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Design of Circular Printed Slot Antenna for Multiband Wireless Communication Applications

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ABSRACT

In this paper, a printed antenna with circular slot is presented as a candidate for use in multiband wireless communication applications. The slot structure of the proposed antenna is with a circular slot structure. A smaller annular conducting ring with thickness w has been embedded in the slot structure. The slot structure together with the conducting ring has been etched on the ground plane of a substrate with relative dielectric constant of 4.4 and 1.6 mm thickness. A 50 Ω microstrip feed line has been printed on the reverse side of the substrate. Modeling and performance evaluation of the proposed antenna have been carried out using the commercially available EM simulator, HFSS from Ans of Corp. Simulation results show that the proposed antenna has a return loss response with four resonant bands. A parametric study shows that the antenna can cover most of the communication services below 6.0 GHz by varying the width of the inner conducting ring. The results also reveal that for the multi-band configurations studied, the ratios of the resonant frequencies (f_2/f_1) and (f_3/f_2) are with a considerable range. This shows flexibility in designing dual frequency antennas with the desired resonant frequencies. Furthermore, results show that the antenna has reasonable radiation characteristics and gain throughout the four resonating bands.

Keywords: Multiband antenna, Printed antenna, Slot antenna, Microstrip-fed antenna.

تصميم هوائي شقي دائري مطبوع لتطبيقات الاتصالات اللاسلكية متعددة النطاق الترددي

الخلاصة:

يقدم في هذا البحث تصميم لهوائي شقي دائري مطبوع لغرض الاستخدام في تطبيقات انظمة الاتصالات اللاسلكية ذات الانطقة الترددية المتعددة. ان الشكل الشقي للهوائي المقترح يكون دائريا يحتوي على تركيب حلقي موصل بسمك معين متمركز داخله. ان الشكل الشقي مع الحلقة الموصلة مطبوعان في المستوي الارضي لشريحة دقيقة ذات ثابت عزل نسبي بقدر 4.4 و ذات سمك قدره 1.6 ملم. تتم طباعة خط نقل من نوع الشريحة الدقيقة و ذي ممانعة مميزة قدرها 50 أوم على الجانب الاخر من الشريحة العازلة. جرى بناء نموذج الهوائي المقترح وتقييم ادائه باستخدام باستخدام الحقيبة البرمجية للمحاكاة الكهرومغناطيسية HFSS المتوفرة تجاريا من شركة Ansoft . بينت نتائج المحاكاة للهوائي المقترح بانه يمتلك استجابة لخسارة الفقد ذات اربع حزم رنينية. كما بينت الدراسة المعلمية التي اجريت باستخدام الحقيبة البرمجية نفسها بان الهوائي يمكنه ان يغطي الانطقة الترددية لغالبية خدمات الاتصالات العاملة تحت 6.0 كيكاهيرتز و ذلك من خلال تغيير سمك الحلقة الموصلة الداخلية. و بالاضافة الى ذلك بينت النتائج بان للهوائي المقترح خصائص بث و كسب مقبولة خلال الانطقة الترددية الاربعة.

INTRODUCTION

Due to the increasing availability of communication services below 6 GHz in the last decade, more communication systems that incorporate multiband operation accordingly become valid [1]. This has attracted antenna designers to seek antenna structures that have multiple band responses. In this respect, different fractal geometries, such as Peano, Minkowski, Koch …etc, have been adopted for such a task [2–6]. Unfortunately, most of the fractal based dual-band and multiband reported antenna structures are complex and consequently, fabrication inaccuracies might be encountered. In addition, fractal based antennas are characterized by the compact size which in turns leads to low physical aperture and thus low resulting gain.

Among the adopted techniques, to design dual-band and multiband antennas, is the use of multi-elements antenna structures [7–12]. In such a technique, all elements operate simultaneously and contribute to the resulting antenna performance such that each element resonates at a specified frequency.

