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# Circular Polarization Fractal Slot by Jerusalem Cross Slot for Wireless Applications

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**Abstract**—In this letter, a new model of antenna with Jerusalem crosses (JC) as fractal slots for circular polarization applications is designed. The proposed slot antenna has a fractal cross formation with four Jerusalem crosses (JC) to achieve wide bandwidth and a compact size as well as circular polarization. A T-shaped feed line is implemented in the proposed antenna for improving the bandwidth while the interaction of the feed line with cross-shaped slots makes circular polarization. The proposed antenna shows bi-directional pattern and bandwidth at 2.42–3.0 GHz with VSWR $< 2$, which can be used in Wi-Fi and Bluetooth applications with a gain of 3.5 dBi. The proposed fractal antenna size is $40 \times 40$ mm, and it is designed and fabricated on an FR-4 low-cost substrate with thickness of 1.6 mm. It is simulated by HFSS full wave software. In addition, the experimental results are presented and compared with the simulation for VSWR, radiation pattern and axial ratio.

## 1. INTRODUCTION

Nowadays, WiMAX technologies use new protocols and standards for local wireless communication. Different technologies such as 2G/3G/4G and Long Term Evolution (LTE) are modified and developed for wireless data services in Wi-Fi, WiMAX and Industrial Scientific Medical (ISM) applications with circular polarization. WiMAX covers three different bands for low, middle and high frequencies at 2.5–2.8 GHz, 3.2–3.8 GHz and 5.2–5.8 GHz, respectively [1, 2]. Microstrip slot antennas with various shapes are studied for wideband wireless applications for linear and circular polarization and bidirectional pattern [3, 4]. During last decades, by the development of the satellite communication, circularly polarized antennas are implemented for communication links to reduce the natural loss effects in receivers [5]. On the other hand, circular polarization (CP) in antennas reduces the loss caused by multipath effects, between the transmitter and receiver antennas. The circular polarization (CP) antenna is attractive for portable wireless application such as Radio Frequency Identification (RFID) because of its low profile, small size, and light weight [6]. Receiving orthogonal signals is another benefit of a CP antenna which makes circular polarization important for communication systems [4–6].

Fractal structures are complex shapes made by broken lines and unusual arrangement which have self-affinity in their geometrical structures. They are common shapes in nature such as snowflakes, ferns, trees, coastlines, mountain ranges and even galaxies. The self-similar geometries are also found useful in antenna engineering applications. Self-similar antennas are multi-resonant and relatively small. Multi-band characteristics are associated with self-similarity of the geometry [7, 8]. Bow-tie dipole antenna with Koch fractal shape is designed for multi-band and miniaturization [8]. In addition, fractal-shaped

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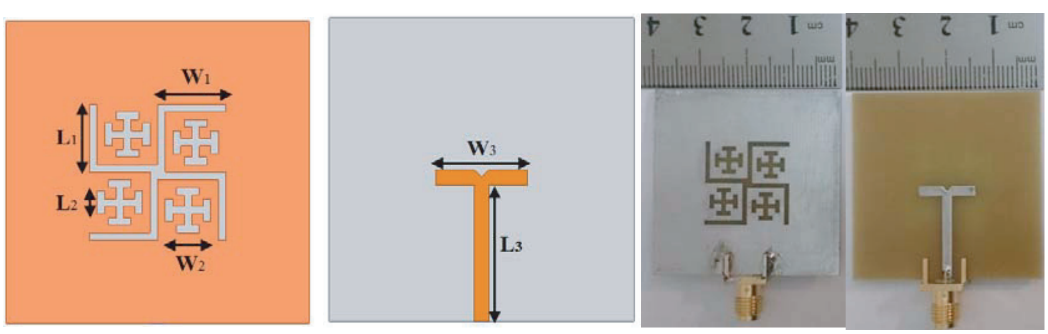
patch-slot configuration is used in miniaturized reflect array unit cell, and Minkowski fractal is compared for different steps [9].

