of monolithic reconfigurable triangular patch antenna

The results of Fig. 11 clearly demonstrate the feasibility of this approach in designing reconfigurable monolithic triangular patch elements.

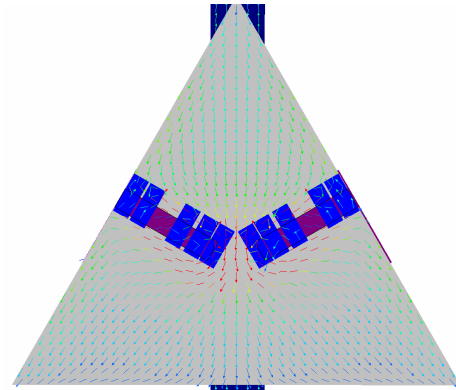


Figure10. Current flow on the triangular patch

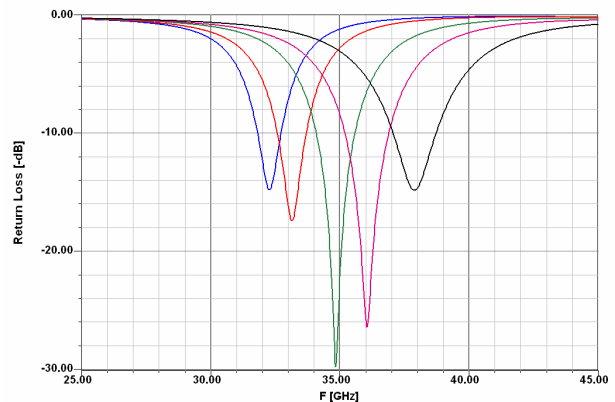


Figure11. Return Loss for of all 5-states

One can even use a MEMS reconfigurable feedline to improve the bandwidth of the feedline technique in an effort to get better return loss performance across the tuning bandwidth. A single switch at the open end of the feedline structure can dramatically improve the impedance match across the full tuning range [10]. Another method uses low-Z stubs on the open end of the microstrip feedline to slightly enhance the impedance bandwidth of the feed as reported in [13-16].

Care of course must be taken in designing these switches since they can cause problems during their integration with the antenna. In this case the up-state isolation was properly accounted both in simulation and in the measured prototypes. However, the finite capacitance of the switch in the down-state (when it shortens the aperture slot) was neglected in obtaining both the simulated and measured results. Surface-roughness effects from the fabrication process tend to reduce the down-state capacitance of capacitive RF MEMS switches even further and one has to understand

these MEMS fabrication tolerances in order to take them into account during the actual design. For example, the non-ideal impedance of the down-state switches is quite high relative to the surface impedance of the antenna center since it was made out of gold. If this is not accounted for in the original design, the resonant RF current will always flow through the center of the antenna, and not through the switches, causing a complete loss in the tunability of the antenna.

#### 2.4. Fractal antennas

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 [17-22]. In Fig. 12 we show RF MEMS switches used in conjunction with a simple Sierpinski fractal antenna as the basis of a new re-configurable antenna approach. The use of fractal shapes permits a highly reconfigurable structure with different current path lengths that can be used in multiple frequency applications. The aim is to be able to adjust the current on each element and therefore the radiation pattern for the required frequency of operation and mission in general. The polarization of this antenna is inherently linear. Still, circular polarization can be achieved with the use of a second separately-fed antenna at a 90 degrees angle.

The RF MEMS switches permit a controlled connectivity of sections of the antenna's conductive parts, and therefore enhance the coupling between the triangular elements allowing clear multiple frequency operation. The antenna is fabricated on a quarter of a silicon wafer with a diameter of 4-inches. Due to its small size, many antennas can be developed on a single silicon wafer with the same MEMS process, making it suitable for mass-production military or commercial applications.

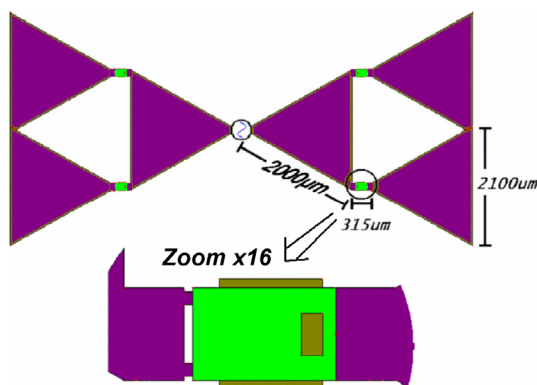


Figure 12. Antenna design and RF-MEMS switch connections

Fig. 13 shows how the biasing network has to also be included in the design since the bias lines have to be placed in such a way so they minimize their effect on the radiated patterns. The figure also shows how the fractal antenna is fed.

