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A Multiband Printed Slot Antenna Loaded with Trapezoidal Slots for WLAN and WiMax Applications

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Abstract- *In this paper, a multiband printed antenna has been proposed. The antenna structure is inspired from that of the classical multi-cavity magnetron resonator. The antenna structure is composed of a slot annular ring structure etched on the ground plane of a substrate. The outer circle of the annular ring is loaded with radially arranged small trapezoidal slots. While on the other side of the substrate, the antenna is fed with a 50-Ohm microstrip line. A parametric study has been conducted to explore the effect of the different antenna dimensions on its performance. The results show that the proposed antenna offers triple band resonant responses with considerable frequency ratios of f_3/f_2, and f_2/f_1. Measured results of the input reflection coefficient responses of a fabricated prototype are found to agree well with the theoretical findings. The antenna has an input reflection coefficient response enables it to serve the 2.4/5.2 GHz WLAN and the 3.5/4.5 GHz WiMax applications. Besides, the antenna offers reasonable radiation characteristic with acceptable values of the gain throughout the four resonant bands.*

Keywords- *Antenna, multiband, WLAN Application*

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1. Introduction

The past two decades have seen increasingly rapid advances in the field of multifunctional wireless communication services. Besides, an additional requirement the antenna designers imposed is that these systems have to be compact. Another condition has to be met is that the antenna performance has to make available an adequate performance with proper bandwidths [1]. Within this respect, many techniques are adopted to meet these challenges. The use of multi-element microstrip antenna structures has proved their ability to offer the multi-resonant behavior but have narrow bandwidths and relatively large sizes which are not suitable for the recently available systems [2-4].

Printed slot antennas have proved their performance to offer antenna response with enhanced bandwidths. In this context, many slot antenna structures have been proposed to meet the bandwidth requirements for different communication applications. Many researchers have suggested printed and microstrip antennas using various slot structures for bandwidth enhancement [5-8]. Since the publication of the Mandelbrot [9], the application of the different fractal geometries has proved its validity to design compact multiband microstrip and printed antennas, where the small size is the results of the space filling of these geometries while the multiband resonant performance is the result of their self-similarity. The proposed antennas using this technique are still characterized by the narrow bandwidths. A considerable research work has been devoted to designing printed and microstrip antenna with slot structures based on the various types of fractal geometries. In this respect, many researchers have successfully employed fractal geometries to produce enhanced bandwidth multiband printed antennas for multiple applications. A combination of fractal-based slot structures has been proposed to maintain the compact size and the multi-resonant behavior gained by applying the fractal geometries and enhancing the bandwidths resulting from the use of the slot structures [10-12].

In this paper, a semi-fractal printed slot structure is proposed to design a multiband antenna for use in wireless communication applications. An annular ring slot structure constitutes the antenna frame etched on the ground plane of the dielectric substrate. The outer circle of the annular ring is loaded with radially arranged small trapezoidal slots. The proposed antenna has shown to offer a compact size with multiband resonant performance; making it suitable for many wireless applications.

2. The Proposed Antenna Structure

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The basic idea of the proposed antenna configuration is inspired by the structure of the classical rising sun magnetron as a resonator.

The anode of a magnetron is fabricated into a cylindrical solid copper block. The cathode which is located in the center of the anode, is not shown in the figure and the concentration will be on the anode block itself. The open space between the anode block and the cathode is called the interaction space. In this space, the electric and magnetic fields interact to exert force upon the electrons. The anode block consists of an even number of cavities, with certain shapes, arranged radially. The frequency of operation is determined primarily by the number of the cavities and their physical dimensions. Figure 1 demonstrates the different forms of the resonant cavities constituting the anode block in the classical magnetrons [14-15]. In the present work, the anode structure with the trapezoidal shaped cavity shown in Figure 1(b) has been adopted to be the base of the proposed antenna slot structure. Accordingly, Figure 2 demonstrates the layout of the proposed printed antenna structure. The proposed antenna structure is composed of a slot annular ring structure etched on the ground plane of a substrate. The outer circle of the annular ring is loaded with n = 8 radially arranged small trapezoidal slots. On the other side of the substrate, the antenna is fed with a 50-Ohm microstrip line.

