# On the Silicon-etched Re-configurable Antenna with RF-MEMS Switches

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**Abstract**— Re-configurability in an antenna system is a desired characteristic that has been the focus of much research in recent years. In this work, RF-MEMS switches are integrated with self-similar planar antennas to provide a re-configurable antenna system that radiates with similar patterns over a wide range of frequencies. The different issues encountered during the integration of the MEMS switches and the overall antenna structure are described and discussed in this paper.

## *INTRODUCTION*

The distribution of currents on the surface of an antenna determines the characteristics of its radiation patterns. The property of self-similarity in an antenna structure can give self-similar patterns to its currents that in turn induce far field radiation patterns of similar nature. Self-similarity is the basis for the design of multiple frequency antennas whose primary predecessor is the well-known Sierpinski Gasket antenna [1].

Depending on the application, the Sierpinski Gasket can be modified to exhibit desirable frequency spacing [2]. Other modifications have been implemented with positive results. Amongst these, filters were applied at the triangles' interconnections to reduce the sidelobes that appear after the 1$^{st}$ resonance [3]. The great majority of research on Sierpinski Gaskets has been done for structures etched on thin dielectric materials with low relative permittivity, approximating the free-space environment. In a previous study [4], a re-configurable 2-iteration Sierpinski antenna was designed. To obtain the desirable re-configurability, the antenna's adjacent triangular patches are interconnected with series cantilever ohmic contact RF-MEMS switches. The introduction of these electrostatic actuators permits the physical connection/disconnection of the antenna's conductive sections relative to each other. The new re-configurable antenna may contain both similar and dissimilar radiating (or receiving) elements. Proper function of the electrostatic actuators imposes structural restrictions on the antenna, especially on its substrate layers. Issues regarding the design and feeding of this type of antenna in [4], the bias of the switches and the resulting solutions are presented. An improved antenna design is introduced. Results of the complete system are presented here and discussed.

## *INTEGRATION OF RF-MEMS SWITCHES WITH THE ANTENNA*

The initial antenna is a planar 2-iteration Sierpinski gasket with a 60° bow-angle and 4000μm height on each arm. The re-configurability of the antenna is accomplished with the use of 4 series cantilever ohmic contact RF-MEMS switches connecting its adjacent metal parts. Using the switches, 2 major radiating configurations are obtained: A '*bowtie*' with all switches '*off*' and a '*MEMS-enabled*' (or fractal) with all switches '*on*'. Since the

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latter consists of 2 iterations of the same shape, it exhibits 2 resonances with similar patterns. Two more configurations are obtained with one switch '*on*' and one '*off*' on each arm, resulting in four different current paths and so in four antenna configurations.

The cantilever ohmic contact switch is etched on a 400μm *Si* wafer and has a flexible membrane made of *Au* suspended 1-2μm above the *Si* substrate (Fig. 1a). This leads to the major restriction that the antenna be etched on the same material. Electrostatic biasing occurs on demand by applying a DC voltage of 20-30Volts on the probe pad that is connected to the pull-down electrode, which is isolated from the membrane via a thin silicon nitride layer. The probe pad and the antenna feed are placed away from the antenna to minimize the deformation of radiation patterns due to metallic probes. For bias accuracy, one or two more lines provide the ground for each switch. All bias lines are highly resistive with $R_s$=5KΩ/sq, and each line has more than 100 squares. The measured switch performance is shown in Fig. 1c. When the switch is '*on*', insertion loss is around 0.4 dB at 15 GHz and half of this loss is due to the transmission line. When the switch is '*off*', isolation is around 18 dB at 15 GHz. The bias network has to be made of high-resistive lines, since the currents formed on metallic lines deform the radiation patterns and cause unwanted resonances. On the high-resistive lines, currents flow for a few microns but attenuate immediately. Deformation of the antenna's radiation patterns is minimal and the slight extension of the current path causes only a small shift at the resonant frequencies. Simulated current flow at 23 GHz appears in Fig. 2a. The line's effect on the antenna performance can be seen in Fig. 2(b-e).

To feed the antenna, a transition from a coplanar strip line to a coplanar waveguide was designed after [5] and then modified. The transition maintains 50Ω characteristic impedance and ends in 150μm pitched pads. It is etched on the same substrate as the antenna and renders the antenna's performance easier to measure. It is fabricated using the same MEMS process as with the switches and consists of only 2 MEMS bridges, one at each discontinuity point, to suppress the non-CPW modes and balance the transmission line, which was made 4000μm long. A back-to-back design of the transition and its simulated performance is shown in Fig. 3. The numbers mark each type of line used for a smooth transition: '*2*' indicates the (top) Un-terminated Slotline Open such that the capacitive effect between this and the upper conductor of the stripline in '*3*' is minimal, and the (bottom) Asymmetric CPS that its upper strip is linearly tapered until it reaches symmetry. A '*3*' indicates the Asymmetric CPW that is linearly tapered to match the width of the symmetric stripline at the end of step '*2*'. Since only half of the back-to-back design is used, the transition performance is improved by –3dB.