The Jerusalem cross (JC) is a famous model of fractal shape used in many researches for making absorber or metamaterial radome for antenna gain and bandwidth enhancement [7, 10]. In addition, the slot antenna has been studied to achieve circular polarization with a change in slot feeds and parasitic elements in some researches [11–16]. Slot antennas with different techniques for circular polarization are implemented, such as square-ring slot antenna fed with an L-shaped coupling strip [12], dual-square-ring-shaped slot [13], and two-slot rings [14]. Coplanar waveguide (CPW)-fed slot antennas such as two asymmetrical C-shaped strips [15] and corner-truncated ground [16] are also noticed for the feasibility of achieving circular polarization.

In this letter, we develop a fractal Jerusalem cross (JC) slot antenna for circular polarization. For this aim, we suggest a special shape of the slot, a broken cross shape, to alter the antenna's surface current distribution to achieve circular polarization. In addition, a T-shaped feed line is used to increase effective length of the antenna for miniaturization and saving symmetrical formation of the antenna for obtaining circular polarization, and a triangular slot in feed line is used for improving the antenna's impedance matching. In addition, by varying the length of the feed line, we are able to control the coupling to the ground plane and therefore obtain the best length for matching. At last, the Jerusalem cross (JC) slot is implemented on the ground plane.

## 2. ANTENNA STRUCTURE

Figures 1(a) and (b) show the modeled antenna ground and feed geometry, respectively. The final antenna model contains a cross slot and four Jerusalem crosses on the ground layer. The antenna is simulated and fabricated on an FR-4 low-cost and lossy substrate with relative permittivity of 4.4, thickness of 1.6 mm and loss tangent of 0.02. The total size of the antenna is 40 mm × 40 mm ($\lambda/3 \times \lambda/3$ at 2.5 GHz). As shown in Fig. 1(b), the antenna is a microstrip slot antenna fed by a T-shaped microstrip line with the width of 2 mm and length of 26 mm ($\sim \lambda_g/2$), which is connected and matched to a 50 Ω SubMiniature version A (SMA). Figs. 1(c) and (d) show the fabricated antenna ground and feed line, respectively, for the fabricated antenna. In addition, the dimensions are $L_1 = 9$ mm, $L_2 = 3$ mm, $L_3 = 20$ mm, $W_1 = 9$ mm, $W_2 = 6$ mm, $W_3 = 12$ mm.




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

**Figure 1.** Geometrical model of the antenna. (a) Ground of antenna with novel Jerusalem slots. (b) T-shaped feed line. (c) The fabricated antenna ground plane. (d) The fabricated antenna feed line.

## 3. SIMULATION AND EXPERIMENTAL RESULT

Simulations have been performed with HFSS as full wave simulation software. The proposed antenna is fabricated and tested with a network analyzer (HP 8722ES), and the pattern is checked in a chamber room. The measured and simulated $S_{11}$ parameters of the antenna are presented in Fig. 2.

Figure 2(a) shows the antenna's $S_{11}$ parameters with and without Jerusalem slots. It can be seen that Jerusalem slots reduce the antenna resonance around 100 MHz and match the antenna for the desired frequency. In addition, the figure shows the simulated $S_{11}$ parameter in comparison with experimental results for the final model of antenna with bandwidth of 580 MHz at 2.73 GHz (2.42–3.0 GHz) that can be utilized in WiMAX and Bluetooth applications

Figure 2(b) shows the parametric study of the proposed antenna for various dimensions of the T part ($w_3$ in Fig. 1(b)) of the feed line. As shown in Fig. 2(b) by increasing $w_3$, the matching and bandwidth are also increased. However, by increasing this parameter to 14 mm, the antenna shows a dual-band characteristic at 2.4 and 2.8 GHz, which makes it suitable for Wi-Fi and LTE applications. Fig. 2(c) shows the effect of the simple cross slot, and as shown here, the frequency is higher than the broken cross slot, and the resonance occurs at 5.25 GHz.