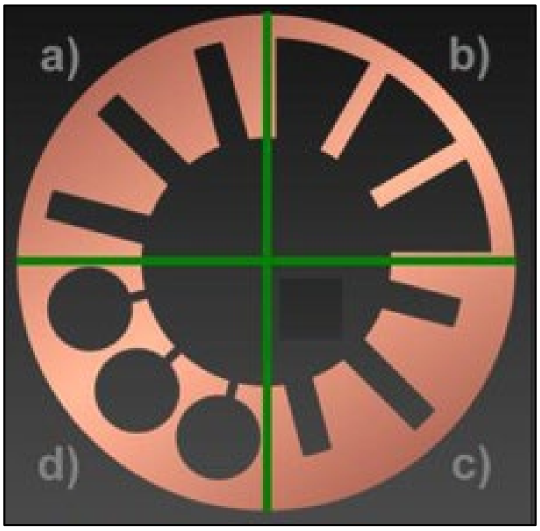

Figure 1: The different forms of the resonant cavities constituting the anode block in a magnetron [13]

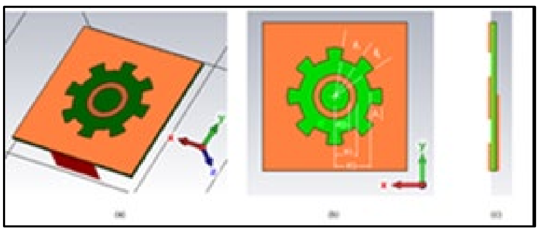

Figure 2: The layout of the modeled antenna; (a) A perspective view, (b) A top view, and (c) A side view

3. Antenna Performance and Parametric study

The effects of the most crucial antenna elements on its performance have been investigated using the EM solver based on CST MWS [16]. The conducted parametric study will provide further interpretation of the role of the different parts of the antenna structure in its overall characteristics. Besides, it offers more information about the resonances which are suitable for specific communication applications. However, it has been found that it is possible by appropriate dimension scaling to produce antenna performance with different resonances, but with the same resonant frequency ratios.

Examining the effects of different antenna elements, it has been shown that the outer slot perimeter essentially governs the antenna lowest resonant frequency. The outer perimeter of the antenna slot structure, P_{out}, can be expressed as:

$$P_{out} = n((R_3 + A)\theta_2 + R_3\theta_1 + 2A) \quad (1)$$

$$\theta_2 = \frac{2\pi - n\theta_1}{n}$$

(2)

Where θ1, θ2, R3, and A are as indicated in Figure 2. The effect of varying the trapezoidal slot width A on the antenna performance is first investigated. The values of A are varied in the range of 1–5 mm in steps of 1 mm. The resulting antenna input reflection coefficient responses corresponding to such variation of the slot width are depicted in Figure 3. The results of Figure 3 imply that as A increases, the positions of the three resonant frequencies become lower in different manners. The decrement of the first lower resonant frequency can be understood from Equation 1 because the increase of A will increase the value of Pout which reduces the resonant frequency. The dimensions of the various antenna parts are summarized in Table 1. The dimensions of the substrate have been kept unchanged.

Table 1: Summary of the proposed antenna dimensions (in mm)

Parameter	R_1	R_2	R_3	A	L_f	θ_1	θ_2
Value	10	5	16	5	24	20°	27°

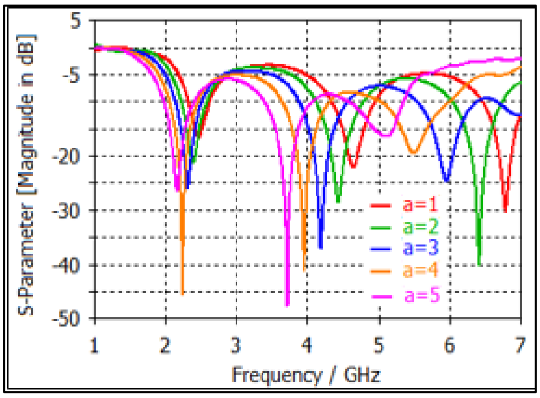

Figure 3: The simulated input reflection coefficients of the modeled antenna with A (mm) as a parameter

With the antenna dimensions depicted in Table 1, the lowest resonant frequency fL1 can be calculated as:

$$f_L = \frac{c}{2.9\lambda_g\sqrt{\varepsilon_{re}}}$$

(3)

And

$$\varepsilon_{re} \approx \frac{\varepsilon_r + 1}{2}$$

(4)

where *c* is the speed of light in free space, ε_{re} and ε_r are the effective and the relative dielectric constants of the substrate material respectively.

However, the range of change of the first resonant frequency is the least as compared with the other resonant frequencies. The change of the lower resonant frequency ranges from 2.2 to 2.5 GHz, and the change of the middle resonant frequency ranges from 3.75 to 4.65 GHz. The third resonant frequency has widely varied from 5.15 to 6.78 GHz. The prescribed variations of the resonant frequencies of the modeled antenna make it suitable for use in most of the recently operating communication services.

