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A Dual Band Fractal Slot Antenna Loaded with Jerusalem Crosses for Wireless and WiMAX Communications

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Abstract—In this paper, a combination of the Jerusalem cross (JC) as a fractal load and fractal Minkowski slot antenna for dual-band application is investigated. The prototype slot antenna has a Minkowski fractal formation with four Jerusalem cross (JC) loads to achieve dual-band application with compact size to improve the bandwidth. A T-shaped feed line is implemented in the final modeled antenna. The fabricated antenna has a bi-directional pattern with sufficient bandwidth at 2.4–3.1 GHz and 5.1–5.9 GHz with VSWR < 2 for Wi-Fi, WiMAX, Bluetooth application as well as an IEEE WLAN protocol with a gain of 5–6 dBi, respectively. The size of the prototype patch antenna is $40 \times 40\,\mathrm{mm}^2$, and the antenna is designed and fabricated on an FR-4 low cost substrate with $\varepsilon_r = 4.4$ and thickness of 1.6 mm. It is simulated by HFSS full wave software. In addition, the VSWR, pattern and axial ratio of experimental results are presented and compared with simulation models. As a result, improvements of the Jerusalem cross compared with conventional cross have been achieved with some parameter tuning to improve the bandwidth.

1. INTRODUCTION

Nowadays, various types of wireless systems are designed for some special benefits such as simplicity, low cost and easy operation. Recently, WLAN systems are implemented because of appropriate price and high-speed data transfer. IEEE 802.11a, IEEE 802.11bg and Hyper LAN/2 standards cover WLAN frequencies and bands. The IEEE 802.11 standard has three major frequency bands at 2.4 GHz (2.4–2.484), 5.2 GHz (5.15–5.35), and 5.8 GHz (5.725–5.825). The frequency range in 3.3-3.8 GHz has also been defined for wireless personal area network (WPAN) and WiMAX [1, 2]. For wireless devices, we need to design a small sized, easy fed, easy fabrication and low cost antenna in multi-band applications, and the slot antennas are common forms of antennas for wireless applications with all prosperities demanded for WLAN and wireless communication systems [3, 4].

Many researches have been done for achieving miniaturized, compact, multi-frequency and power efficient antennas. Therefore, in many of these researches, antenna miniaturization and various methods have been noticed for designing small antennas such as loaded antennas with lumped elements. The application of high dielectric constant materials [5], slotted ground and short circuit [6], optimal antenna geometry [7], fractal antenna based on various forms for frequency miniaturization such as Koch and Minkowski [8, 9] have also been noticed for miniaturization.

On the other hand, slot antennas regularly have wider bandwidth than patch antenna with bi-directional pattern, high gain and directivity [10, 11]. In addition, slot antennas are suitable for achieving circular polarization which has been studied in some researches with slot feeds parameter tuning [12, 13]. Microstrip compact slot antennas for wireless application are one of the slot antenna types that have been designed by some techniques such as slot rings, parasitic elements, and L and U shape slots

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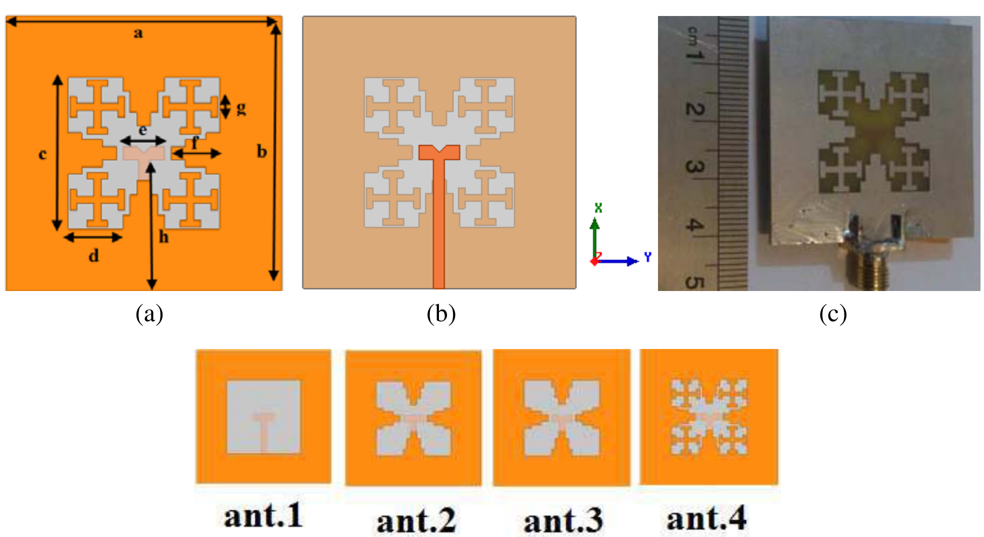
[14, 15]. Fractal structures are well known as self-similarity shapes that are usually found in nature objects such as galaxies, cloud boundaries, mountain ranges, coastlines, snowflakes, trees and leaves. Nowadays, various forms of these fractal structures are used in microstrip antennas and filters [16–18]. Bow-tie dipole and monopole antenna with Koch shape fractal has been designed for multi-band and miniaturization [19–21]. In addition, Fractal-Shaped Patch-Slot configuration used in miniaturized reflect-array unit cell and Minkowski fractal are compared for different steps [22]. The Jerusalem cross is a famous model of fractal shape investigated in many researches for making absorber or metamaterial radome used for antenna gain and bandwidth enhancement [23, 24].

