A Small-sized Reconfigurable Antenna for Ultra-wideband, C-band and X-band Operation

Ali Ramadan, Mohammed Al-Husseini, Karim Y. Kabalan and Ali El-Hajj

ECE Department, American University of Beirut, Beirut 1107 2020, Lebanon
ahr06@aub.edu.lb, husseini@ieee.org, kabalan@aub.edu.lb, elhajj@aub.edu.lb

Abstract

In this paper, a novel printed-circuit-board (PCB) antenna that employs electronic reconfigurability is presented. The antenna is based on a 1.6 mm-thick FR4-epoxy substrate with dimensions 1 cm × 2.5 cm, is microstrip-line fed and has a partial ground plane. The proposed antenna is designed and simulated using the Finite-Element Method (FEM) and the Method of Moments (MoM) for four different switching conditions. The impedance bandwidth, gain, efficiency and radiation pattern results are included in the paper. It is shown that the antenna is suitable for ultra-wideband (UWB), C-band and X-band operation.

1. Introduction

Microstrip antennas are the radiators of choice in high-performance applications where size, weight, cost and ease of installation are constraints [1]. These antennas can be fed using microstrip lines. This feed arrangement can be easily fabricated by etching the feed line on the same substrate in order to preserve a total planar structure.

Several numerical methods for analyzing microstrip antennas are discussed in [2]. Among these, the Method of Moments (MoM) and the Finite-Element Method (FEM) are found to be most popular for use in electromagnetic simulations. Unlike FEM, MoM neglects radiation boundaries. Besides, most MoM-based analyses assume infinite dielectric substrate and ground plane dimensions. However, the authors of [3] present an approximation to Green's functions, which leads to more accurate results when used for MoM solution of a microstrip line fed antenna placed on a finite grounded substrate. Therein, the reflected surface waves from the edge of the truncated dielectric slab are added to Green's functions of the infinite structure, in order to analyze microstrip antenna structures with finite substrate and ground plane.

Tunability in an antenna system is a swiftly evolving feature that aims at pioneering multifunctional antenna designs. Compared to conventional antennas, reconfigurable antennas provide an adjustment of diverse antenna parameters including operational bandwidth, radiation pattern, gain and polarization [4]. The tuning of such antenna parameters is realized by introducing some switching components whose operation impacts the performance of the antenna. In addition to reducing any unfavorable effects resulting from co-site interference and jamming, electronically tunable antennas can be remotely reconfigured without rebuilding the platform on which the antenna structure is placed on [5].

Electronic, mechanical or optical switching may be employed with reconfigurable antennas [6]. However, electronic tunability is more frequently used because of its efficiency and reliability especially in dynamic bandwidth allocation. Electronic reconfigurability is often attained by getting RF MEMS switches incorporated along with the antenna. Compared to PIN diodes and FET transistors, RF MEMS switches have better performance in terms of isolation, insertion loss, power consumption and linearity [7].

This paper introduces a new reconfigurable microstrip antenna design, based on a two-switch operation. The state of the switches influences the functionality of the antenna. The return loss, peak gain, radiation efficiency, and patterns of the proposed antenna for each switching condition are presented herein.