On the other hand, antenna designers have presented different structure to produce dual-band and multiband antennas for various communication applications. In this context, circular and semi-circular based antenna structures have been successfully adopted to achieve such a task. It is important to note here, that the use of these structures in the design of dual-band and multiband antennas can be classified into two main categories; fractal, [13-15], and non-fractal [16-17]. Because of the enhanced bandwidths realized using slot configuration in the antenna design, each of these two categories can also divided into two classes; with slot, [17-18], and patch or printed structures [13-15,19]. However, it is clear that the majority of the published work is devoted to antenna design with slot structures.

In this paper, a circle based printed slot antenna is presented as a candidate for use in multiband wireless communication applications. The multiband behavior of the proposed antenna together with the reasonable radiation characteristics makes the antenna suitable for use in a wide variety of communication applications.

The Proposed Antenna Structure

The antenna presented in this paper is with a circular slot structure. A circular conducting ring with thickness w has been embedded in the slot structure. The slot structure together with the conducting ring has been etched on the ground plane of a substrate with relative dielectric constant of 4.4 and 1.6 mm thickness. A 50 Ω microstrip feed line has been printed on the reverse side of the substrate. Figure 1 shows the top and side view of the proposed antenna structure.

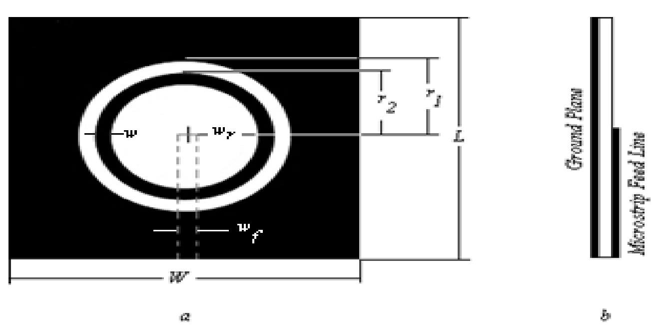

Figure (1). The proposed circular slot antenna structure: (a). Top view, and (b). Side view.

The Antenna Design

The antenna structure depicted in Fig. 1 has been modeled using a mentioned substrate. Modeling and performance evaluation of this antenna have been carried out using the commercially available EM simulator, HFSS, from Ansof Corp. [20]. The performance of the antenna has been evaluated throughout a swept frequency range of 0.5 – 6.0 GHz, since most of the recently available communication applications operate in this frequency range. The modeled antenna has been found to possess a multiband return loss response within the specified frequency range. The first step in the modeling process is to scale the dimension of the proposed antenna structure such that the lowest resonant frequency is allocated at 0.80 GHz. To achieve this, the antenna has been found to possess the dimensions summarized in Table 1. Figure 2 shows the layout of the modeled antenna structure with respect to the coordinate system.

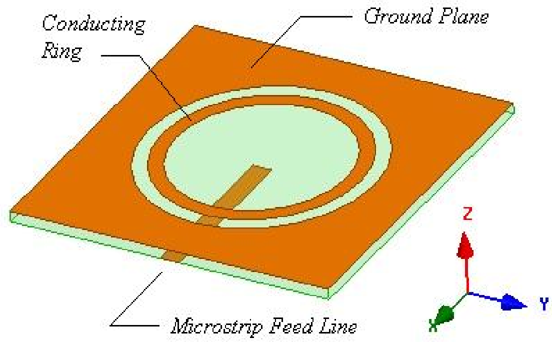

Figure (2). The proposed antenna layout with respect to the coordinate system.

The corresponding return loss response of this antenna is shown in Fig. 3. It is clear that the antenna offers a quad-band return loss response within the swept frequency. These resonant frequencies are poisoned at 0.80, 3.0, 3.8, and 4.8 GHz with fractional bandwidths of about 11.90, 6.78, 5.45, and 4.01% respectively.