In this paper, the proposed antenna is designed in four steps and is modified for achieving dual-band characteristic and proper matching in the final structure. The triangular slot antenna has been finally made in a feed line structure which provides better matching. The proposed antenna has a Minkowski fractal formation with four Jerusalem cross loads which provides dual-band application. Furthermore, the radiation pattern, gain ratio and current distributions are studied. The proposed antenna is successfully designed, and the simulated result shows good agreement with the experimental one.

2. ANTENNA STRUCTURE

Figures 1(a) and (b) show the simulated and fabricated prototype antenna configurations and geometries. The final antenna (ant.4 in Fig. 1(d)) is fabricated on an FR-4 low cost and lossy substrate with relative permittivity of 4.4 and thickness of 1.6 mm. The total size of the antenna is $40 \times 40\,\mathrm{mm}^2$ ($\lambda/3 \times \lambda/3$ for 2.5 GHz). As shown in Fig. 1(b), the antenna is a microstrip slot antenna fed by a T-shaped microstrip line with width of 1.6 mm and length of 23 mm ($\sim \lambda_g/2$), and is connected and matched with the $50\,\Omega$ transmission line. It is fabricated on an FR-4 for experimental measurement. The Jerusalem cross loads are applied to achieve higher bandwidth and dual resonances. On the other hand, the final antenna has a special form of a feed line matched with the $50\,\Omega$ transmission line. The fabricated antenna is shown in Fig. 1(c). The dimensions mentioned in Fig. 1(a) are $a = b = 40$ mm, $c = 22$ mm, $d = 8$ mm, $e = 6$ mm, $f = 7$ mm, $g = 3$ mm and $h = 19$ mm.

Meanwhile, four steps of the antenna design are presented in Fig. 1(d) to clarify the antenna's design procedure: simple slot antenna, fractal implementation, feed modification and Jerusalem cross load adding, respectively.



(a) (b) (c)

(d)

Figure 1. The prototype antennas (a) top view, (b) bottom view (c) fabricated antenna on an FR-4 dielectric, and (d) four steps of the antenna designing for simple slot antenna, fractal implementation, feed modification and Jerusalem cross load adding.

3. SIMULATION AND EXPERIMENTAL RESULTS

Figure 2(a) shows the magnitude of S_{11} for antennas 1 to 4 (ant.1 to ant.4 in Fig. 1(d)) in the range of 2–6 GHz. The first antenna (Ant.1) does not have any resonance at the range of 2–6 GHz. The second antenna (Ant.2) shows better matching mostly in the range of 2.6–2.99 GHz when the fractal slot is used in the ground plane, so the fractal formation changes the current distribution and makes better matching of this antenna as shown in Fig. (2). On the other hand, non-uniform current distribution in the second antenna (Ant.2) has a suitable dual-band characteristic. In addition, the effective length of the aperture is increased and reduces the resonance frequency from 4 GHz (at best point) on the first antenna to 2.5 GHz on the second model. The third antenna (Ant.3) as well as second antenna (Ant.2) has one resonance between 2.6–2.99 GHz. In this antenna, a triangular slot is made on the feed line for bandwidth improvement. However, in this case, it shows a slight improvement. Finally, by adding Jerusalem cross loads in the fourth antenna (Ant.4), the proposed antenna achieves a dual-band characteristic. It also has wider bandwidth than other structures which have been discussed before, and as shown in Fig. 3, the Jerusalem cross loads modify the antenna current distribution. In this final design, a new capacitive property is added to the antenna, and interacting with the inductance of Jerusalem cross loads makes new resonator at higher frequencies for WLAN application. The coupling between the feed and Jerusalem loads makes the second resonance and improves the first resonance. Fig. 2(b) shows the antenna magnitude of S_{11} in the presence and absence of the triangular slot in the feed line. It is observed that by removing the triangular slot in the feed line, better VSWR is obtained in the first frequency band. However, the coupling of the electric field with the Jerusalem cross loads is decreased