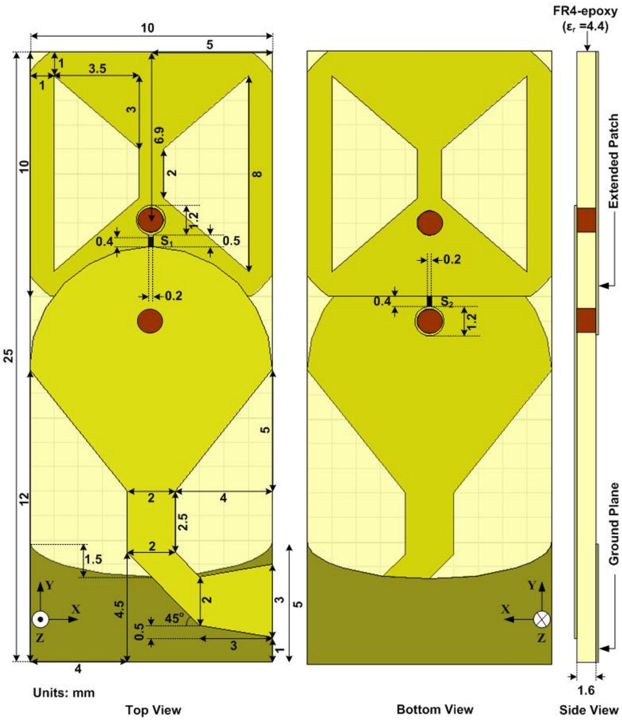

Fig. 1. Geometry of the designed antenna

2. Antenna Configuration

Fig. 1 shows the geometry of the proposed antenna. It is based on a compact 10 mm × 25 mm × 1.6 mm FR4-epoxy substrate and features a microstrip-line feed with two 45^o bends and a tapered section for size reduction and matching, respectively. The patch is made of a trapezoidal section and a semi-circular one joined at the large base of the trapezoid. The antenna's ground plane is partial and initially rectangular in shape, however a semi-elliptical strip is cut from its upper part. A square patch, that we call an extended patch and whose corners are rounded by intersecting it with a circle which is co-centered with the same patch and has a radius of 6.5 mm, is printed on the bottom surface of the substrate. Two symmetrical and congruent isosceles trapezoidal slots are incorporated into the extended patch. Two cylindrical PEC VIA's, 1.6-mm in height and 1-mm in diameter, are used. The first VIA has a circular conducting pad on top and touches the extended patch from the bottom. However, the second VIA has a circular conducting pad on bottom and touches the semi-circular part of the antenna's patch from top. In order to achieve electronic reconfigurability, two 0.4 mm × 0.2 mm rectangular strips (S_1 and S_2), having the dimensions of a MEMS switch [8], are integrated along with the antenna structure, as depicted in Fig. 1. Electrically speaking, a switch in RF systems can be represented either by a resistor to act as a short circuit or by a capacitor to act as an open circuit. Therefore, an OFF state is represented by taking this rectangular strip off the antenna, and an ON state is modeled by including the conducting strip. This method for representing RF MEMS was used in [9]–[10]. RF MEMS are known to possess good performance in terms of isolation and insertion loss. So, representing these by including or omitting copper strips of the same size is considered valid. However, the MEMS biasing lines are expected to slightly perturb the radiation patterns, but optimizing their locations would make the error tolerable.

3. Results and Discussion

The antenna is designed and simulated using Ansoft HFSS [11], which is based on the Finite-Element Method (FEM), and Agilent's ADS Momentum [12], which is based on the Method of Moments (MoM). Four switching conditions, as listed in Table 1, are specifically selected to operate the proposed antenna on desired frequency bands.

Table 1. Switching conditions

Case	S_1	S_2
1	OFF	OFF
2	OFF	ON
3	ON	OFF
4	ON	ON

Figs. 3–6 depict both FEM and MoM computed S_{11} plots of the above tabulated cases. Both methods provided similar return loss results. The operable frequency bands, per case, of the proposed antenna are depicted in Fig. 2. For Case 1, an impedance bandwidth in the 4–14 GHz range for $S_{11} \leq -10$ dB is obtained. It covers both the C-band (4–8 GHz) and the X-band (8–12 GHz). Besides a 6–14 GHz operable bandwidth, Cases 2 and 3 reveal a resonance about 3.56 GHz (13.5 % bandwidth) and 3.46 GHz (12.5 % bandwidth), respectively. Case 4 illustrates an 8–14 GHz impedance bandwidth in addition to a resonance at 3.8 GHz (22.8 % bandwidth). The superimposed return loss plots for the four switching conditions, both FEM- and MoM-based, are illustrated in Fig. 7 and Fig. 8, respectively. It's worth mentioning that a satisfactorily frequency-selective behavior, which achieves UWB-band, C-band and X-band operation, is obtained using reconfigurability.

