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A RECONFIGURABLE U-KOCH MICROSTRIP ANTENNA FOR WIRELESS APPLICATIONS

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Abstract—In this paper, a low-cost multiband printed-circuit-board (PCB) antenna that employs Koch fractal geometry and tunability is demonstrated. The antenna is fabricated on a 1.6 mm-thick FR4-epoxy substrate with dimensions 4 cm × 4.5 cm, is microstrip-line fed and has a partial ground plane flushed with the feed line. The proposed antenna is simulated using the Finite-Element Method for three different switching cases and the return loss is measured for each case. It is shown that the antenna can cover the bands of several applications including 3G, WiFi, WiMAX as well as a portion of the UWB range. The radiation patterns are satisfactorily omnidirectional across the antenna's operation bands.

1. INTRODUCTION

With the tremendous advancements in wireless communications, there is an increasing demand for miniature, low-cost, easy-to-fabricate, multiband and wideband antennas for use in commercial communications systems. As a part of an effort to further enhance modern communications systems technology, researchers have been studying different approaches for creating novel and innovative antennas [1]. The approach adopted in this paper combines fractal geometry and reconfigurability in order to come up with a new antenna design suitable for several wireless applications.

The fact that different wireless standards, such as UMTS, WLAN and WiMAX, use different operation bands pushes the need for terminal antennas that are multiband and/or wideband [2, 3].

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The antennas should also be well-suited in terms of cost, size, radiation patterns, gain and ease of integration in the circuit boards of communication devices. To meet these constraints, we use a printed-type monopole with a microstrip-line feed. To obtain a multiband/wideband operation, a U-slotted rectangular patch and a partial ground plane flushed with the feed line are used. A Koch fractal geometry is introduced in the patch and the U-slot to increase the antenna's electrical length. This will help obtain a resonance at a lower frequency without increasing the overall antenna dimensions. Then, a dynamic technique which achieves selectivity in frequency is used [4]. This technique, known as reconfigurability, has an important switching property that allows users to access a great number of services of different frequency bands with a single wireless device [5]. Consequently, the mounting of RF switches across the U-slot would lead to a different set of resonance frequencies for each switching scenario.

1.1. Fractal Antenna Engineering

Fractal antenna engineering is a swiftly evolving field that aims at developing a new class of antennas that are multiband, wideband and/or compact in size [6]. A fractal is a self-repetitive geometry which is generated using an iterative process and whose parts have the same shape as the whole geometry but at different scales. Accordingly, fractal-based radiators are expected to operate similarly at multiple wavelengths and keep similar radiation parameters over several bands [7]. Another property of fractal geometries, which makes them attractive candidates for use in the design of fractal antennas, is their space-filling property [6]. This feature can be exploited to miniaturize classical antenna elements, such as dipoles and loops, and overcome some of the limitations of small antennas. The line that is used to represent the fractal geometry can meander in such a way that effectively fills the available space, leading to curves that are electrically long but compacted in a small physical space [8].

Koch curve is a good example of self-similar space-filling fractals which have been used to develop wideband/multiband and/or miniaturized antennas. The first four iterations of Koch curve are shown in Fig. 1. In [9], it was shown that self-similar fractals affect the electromagnetic properties of antennas created on the basis of these geometries, and that Koch fractal antennas are multiband structures. The authors of [10] related multiple resonant frequencies of Koch fractal antennas to their fractal dimension. In [11], a dual wideband CPW-fed modified Koch fractal printed slot antenna, suitable for WLAN and WiMAX operations, was proposed.

Iteration 1

Iteration 2

Iteration 3

Iteration 4

Figure 1. The first four iterations in the construction of the standard Koch curve.

In [12], Koch fractal dipoles were introduced as the basic structural elements of a planar Log-Periodic Koch-Dipole Antenna (LPKDA) array, thus replacing the full-sized Euclidean monopoles. Compared to the Euclidean LPDA, the proposed design revealed very similar characteristics, while achieving 12% less space. Another Koch-based antenna-size compacting scenario was proposed in [13]. Here, the authors introduced a second-iterated Koch fractal, with an indentation angle of 20°, along the sides of a regular Euclidean shaped patch to increase the overall electrical length of the patch.