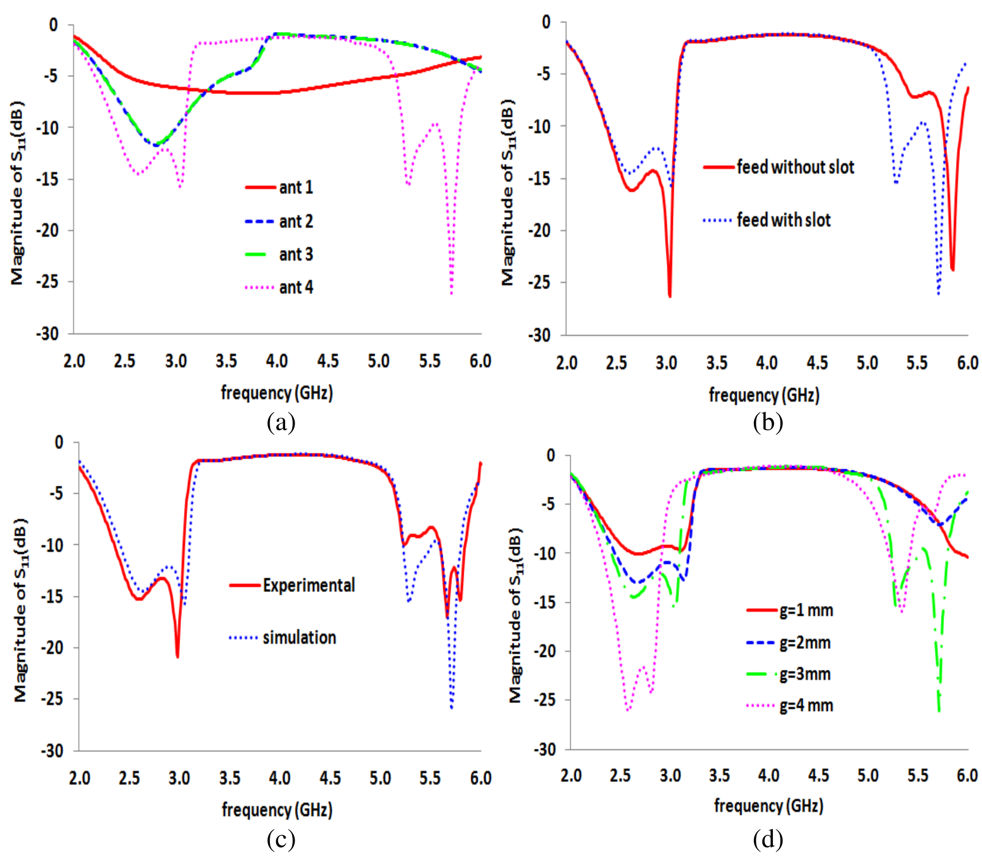


Figure 2. Magnitude of S_{11} results (a) magnitude of S_{11} for antenna steps 1 to 4 that presented in Fig. 1(c), (b) presence and absence of a triangular slot for final antenna, (c) simulation and experimental comparison of the prototype antenna, (d) magnitude of S_{11} results for parametric study of (g) at Jerusalem cross load.

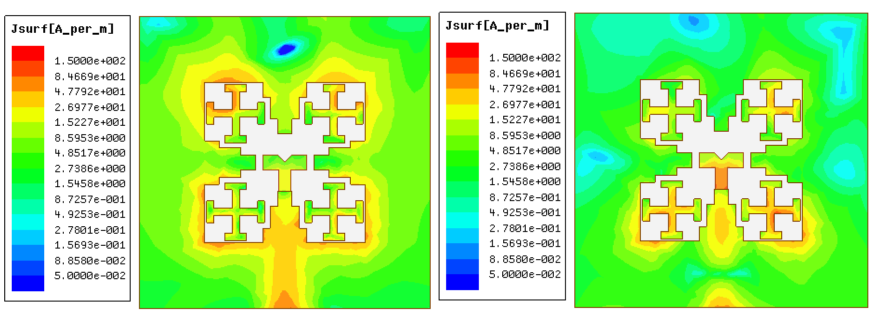
which drastically reduces the bandwidth for the second resonance. The simulations have been performed in HFSS full-wave simulation software, and the experimental results have been presented and compared with simulation. The comparison between simulated and the experimental results from HFSS with HP8722ET network analyzer is presented in Fig. 2(c). A good agreement is shown between simulated and experimental results, but some distortions on the second resonance in experimental results are seen due to losses of dielectric and SMA connector at higher frequencies. The parameter tuning shows the advantage of the structures and the stability of the errors during fabrication progress. Parameter 'g' in Fig. 1(a) varies between 1 to 4 mm, and the effects on S11 are presented in Fig. 2(d). Optimal results have been reached when 'g' is 3 mm. But more miniaturization is achievable by increasing 'g' to 4 mm in the proposed antenna, which leads to the best matching at lower frequencies with a return loss of -25 dB.