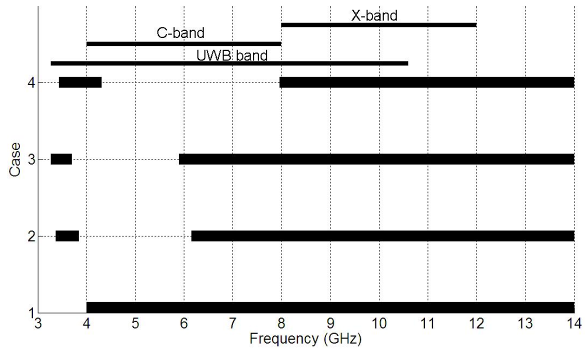

Fig. 2. Operable frequency bands per Case

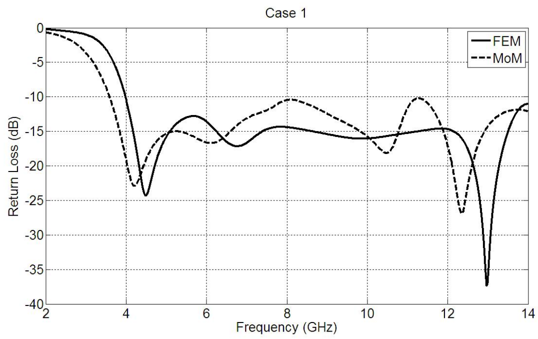

Fig. 3. Return loss of the antenna for Case 1

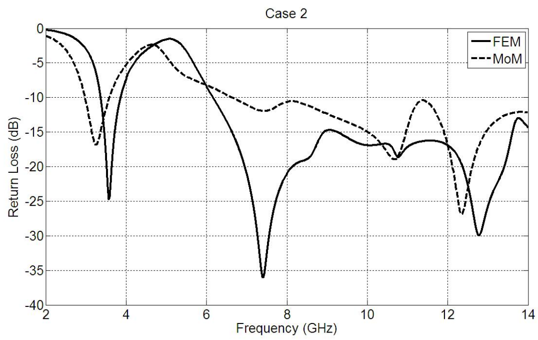

Fig. 4. Return loss of the antenna for Case 2

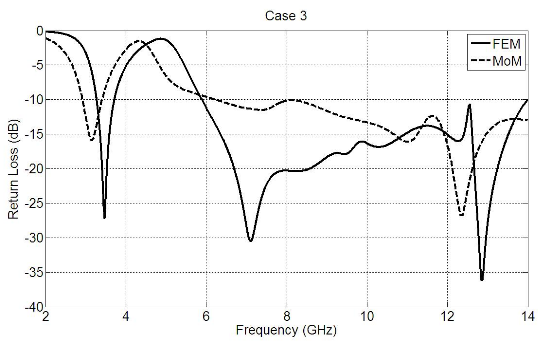

Fig. 5. Return loss of the antenna for Case 3

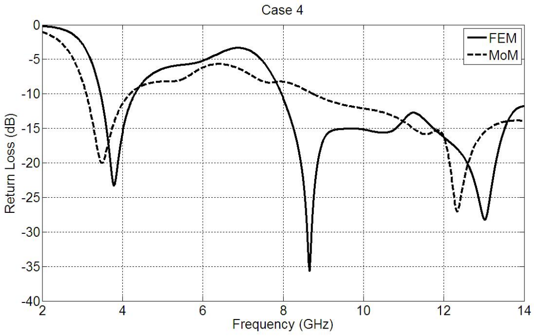

Fig. 6. Return loss of the antenna for Case 4

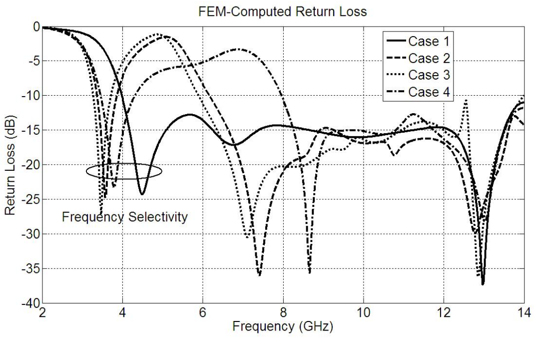

Fig. 7. Superimposed FEM-Computed S_{11} plots of the antenna for four switching conditions

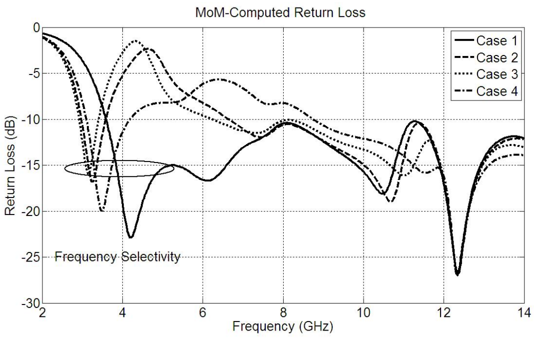

Fig. 8. Superimposed MoM-Computed S_{11} plots of the antenna for four switching conditions

The FEM-computed radiation patterns, for each case, of the proposed antenna are shown in Fig. 9. The results reveal satisfactorily omni-directional patterns over the desired frequency bands.

For each switching condition, the antenna's FEM-computed peak gain and radiation efficiency show acceptable values, as illustrated in Fig.10 and Fig.11, over the frequency span of interest. For Case 1, the gain is 3 dB and 4 dB at the central frequencies of the C-band and the X-band, respectively. For Case 2, a 2.12 dB and a 4 dB peak gain figures are obtained at 3.56 GHz and 10 GHz, respectively. A 2.1 dB peak gain was obtained in Case 3 at 3.46 GHz, and in Case 4 at 3.8 GHz. However, Case 4 achieves a 3.71 dB peak gain at 10 GHz, which is 0.327 dB less than Case 3's value at the same frequency. The radiation efficiency in Case 1 is 97.09% at 6 GHz and 93.42% at 10 GHz. For Case 2, a 99.24% and a 93.37% radiation efficiency values are recorded at 3.56 GHz and 10 GHz, respectively. Cases 3 and 4 respectively record 98.53% and 99.56% radiation efficiency values at 3.46 GHz and 3.8 GHz. Nonetheless, both cases lead to an average efficiency of 93.63% at 10 GHz. The efficiency smoothly decays against frequency due to more losses in the FR4-epoxy substrate at high frequencies.