Table (1). Summary of the Antenna Dimensions

Antenna Element	**Symbol**	**Dimensions in mm**
Ground plane width	W	105
Ground plane length	L	105
Slot radius	r_1	37.5
Outer ring radius	r_2	28.0
Feed line width	w_f	3.05
Circular ring radius	w_r	4.6

Several antenna models, with different dimensions, have been investigated and their return loss responses are observed. This reveals that the lowest resonant frequency, f_L, is dependent on the perimeter of the antenna slot r_1 as in Equ. (1):

$$f_L \approx \frac{c}{5.5 r_1 \sqrt{e_{eff}}} \quad \dots (1)$$

where c is the speed of light in the free space and ε_{eff} is the effective dielectric constant of the substrate material which is given by:

$$e_{eff} = \frac{1}{2}\left[(e_r + 1) + (e_r - 1)\left(1 + \frac{10h}{w}\right)^{-1/2}\right] \qquad \ldots (2)$$

where ε_r the relative dielectric constant of the substrate material, ***h*** is the substrate thickness and ***w*** is the width of the microstrip transmission line at the design frequency. In this respect, most of the recently available EM simulators provide direct calculation of the effective dielectric constant of the substrate material ε_{eff} at a specified frequency for given substrate specifications [20].

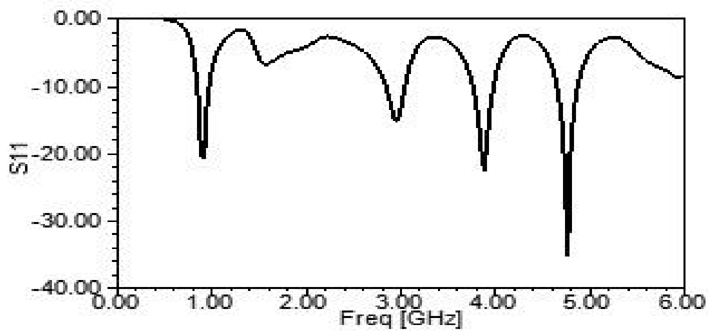

Figure (3). The simulated return loss response of the modeled antenna depicted in Figure(2).

Parametric Study

The results of the antenna return loss depicted in Fig. 3 are corresponding to the proposed antenna with dimensions summarized in Table 1. In this section, a parametric study is conducted to explore the effect of the antenna aspect ratio on its performance. Here, the antenna aspect ratio is defined as the ratio of the antenna width, W, to its length, L, shown in Fig. 1. In this context, different values of the aspect ratio are considered as a result of varying the antenna ground plane width and maintaining its length unchanged. Simulated return loss responses shown in Fig. 4 are corresponding to three values of the antenna aspect ratio of 0.9, 1.0, and 1.1. It is clear that varying the antenna aspect ratio has a considerable impact on the resulting performance. As the antenna aspect ratio increases, the lowest resonant frequency becomes lower. This is a result of the corresponding slot perimeter increase and confirms what is predicted by Equ.1. However, the rate of change of this frequency against the variation of the aspect ratio is relatively small.

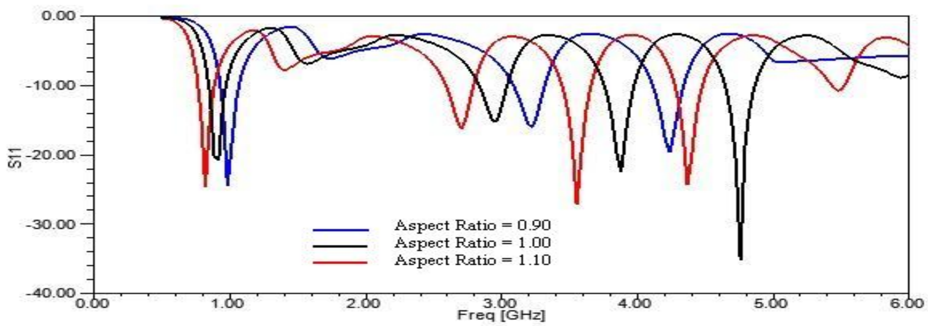

Figure (4). The simulated return loss responses of the proposed antenna for different values of antenna aspect ratio as a parameter: 0.90 (blue), 1.0 (black), 1.1 (red).