Figure 3 shows the antenna current distribution at two resonances at 2.5 and 5.5 GHz. As shown in Fig. 3(a), the current at 2.5 GHz is dispensed uniformly per each unit cell, and it makes an omnidirectional radiation pattern. However, the current is limited in unit cells that are close to feed point at 5.5 GHz.

Figure 4 shows the measured radiation pattern of the antenna in phi = 0 and phi = 90 for 2.5 GHz and 5.5 GHz for co/cross polarization. Therefore, the prototype antenna shows a bidirectional pattern at both frequencies, and the proposed design exhibits an omnidirectional pattern in H-plane.

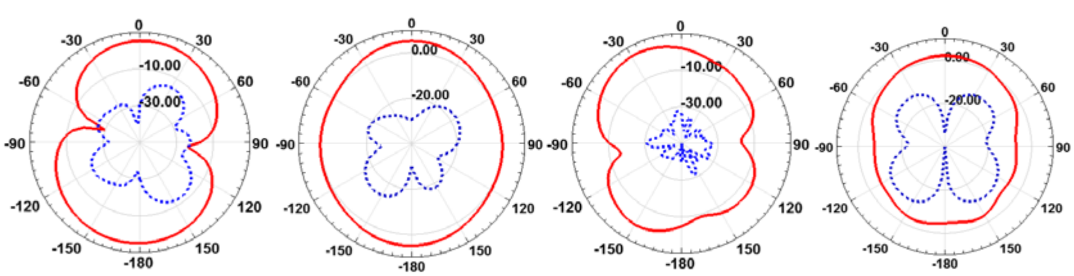
The gain and efficiency of the designed antenna is presented in Fig. 5. Obviously, the antenna efficiency is more than 90% for 2.4 to 3.1 GHz, and it is reduced drastically around 45% in the second band. As a result, with considering Figs. 3(a) and (b), it can be seen that the current is distributed in 50% of the unit cell in Fig. 3(b) compared with Fig. 3(a). Therefore, it is expected that the effective aperture is reduced to 50%, shown in Fig. 5.

The comparison between simulated and measured gains of the antenna is presented in Fig. 5 as well, which reach the value around 3–4 dBi. The radiation parameters for the prototype antenna are also compared in Table 1 for simulated and experimental results.



(a) (b)

Figure 3. The second antenna current distribution, (a) 2.5 GHz, (b) 5.5 GHz.



(a) (b) (c) (d)

Figure 4. The prototype antenna experimental pattern, (a) phi = 0 at 2.5 GHz, (b) phi = 90 at 2.5 GHz, (c) phi = 0 at 5.5 GHz, (d) phi = 90 at 5.5 GHz (solid line for co-polarized and dash line of cross-polarization).

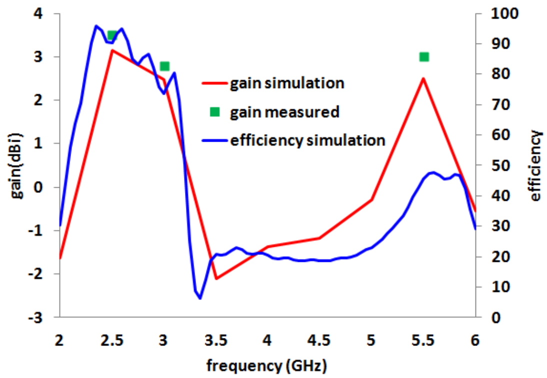


Figure 5. Simulation and measurement of the gain with simulation of efficiency.

Table 1. Radiation parameters for prototype antenna, simulation and experimental results.

frequency	*Gain (dB) Simulation*	*Gain (dB) Experimental*	*Efficiency simulation*	*Efficiency Test*
2.5 GHz	3.14	3.5	94%	90%
5.5 GHz	2.5	3	45%	48%
frequency	HPBW Simulation E-plane	HPBW Experimental E-plane	HPBW Simulation H-plane	HPBW Experimental H-plane
2.5 GHz	60	50	360	360
5.5 GHz	80	70	360	340

4. CONCLUSION

This paper presents a novel arrangement for a slot antenna with fractal form and Jerusalem cross loads for dual-band application at 2.75 and 5.5 GHz with 25 % and 14.5% bandwidth, respectively. The results reveal that the fractal techniques and loads improve the matching for wireless requested frequencies and become suitable for indoor application with high gain (3–4 dBi) and efficiency (more than 90% for 2.5 GHz). Parametric modeling shows that the Jerusalem cross loads small with arms are important for achieving better matching in antenna

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