Fractal geometries have also been used to design antenna arrays in [6]. Fractal arrays have shown to possess desirable attributes, including multiband performance, low side-lobe levels and the ability to develop rapid beamforming algorithms based on the recursive nature of fractals. Fractal elements and arrays have been also recognized as perfect candidates for use in reconfigurable systems.

1.2. Reconfigurability

Reconfigurability in antenna systems is a desired feature that has recently received significant attention in developing novel and pioneering multifunctional antenna designs. Compared to conventional antennas, reconfigurable antennas provide the ability to dynamically adjust various antenna parameters. The active tuning of such antenna parameters is typically achieved by manipulating a certain switching behavior.

Reconfigurable antennas reduce any unfavorable effects resulting from co-site interference and jamming [4]. In addition, they have a remarkable characteristic of achieving diversity in operation, meaning that one or multiple parameters, including operating frequency, radiation pattern, gain and/or polarization, can be reconfigured with a single antenna [14]. The use of reconfigurability in coordination with a self-similar antenna leads to a considerable improvement in antenna performance. This is because not only a wider selection of frequencies is achieved, but also similar radiation properties for all designed frequency bands are obtained [4, 15].

Electronic, mechanical or optical switching may be employed with reconfigurable antennas [14]. Nonetheless, electronic tunability is more frequently used because of its efficiency and reliability especially in dynamic bandwidth allocation. Electronic reconfigurability is often attained using lumped components such as PIN diodes, FET transistors or RF MEMS switches [16, 17]. Compared to PIN diodes and FET transistors, RF MEMS switches have better performance in terms of isolation, insertion loss, power consumption and linearity [17].

2. ANTENNA CONFIGURATION

The geometrical structure and dimensions of the proposed printed monopole antenna are detailed in Fig. 2. The substrate, which is 1.6 mm in thickness, is based on the low-cost FR4-epoxy material with a dielectric constant $\epsilon_r = 4.4$. The other dimensions of the substrate are 4 cm for the width and 4.5 cm for the height. The ground plane is partial, and is flushed with the feed line, which has zigzag edges. A trapezoidal matching section connects the feed line to a U-Koch-slotted rectangular-Koch patch. The first-iterated Koch fractal geometry is used in the patch and the U-slot to increase the antenna's electrical length for operation at lower frequency bands.

Five pairs of RF MEMS are mounted across the slot, as indicated in Fig. 2. 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, the simplest way to demonstrate an RF switch for use in this design is to construct a 400 μm × 200 μm rectangular strip that has the same dimensions of those presented in [18]. Hence, an OFF state is represented by taking this rectangular strip off the antenna, and mounting it again in the same location activates its ON state, as depicted in Fig. 3. This method for representing RF MEMS was used in [19, 20]. 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

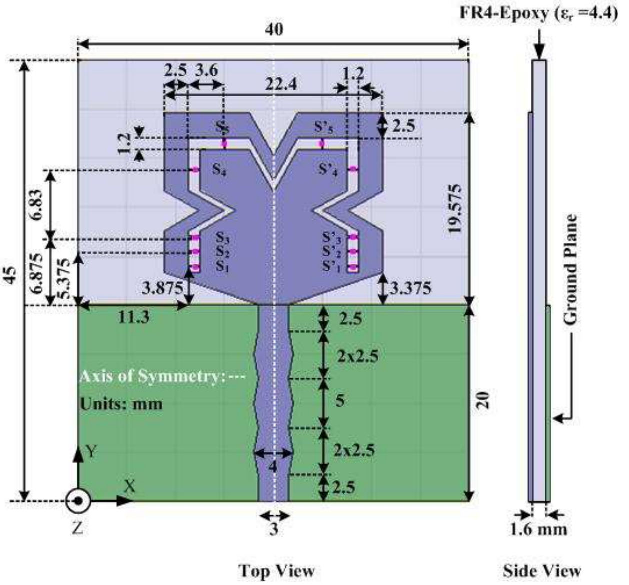


Figure 2. The U-koch reconfigurable microstrip antenna structure.