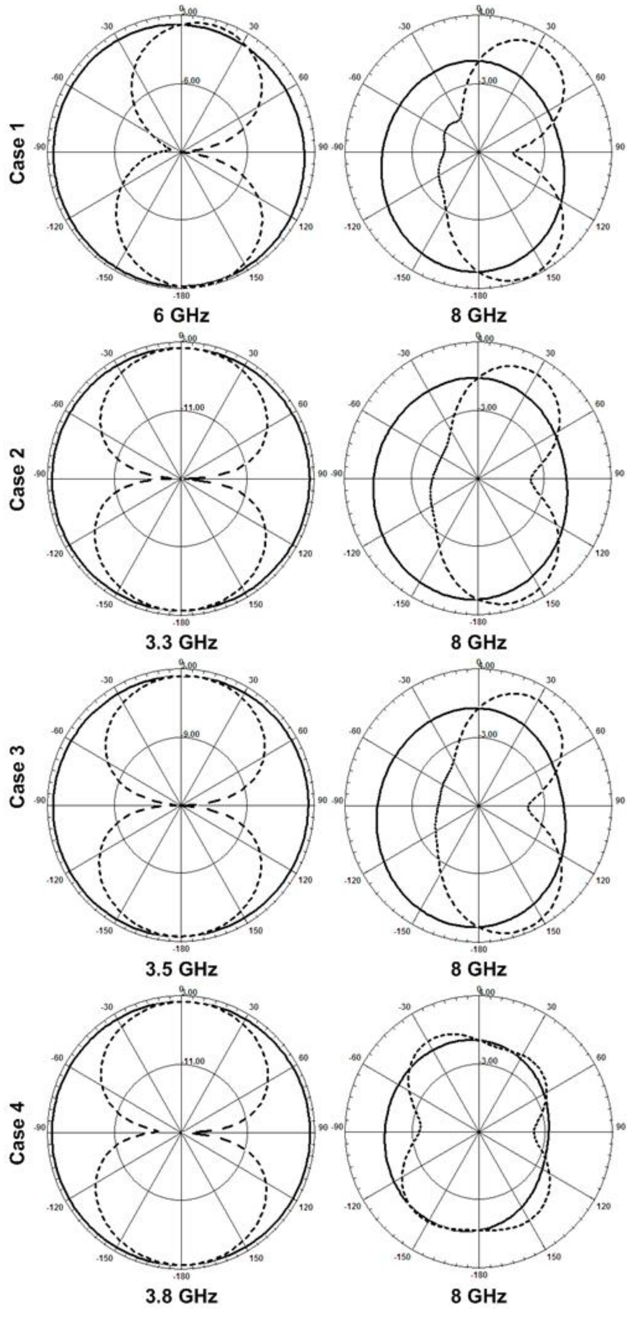

Fig. 9. Computed radiation patterns in the X-Z plane (solid line) and Y-Z plane (dotted line)

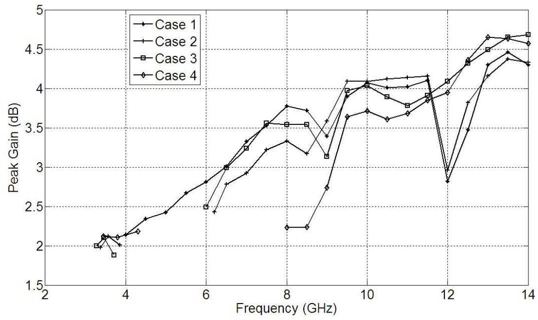

Fig. 10. Peak gain of the antenna

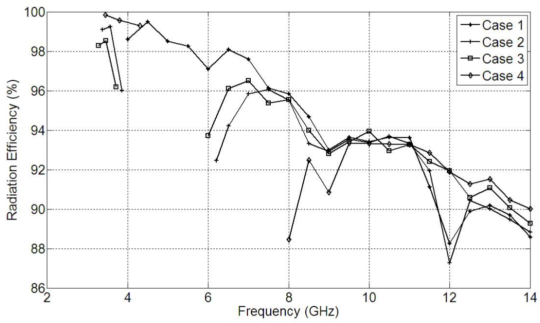

Fig. 11. Radiation efficiency of the antenna

4. Conclusions

A novel, reconfigurable, low-cost and easy-to-fabricate monopole-type microstrip antenna for ultra-wideband, C-band and X-band operation was presented in this paper. The antenna is based on a 1.6 mm-thick 1cm × 2.5cm FR4-epoxy substrate, and uses tunability to achieve multiband/wideband behavior. FEM- and MoM-based packages were used in the design and simulation of the antenna. The antenna possesses satisfactorily omnidirectional patterns, acceptable peak gain values, and good radiation efficiency figures over the frequency range(s) of interest.

5. References

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