Next, the variation of the parameter R_1 is to be examined. The values of R_1 are varied in the range of 10–15 mm in steps of 1 mm. Here, the positions of the three resonant frequencies have changed but in a different way as demonstrated in Figure 4. In this case, the rate of change of the lower resonant frequency is the widest as compared with the other resonant frequencies. The change of the lower resonant frequency ranges from 1.45 to 2.18 GHz, and the change of the middle resonant frequency ranges from 3.45 to 3.72 GHz. The third resonant frequency has widely varied from 4.75 to 5.18 GHz. However, for the larger values of R_1, the middle and the third resonances tend to be diminished. This behavior of the antenna can be attributed to the increased or decreased coupling of the various parts of the antenna slot structure with the feed line as a result of the increase of R_1.

The effect of varying the parameter R3 has been depicted in Figure 5. The values of R_3 are varied in the range of 12.5–16.5 mm in steps of 1 mm. In this case, the antenna performance is less affected as compared with the preceding states. In this case, the change of the lower resonant frequency has a narrow range from 2.05 to 2.35 GHz. However, there is an introduction of fourth resonant and loss of other middle and third resonant bands. Besides, the consequence of varying other antenna parts, such as R_2, has been inspected, but since their effects are insignificant, the corresponding results are not shown.

As a result of the parametric study, and with suitable dimension scaling, the simulated input reflection coefficient of the proposed antenna is shown in Figure 6. It is evident that the antenna offers a triple-band resonant response. The lower band, centered at 2.25 GHz with a bandwidth extended from 2.09–2.48 GHz, the second resonant band is centered at 3.71 GHz with a bandwidth extended from 3.39–4.15 GHz and the third resonant band is centered at 5.10 GHz with a bandwidth extended from 4.41–5.33 GHz. The corresponding values of the realized gain at the center frequencies are 3.83, 3.85, and 5.33 dB respectively.The values of the realized gain are considered high when compared with those of the antennas of the similar category reported in the literature. The resulting bandwidths and the relevant values of the realized gains imply that the modeled antenna is suitable for a wide range of the currently available communication services such as 2.4/5.2 GHz WLAN and the 3.5/4.5 GHz WiMax. However, the results of the conducted parametric study reveal that more applications.

A prototype of the proposed antenna has been fabricated to validate the theoretical predictions. The dimensions of the fabricated antenna are as depicted in Table 1. Figure 6 shows the photos of the antenna prototype. The simulated and the measured antenna responses are shown in Figure 7. The results in Figure 7 imply that there is a reasonable agreement between the simulated and measured results. The slight differences between the measured and the simulated results is mainly due to the fabrication tolerances which lead to the small shifts of the centers of the two resonant bands.

The antenna radiation patterns for $\varphi = 0^\circ$ and 90° (H-plane) and $\theta = 0^\circ$ and 90° (E-plane) for 2.4 GHz, 3.5 GHz and 5.2 GHz frequencies are demonstrated in Figure 8. The results indicate the omnidirectionality if the antenna.

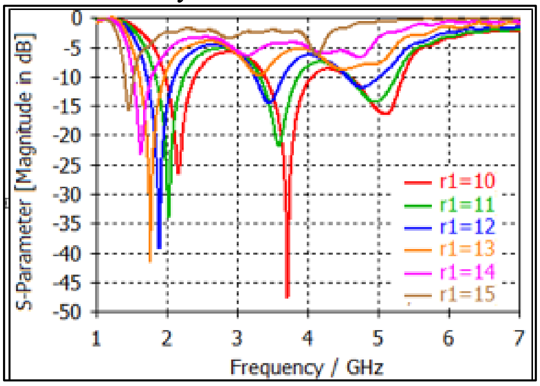

Figure 4: The simulated input reflection coefficients of the modeled antenna with R_1 (mm) as a parameter

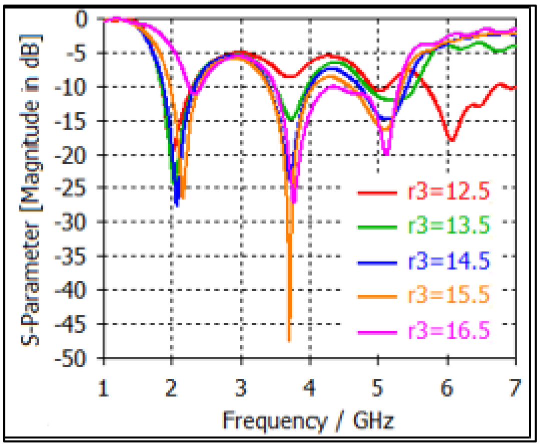

Figure 5: The simulated input reflection coefficient of the modeled antenna with R_3 (mm) as a parameter