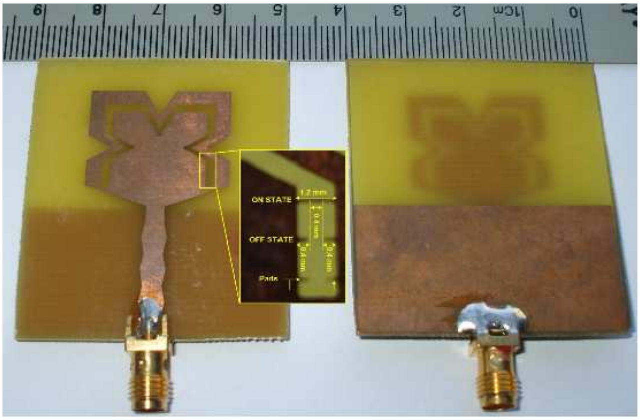


Figure 3. Photograph of the fabricated antenna prototypes.

their locations would make the error tolerable.

Although 10 switches are brought in to operate in a dual manner, only three switching conditions are chosen, as listed in Table 1. These three switching cases were enough to introduce desirable frequency selectivity, as shown in the next section.

Table 1. Switches' states for each case.

Case	(S_1, S_1')	(S_2, S_2')	(S_3, S_3')	(S_4, S_4')	(S_5, S_5')
1	ON	OFF	OFF	OFF	OFF
2	OFF	ON	OFF	OFF	OFF
3	ON	ON	ON	ON	ON

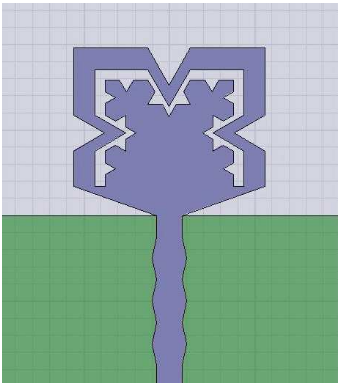


Figure 4. Design with first-iteration and second-iteration Koch fractals.

3. RESULTS AND DISCUSSION

Before reaching the final design presented in this paper and optimizing the placement of the swithces, Ansoft HFSS [21], which is an EM simulator based on the Finite-Element Method (FEM), was used to check and compare the following three cases: 1) Design before applying Koch fractal, 2) design when first-iteration Koch is applied to the edges of the patch and the U-slot, and 3) design when second-iteration Koch is applied to internal edges of the U-slot (inner section of the patch) and first-iteration Koch is applied to the outer edges of the patch and the U-slot (second-iteration Koch not possible due to slot location), as shown in Fig. 4. The resulting computed return loss plots are shown in Fig. 5. These results indicate that introducing the first-iteration Koch lowered the frequency of the first resonance, whereas the second-iteration (or higher-iteration) in the inner section of the patch did not lead to lower frequency resonance though it widened the middle operation band. Since we were interested in exploiting the space-filling property of Koch fractals, we picked the case when only a first-iteration Koch is used.

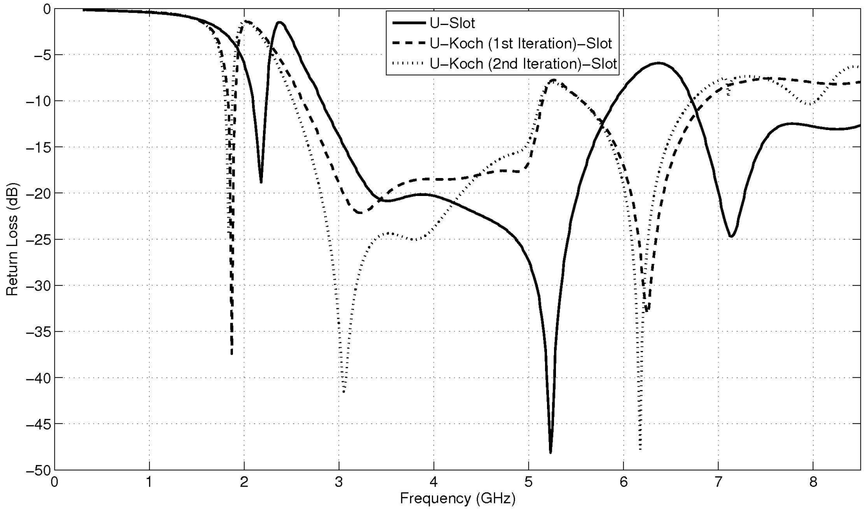


Figure 5. Return loss comparison of U-slotted rectangular patch versus U-Koch-slotted rectangular-Koch designs.