## *RE-CONFIGURABLE ANTENNA RESULTS*

The complete system was modeled in the RF simulator. Even though the antenna shows good characteristics, interferers may lead to a system failure. The antenna needs not only to be better matched in its various configurations but also to maintain the form of its radiation patterns. Improved matching can be achieved when the antenna bow angle is narrowed. The trade-off is a reduction in the bandwidth of the '*bowtie*' resonance. A bowtie antenna with 35°-bow angle was found to have very good match with $Z_{in}$=49.8+j1.4Ω and small frequency shift. Since the Sierpinski's active region when in '*bowtie*' configuration is a bowtie-like antenna and the other triangles only load it capacitively, a similarly good match is expected when Sierpinski is used in our system. The results shown in Fig. 4 reveal that the antenna is better matched and maintains its radiation pattern characteristics. The proposed re-configurable antenna works at 3 frequencies with a return loss smaller than -15dB. These are $f_{1(\text{MEMS 1})}$ = 8 GHz, $f_{2(\text{Bowtie})}$ =

13.5 GHz and $f_{3(\mathrm{MEMS}\ 2)}$ = 25.75 GHz with respective bandwidths: $BW_1$=1 GHz, $BW_2$=3.5 GHz and $BW_3$=3.25 GHz. The '*bowtie*' mode has also a fairly good match from 17 GHz to 22.5 GHz with the same radiation pattern as at 14 GHz. The use of this band depends solely on the performance of the measured model. The two additional non-symmetric configurations mentioned before also exhibited dipole-like radiation patterns.

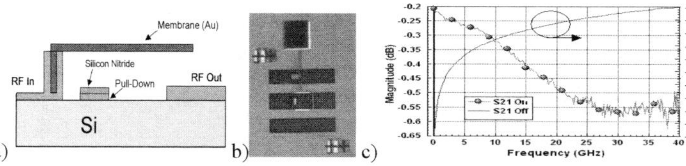

Figure 1. a) Schematic of the cantilever ohmic-contact switch. b) Photograph of the fabricated switch [4]. c) Measured insertion loss in both states [4].

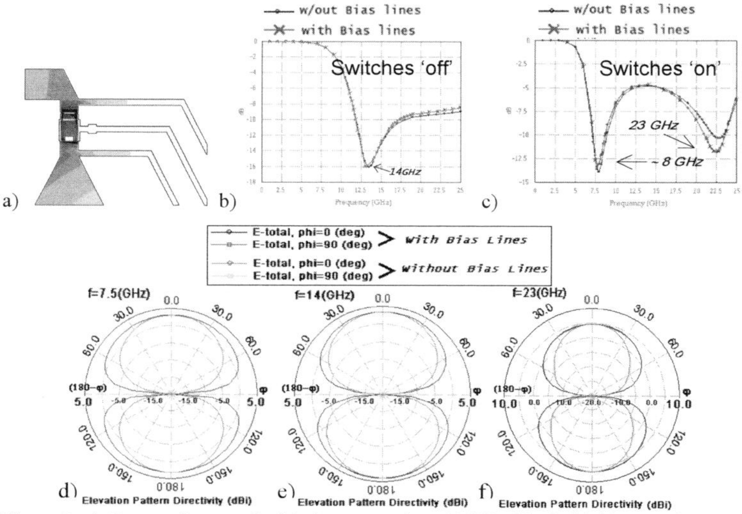

Figure 2. a) Current flow on the biasing network at 23GHz: black (high), gray (average), and white (minimum current flow). b,c) $S_{11}$ of the system with and without bias lines for different states. d-f) Effect of the bias network on the radiation patterns.

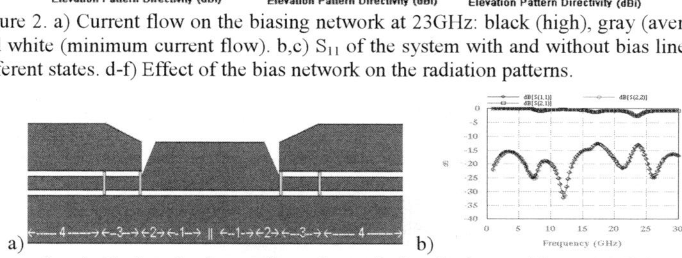

Figure 3. a) Back-to-back configuration of the feed transition: 1:SCPS, 2-top: Unterminated Slotline Open, 2-bottom: Asymmetric CPS, 3:Asymmetric CPW, 4: SCPW. b) S-parameters for the back-to-back configuration

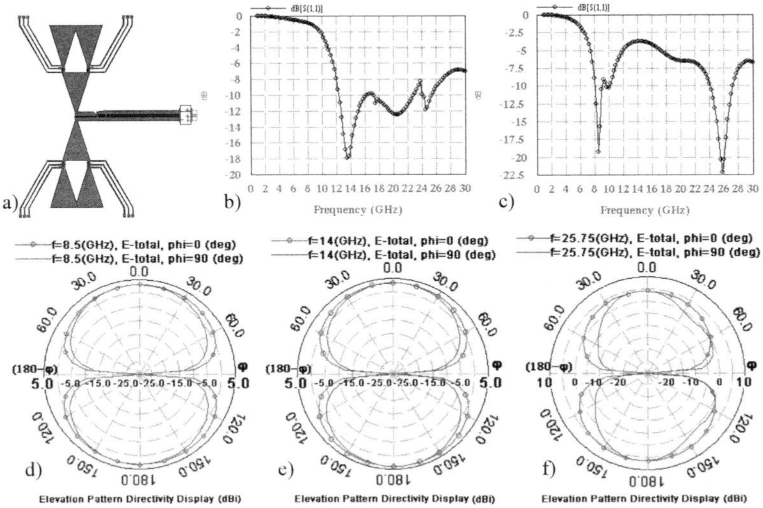


Figure 4. a) The proposed antenna design. b,c) $S_{11}$ of the reconfigurable system for different states. d-f) Radiation patterns of the system for different switch states.

## *CONCLUSIONS*

A silicon-etched RF-MEMS re-configurable Sierpinski gasket antenna and a modified version that exhibits better matching at the same resonant frequencies were designed. The complete system was simulated and the desirable re-configurability was demonstrated. Results obtained along with some measurements were presented in this paper.

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