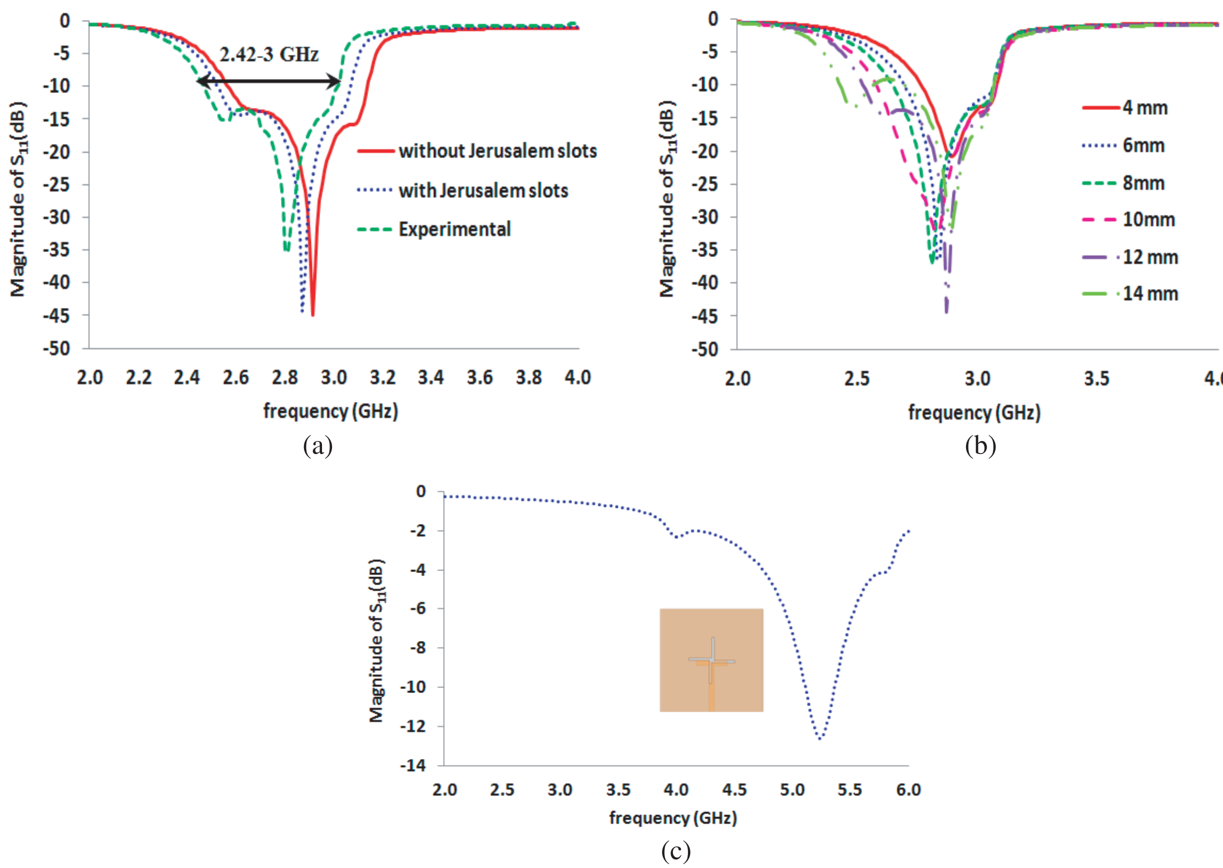



**Figure 2.** $S_{11}$ parameters of the proposed antenna. (a) Jerusalem slot effect simulation and compared with experimental. (b) The feed parameter effect. (c) The simple cross return loss.

Figures 3(a) and (b) show the measured radiation pattern of the antenna in azimuth and evaluation planes (cross (dash line) and co (solid line) polarizations) at 2.6 GHz, respectively. In addition, the maximum gain of the antenna at 2.6 GHz is around 3.5 dBi, and the antenna has a bi-directional pattern as shown in Fig. 3(c), which is simulated in HFSS software. The right- and left-hand circular polarizations at 2.6 GHz are presented in Figs. 3(d) and (e), respectively. As shown here, the RHCP gain is around 2.56 dBi in $Z$ direction, and on the other hand, the antenna gain for LHCP is 3.21 dB in $z$ direction, so the antenna has circular polarization. The simulated efficiency is around 70% at 2600 MHz.