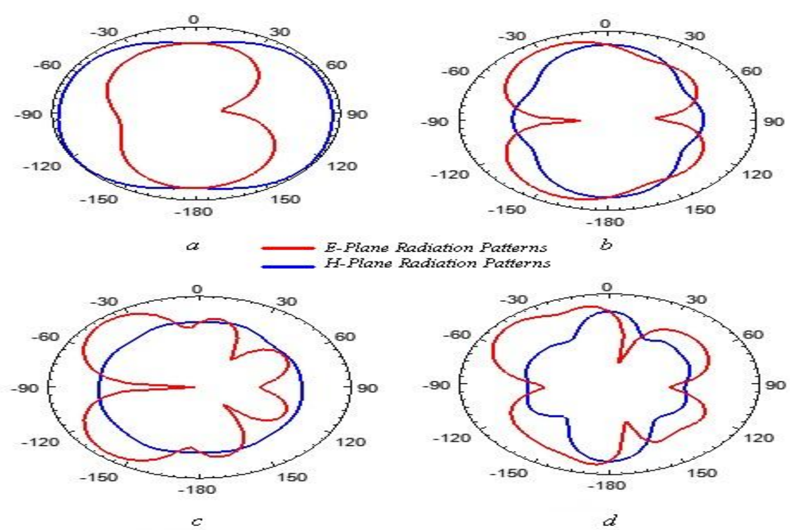

Figure (5). The simulated E-plane and H-plane radiation patterns of the proposed antenna at: (a). 0.90 GHz, (b). 3.0 GHz, (c). 3.8 GHz, and (d). 4.8 GHz.

On the other hand, the rate of change of the higher resonant frequencies against the same variation of the aspect ratio is significantly interesting. It is clearly shown that antenna has the capability of covering most of the recently operating services below 6.0 GHz.

Simulation results of the E and H-planes radiation patterns of the proposed antenna imply that it almost offers a monopole like radiation characteristics. Figure 5 demonstrates the simulated E and H-plane radiation patterns at the four resonant bands. At the center of the lowest resonant band, 0.9 GHz, the E-plane radiation pattern almost has the conventional shape of figure eight for the monopole antenna, while it has an omnidirectional radiation pattern in the H-plane, as shown in Fig. 5(a). At the center of second resonant band, 3.0 GHz, the E and H-planes radiation patterns are slightly distorted as shown in Fig. 5(b). However, the E and H-planes radiation patterns at the centers of the third and fourth resonant bands, 3.8 and 4.8 GHz respectively, encounter another slight distortion. In terms of the resulting peak gain, the antenna offers considerable value of about 11.4, 6.0, 8.0, and 7.5 dB at the centers of the four respective resonant bands. These large values of realized gain are partially attributed by the relatively large value of the antenna physical aperture.

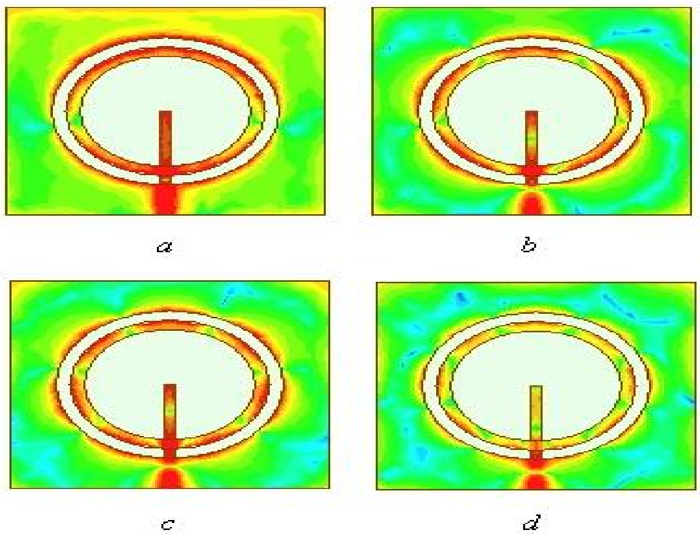

Figure (6). The simulated current distribution on the surface of the proposed antenna at: (a). 0.90 GHz, (b). 3.0 GHz, (c). 3.8 GHz, and (d). 4.8 GHz.