The chosen design was used in a reconfigurability scheme after optimizing the locations of the switches, as indicated in the previous section. FEM-simulated and measured return loss responses are given in Figs. 6–8 for the three switching cases, respectively. The measurements were done using the Agilent's E5071B network analyzer, which operates in the 300 KHz–8.5 GHz range. A good agreement is witnessed between the FEM-simulated and measured return loss plots. Figs. 9 and 10 respectively demonstrate the HFSS-simulated and measured S_{11} plots superimposed for the three switching cases. For Case 1, a narrow resonance is obtained at 1.9 GHz, in addition to two wide bands in the 2.7–6.6 GHz range. For Case 2, the lower narrow resonance is shifted to 2.1 GHz, and there exists a wide band covering the 2.4–6.7 GHz range. The switching condition of Case 3 removes the lower narrow resonance, and results in a wide band in the 2.5–6.7 GHz frequency span.

The HFSS-computed gain patterns in the X-Z and Y-Z planes, for each case, are shown in Figs. 11–13. The three cases result in omnidirectional patterns with equal radiation in the X-Z plane and an '8'-shaped pattern corresponding to a 3D pattern with the shape of a donut. This result is expected since the proposed antenna is a printed monopole. Furthermore, the omnidirectional property is almost preserved over the previously indicated operation bands.

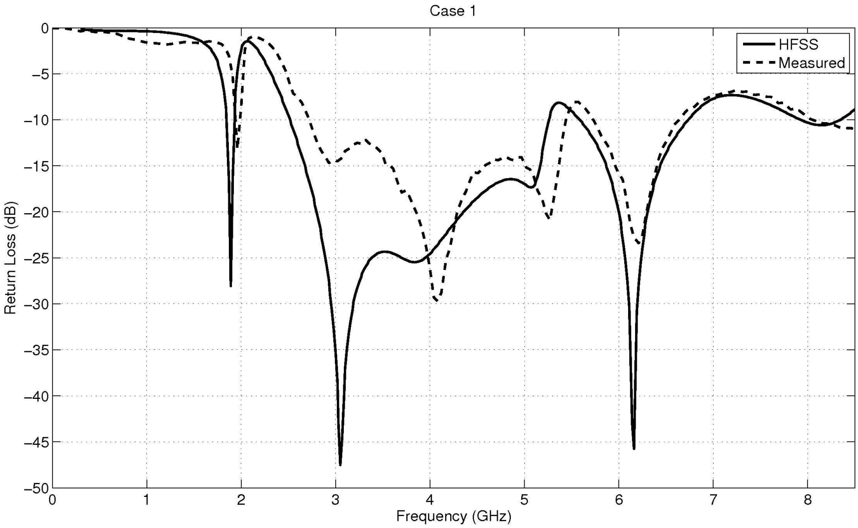


Figure 6. Simulated and measured S_{11} of the antenna for switching Case 1.

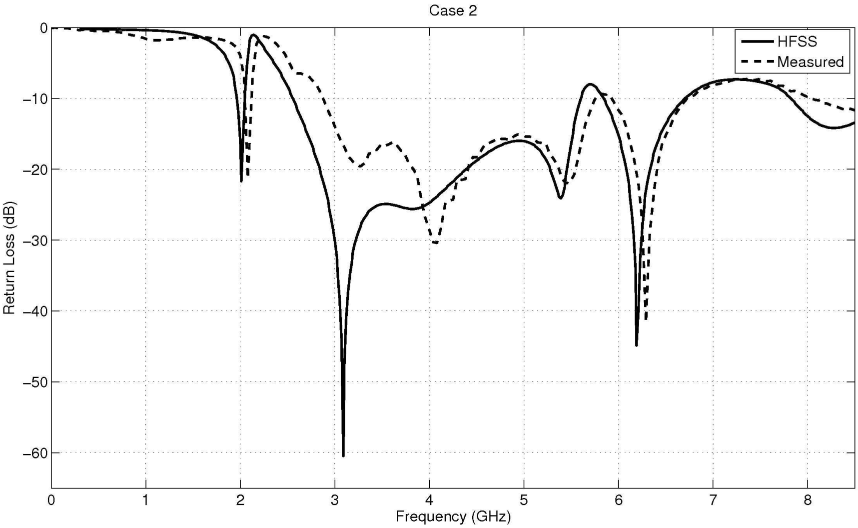


Figure 7. Simulated and measured S_{11} of the antenna for switching Case 2.