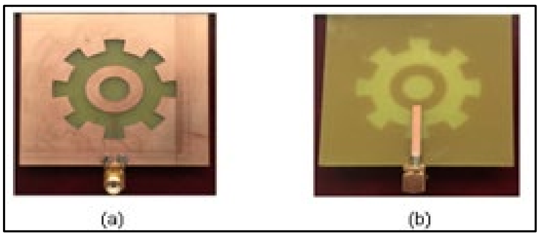

Figure 6: Photos of the fabricated prototype; (a) front view, and (b) the bottom view

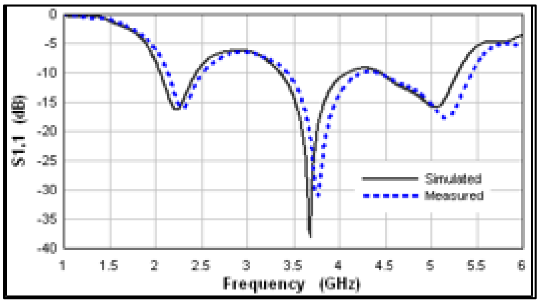

Figure 7: The simulated and measured input reflection coefficient responses of the fabricated antenna

Figure 8 represents current distributions at the surface of the antenna for the frequency bands.The simulated current density distributions on the surface of the antenna at the resonant frequencies are depicted in Figure 9. The current density distribution is a significant aid to provide an additional physical interpretation of the antenna resonant behavior. The simulated current distribution at 2.4 GHz is shown in Figure 9(a). It reveals that approximately most of the outer slot perimeter, P_{out}, contributes to exciting the lowest resonant band. Thus, at this resonant frequency,the current density concentrates on a larger path as indicated; causing the radiated field at the lower band. The results of Figures 9(b) and (c), corresponding to the current distributions at 3.5 GHz and 5.2 GHz respectively, demonstrate that lower radiating path lengths have resulted making the excitation of higher resonant bands possible.

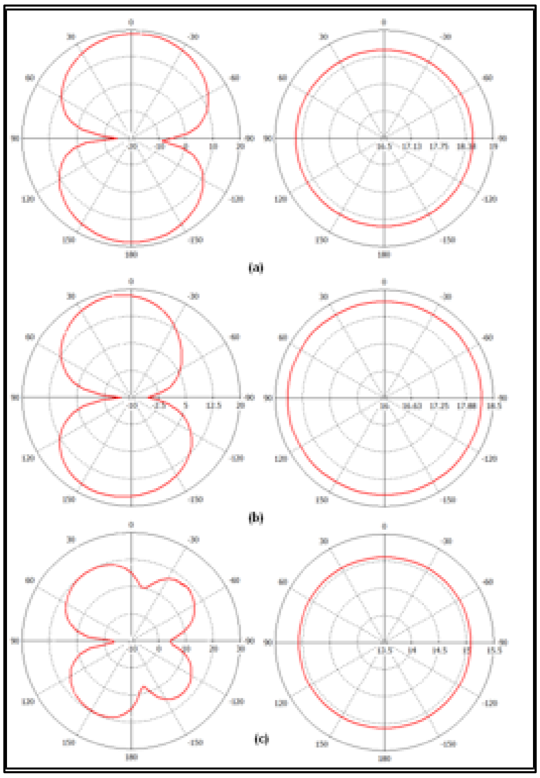

Figure 8: The simulated radiation patterns of the proposed antenna at; (a) 2.4 GHz, (b) 3.5 GHz, and (c) 5.2 GHz

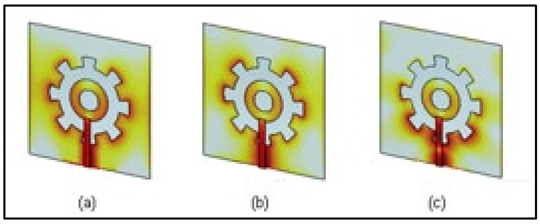

Figure 9. The simulated current distributions on the surface of the proposed antenna at; (a) 2.4 GHz, (b) 3.5 GHz, and (c) 5.2 GHz

4. Conclusion

In this paper, a new multiband slot antenna is presented as a candidate for use in multi-function wireless systems. The idea of the proposed antenna structure is stimulated by the construction of the classical multi-cavity magnetron resonator with trapezoidal shaped cavities. As in the cavity magnetron, it is shown that the dimensions of the cavity determine the operating of the resulting antenna structure. The conducted parametric study reveals that the antenna offers a triple band response with reasonable radiation characteristics. However, the results show that situations, the antenna is capable of exciting a triple-band response within the swept frequency range adopted in this work. The resulting antenna performance fulfills the requirements of a wide range of the currently available commercial communication services such as 2.4/5.2 GHz WLAN and the 3.5/4.5 GHz WiMax. The range of applications can be extended to those occupying a lower frequency range such as the LTE and any other communication systems by an appropriate dimension scaling and the wide range of the resonant frequency ratio the antenna offers.

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