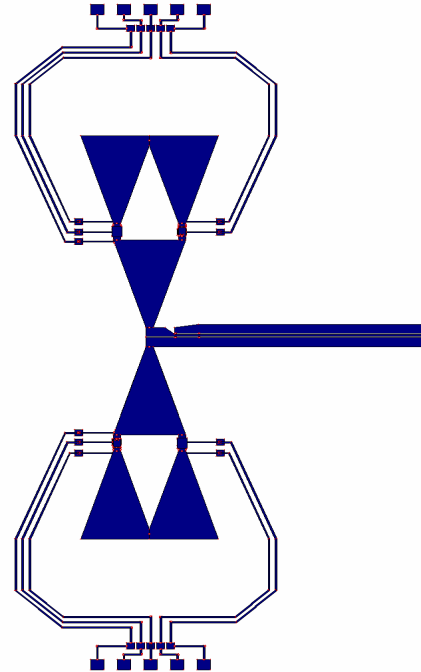


Figure 13. A basic fractal antenna with the biasing network for the MEMS switches.

There is a large number of possible resonant configurations that can be obtained from such a reconfigurable antenna design. The accurate computation of each configuration's frequency response and radiation pattern is very time consuming and it is often hard to predict what switches should be on to achieve a desired frequency response. Since there is no closed form solution in this particular case that can be used to determine the optimal number and position of the switches we can use Neural Networks (NN). NN techniques can be easily applied in antenna simulation and synthesis, to facilitate the design process [23]. As an example, Fig. 14 shows a comparison of the predicted results obtained via an artificial neural network (ANN) and measured data for the antenna structure shown in Fig. 15. The ON switch positions are marked with small circles and the corresponding activated array elements are shown as black triangles.

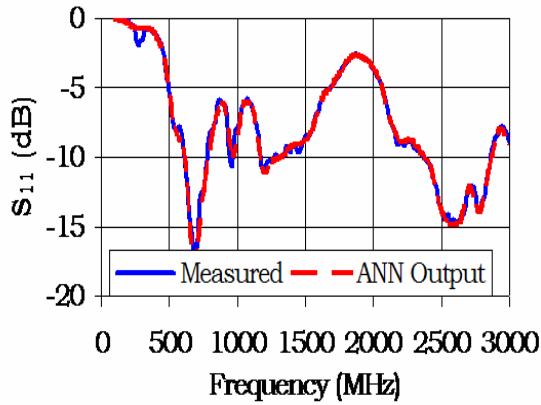


Figure 14. A comparison between the neural network prediction and measured data.

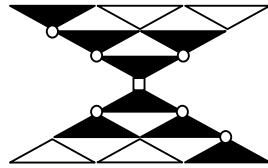


Figure 15. The ON switch positions are marked with small circles.

Since there several switch combinations that yield the same frequency response some final decision has to be made by the designer. That final decision can be made using another NN or another optimization technique. NN techniques can be used to yield a desired radiation pattern instead of a desired frequency response. A typical, dipole-like, radiation pattern that results from such fractal antennas is shown in Fig. 16.

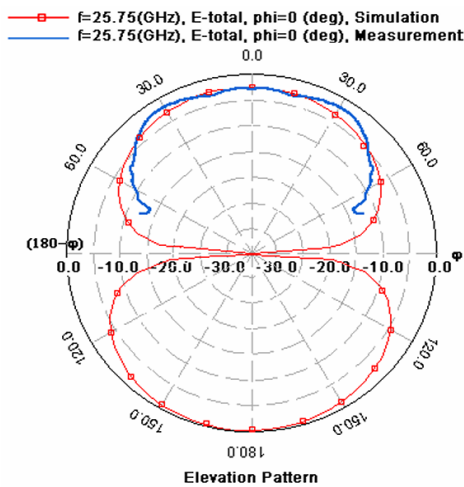


Figure 16. Measured and simulated radiation patterns for a fractal antenna at 8.5 GHz

### 3. CONCLUSIONS

Several reconfigurable antennas have been presented and discussed. These antennas can take various shapes such as a plane dipole or monopole, a triangular patch or even fractal antenna. In all cases switches are used to provide the antenna with greater flexibility and frequency agility. These antennas can provide also radiation diversity along with frequency agility. The increased demand for multifunctional antennas that can be used in applications such as direction finding, radar, control and command, make these reconfigurable antennas the prime candidates for the job.

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