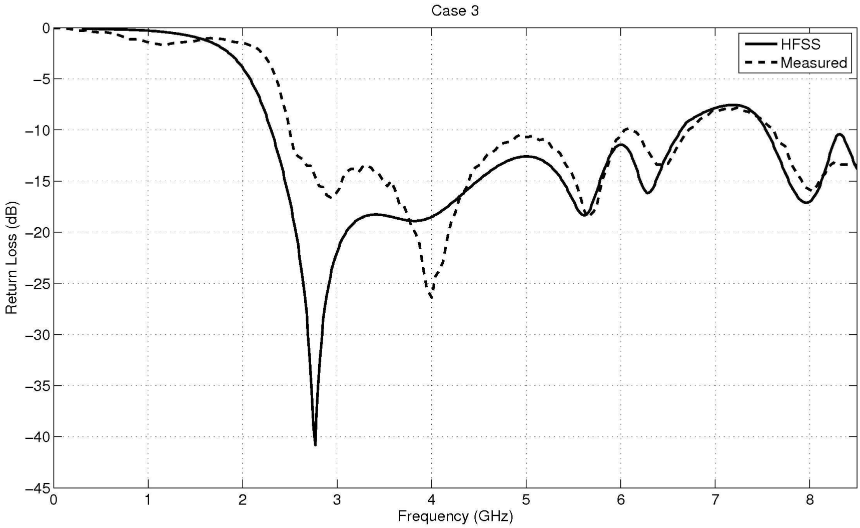


Figure 8. Simulated and measured S_{11} of the antenna for switching Case 3.

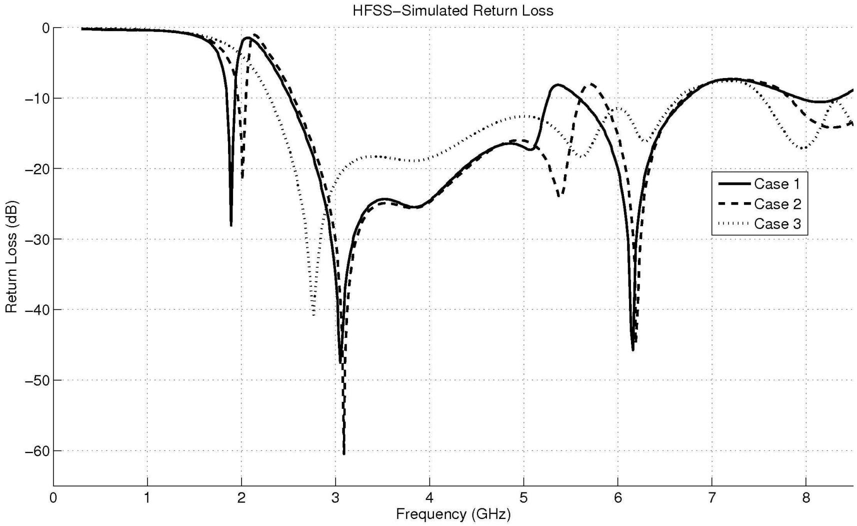


Figure 9. FEM-computed S_{11} of the proposed antenna over the 0.3–8.5 GHz frequency range.