Figure 6 demonstrates the current density distribution on the surface of the proposed antenna at the four resonant frequencies. At the lowest resonant frequency, 0.9 GHz, the surface current is concentrated on both the inner antenna slot perimeter and the conducting ring as shown in Fig. 6(a). This will result in a largest current path attributed to the radiation field at this frequency.

The current distribution at the second and third resonances, shown in Figs. 6(b) and (c) are attributed to the current density distributions on the same antenna elements as in Fig. 6(a) but with less values of the current density. It is clear that the current path is shorter and consequently resulting in higher resonant frequencies. At the fourth resonance, 4.80 GHz, the current density distribution is as shown in Fig. 6(d). It shows the lowest values of the current density on the antenna surface. It is clear that the inner conducting ring contributes on most of the current density in this case. This results into shortest current path and accordingly the highest radiated field.

The current distribution at the second and third resonances, shown in Figs. 6(b) and (c) are attributed to the current density distributions on the same antenna elements as in Fig. 6(a) but with less values of the current density. It is clear that the current path is shorter and consequently resulting in higher resonant frequencies. At the fourth resonance, 4.80 GHz, the current density distribution is as shown in Fig. 6(d). It shows the lowest values of the current density on the antenna surface. It is clear that the inner conducting ring contributes on most of the current density in this case. This results into shortest current path and accordingly the highest radiated field.

The impact of another antenna element has been examined in this parametric study. Based on the current distribution on the antenna surface shown in Fig. 6, the inner conducting ring has been found to have a considerable effect on the antenna performance. To confirm this effect, the proposed antenna has been modeled again but without this ring and its performance is evaluated.

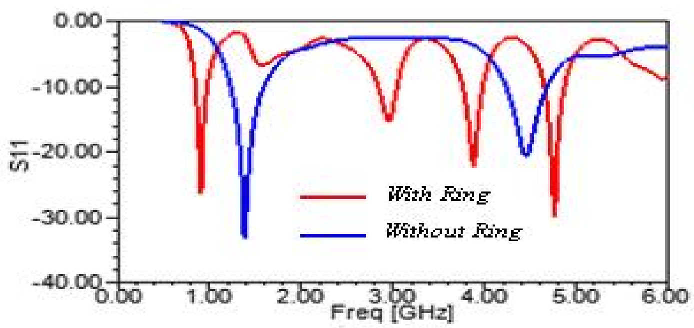

Figure (7). The simulated return loss responses of the proposed antenna with and without the conducting ring.

For comparison, the antenna return loss responses with and without the conducting ring are shown in Fig. 7. Return loss response of the slot antenna without the conducting ring has a dual-band resonant behavior. It is obvious that the appearance of the two additional resonant bands at 1.40 and 4.52 GHz is mainly attributed to the conducting ring.

Conclusions

The antenna presented in this paper has been found to offer a multiband response making it as a suitable candidate for use in multifunction communication services operating below 6 GHz. A conducted parametric study reveals that the proposed antenna offers return loss response covering most of the recently operating communication systems below 6 GHz. The antenna has reasonable radiation characteristics throughout the resonant bands. Furthermore, simulation results show that the antenna offers an enhanced gain at each of the four resonant bands with values of about 11.4, 6.0, 8.0, and 7.5 dB respectively. The corresponding antenna fractional bandwidths are found to be about 11.90, 6.78, 5.45, and 4.01% respectively. It is hopeful that these features together with the antenna simple structure will make the proposed antenna an attractive choice of antenna designers seeking for multiband antennas with considerable gain and reasonable radiation characteristics.

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