The prototyped antenna shows circular polarization characteristic at 2.6 and 3.1 GHz. The measured axial ratio results are presented in Fig. 4 and for calculation of axial ratio in chamber room; we teste the antenna's horizontal and vertical fields at various frequencies. Axial ratio is a term for measuring quality of the CP and is obtained by Eq. (1). $AR$ is the ratio of major and minor axes of the polarization along the bore-sight of the proposed antenna, derived from the measured results on the

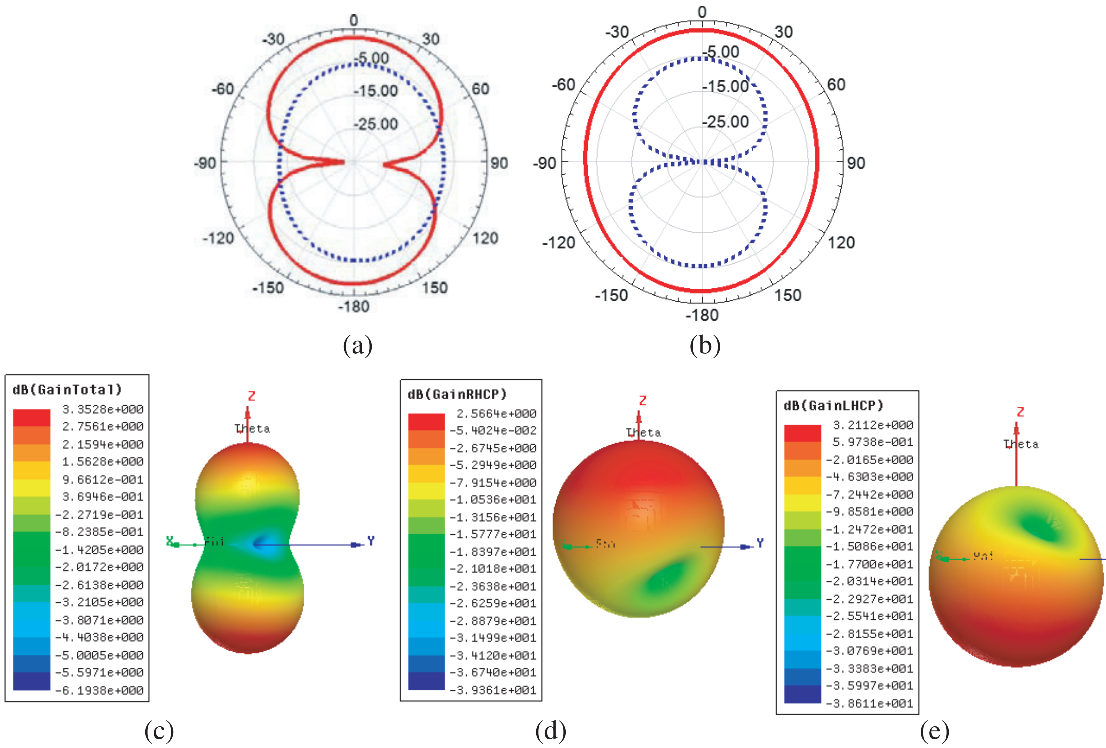



**Figure 3.** Pattern and gain of proposed antenna for 2D plane and 3D pattern. (a) Measured azimuth (phi = 0) at 2.6 GHz. (b) Measured Elevation (phi = 90) at 2.6 GHz. (c) 3D simulation gain pattern of the antenna at 2.6 GHz. (d) RHCP 3D simulation pattern antenna at 2.6 GHz. (e) LHCP 3D simulation pattern antenna at 2.6 GHz.