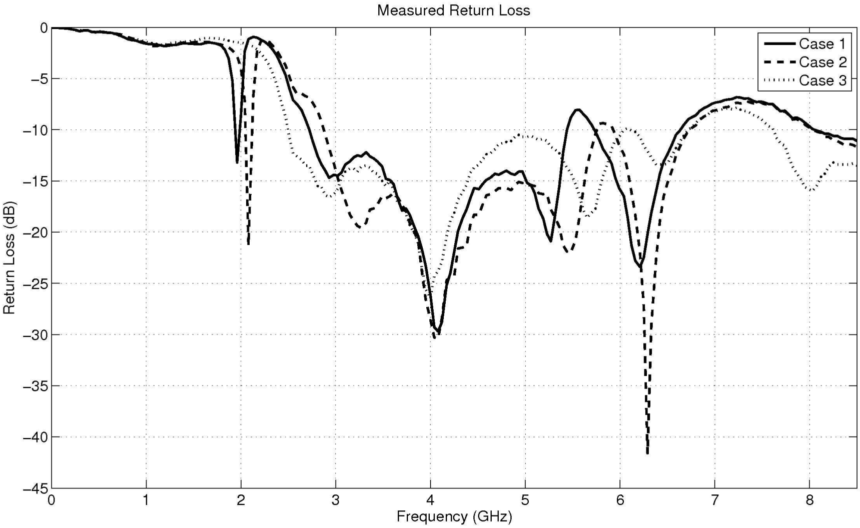
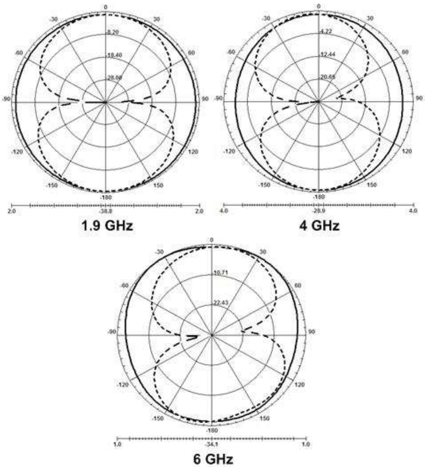


Figure 10. Measured S_{11} of the proposed antenna in the 0.3–8.5 GHz frequency range.



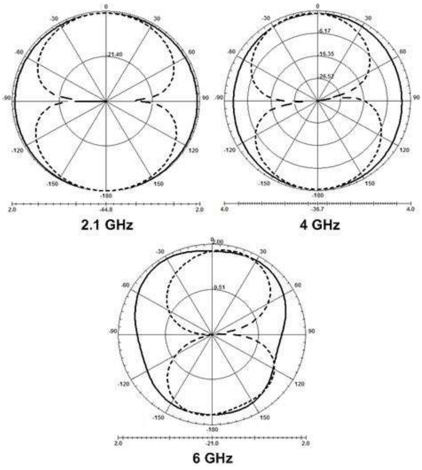


Figure 11. Radiation patterns of the antenna in X-Z plane (solid line) and Y-Z plane (dashed line) for Case 1.

Figure 12. Radiation patterns of the antenna in X-Z plane (solid line) and Y-Z plane (dashed line) for Case 2.

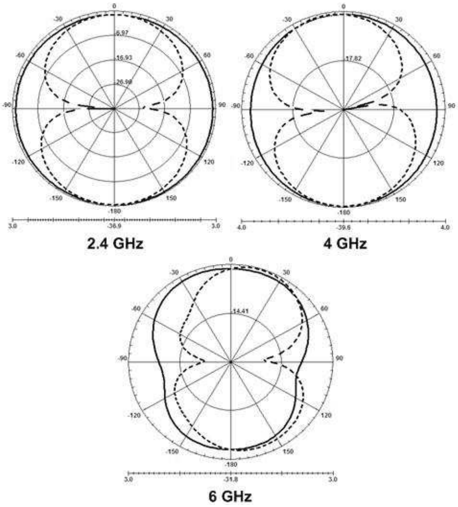


Figure 13. Radiation patterns of the antenna in X-Z plane (solid line) and Y-Z plane (dashed line) for Case 3.

4. CONCLUSION

A hybrid antenna design approach which combines fractal shapes and electronic reconfigurability was presented in this paper. The proposed design is low in cost, easy to fabricate and integrate with microwave circuits, and multiband/wideband in operation. The antenna is based on a U-slotted rectangular patch. Koch fractal geometry was applied to the patch and slot sides to increase the electrical length of the antenna without increasing its overall size, thus leading to resonance at a lower frequency.

Reconfigurability is achieved by mounting RF switches at selected locations across the slot. Three switching scenarios were selected, and these showed clear frequency tunability of the antenna, as shown by simulated and measured return loss results. Calculated radiation patterns showed satisfactory omnidirectional behavior over the indicated operation frequency bands.

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