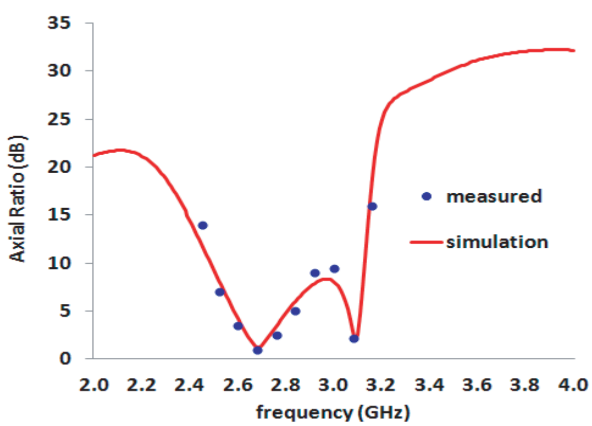



**Figure 4.** Measured and simulation axial ratio of the prototype antenna.

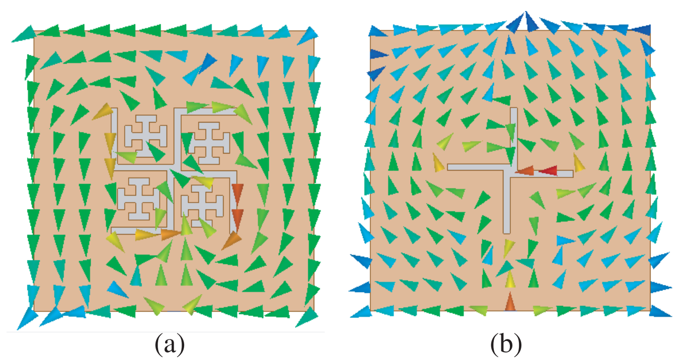



**Figure 5.** The antenna current distribution (a) on the prototyped antenna at 2.6 GHz, (b) on the antenna with a simple cross at 5.2 GHz.

fabricated antenna [17].

$$AR\,[\mathrm{dB}] = 20 \log \frac{E_{\max}}{E_{\min}} \tag{1}$$

Figure 5 shows the antenna's current distribution at the resonance frequencies for the final prototyped antenna and the antenna with a simple crossed slot. As shown in Fig. 5(a), the current is distributed in two loops, and it makes circular polarization in the antenna. Obviously, the cross structure has shaped the current on the antenna to achieve circular polarization. However, for a simple cross model, the current loop was not shaped on the surface of the antenna, and therefore the antenna shows linear polarization at 5.2 GHz.

## 4. COMPARISON

Table 1 shows the comparison between the proposed antennas and previously designed antennas by other researchers. It can be revealed that the prototype antenna has a good performance considering parameters such as bandwidth, gain and efficiency. However, the broken cross slot is useful for antenna miniaturization in comparison with the pervious researches.

**Table 1.** Comparison between prototype antenna and pervious research.

| *parameter* | *Bandwidth* | *gain* | *Size* | *Efficiency* |
|---|---|---|---|---|
| Prototype antenna | 2.4–3.0 GHz | 3.3 dBi | $40 \times 40 \times 1.6\,\text{mm}^3$ | 70% |
| Ref. (1) | 1.5–3.1 GHz | —— | $40 \times 40 \times 0.85\,\text{mm}^3$ | —— |
| Ref. (2) | 1.83–2.73 GHz | 3.5 dBi | $50 \times 50 \times 1.6\,\text{mm}^3$ | —— |
| Ref. (4) | 1.69–2.76 GHz | 5.2 dBi | $60 \times 50 \times 0.8\,\text{mm}^3$ | —— |
| Ref. (6) | 2.2–2.6 GHz | 6.25 dBi | $58 \times 58 \times 11\,\text{mm}^3$ | 87% |
| Ref. (11) | 2.4–3.1 GHz | 3.7 dBi | $50 \times 42 \times 1.6\,\text{mm}^3$ | 85% |
| Ref. (12) | 2.5–2.7 GHz | —— | $56 \times 23 \times 1.6\,\text{mm}^3$ | —— |
| Ref. (13) | 1.92–4.25 GHz | 3 dBi | $50 \times 40 \times 1.6\,\text{mm}^3$ | —— |

## 5. CONCLUSION

This article presents a novel fractal antenna for WiMAX and bluetooth applications at 2.6 GHz with circular polarization. Here, the fractal Jerusalem slot reduces the antenna frequency and matches it with our requested frequency. Axial ratio results also confirm circular polarization in the antenna. The gain, bandwidth and efficiency of the proposed antenna are also compared with the ones in other published researches. By taking the small size of the antenna into account, we conclude that the prototyped antenna has an acceptable performance.

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