Progress In Electromagnetics Research Letters, Vol. 5, 87–98, 2008

TWO NOVEL COMPACT TRIPLE-BAND MICROSTRIP ANNULAR-RING SLOT ANTENNA FOR PCS-1900 AND WLAN APPLICATIONS

H. Sabri and Z. Atlasbaf

Faculty of Engineering, Department of Electrical Engineering
Tarbiat Modares University (TMU)
Tehran, Iran

Abstract—This paper presents two compact ring slot antennas which are suitable for the PCS-1900 and the 2.4/5-GHz triple-band operations. The first antenna consists of three annular ring slots. The outer ring is responsible for exciting the first resonant mode whereas the middle ring excites the second resonant mode. The inner most rings, through their Y-shaped slots, create a wide upper operating band by combining the third and fourth resonant modes. To improve this antenna, we have employed circular Photonic Bandgap (PBG) structures in order to obtain a smaller slot antenna with better radiation characteristics. In this design, the cross-polarization level in the E-plane has reduced compared to the first antenna by 5.5 dB, 0.3 dB and 4 dB in the three resonant bands. Also, the cross-polarization in H-plane has reduced by an amount of 3 dB. In addition, the obtained results show that the co-polarization patterns are very similar in all three frequency bands. In both cases we have reduced the size of antennas to 56% and 42% respectively, of conventional microstrip slot antennas. The simulation results are verified by measurements.

1. INTRODUCTION

The rapid progress in wireless communications requires the development of lightweight, low-profile, flush-mounted and single-feed antennas. Also, it is highly desirable to integrate several RF modules for different frequencies into one piece of equipment. Hence, multi-band antennas that can be used simultaneously in different standards have been in the focus points of many research projects [1, 12–19]. Among these standards, the following frequency bands can be mentioned:

(1) PCS-1900 requires a band of 1.85–1.99 GHz;
(2) IEEE 802.11b/g requires a band of 2.4–2.484 GHz;
(3) IEEE 802.11a requires a band of 5.15–5.35 GHz and an additional band of 5.725–5.825 GHz;
(4) HiperLAN2 requires a band of 5.47–5.725 GHz besides the band of 5.15–5.35 GHz.

Microstrip antennas are very attractive because of their low profile, low weight, conformal to the surface of objects and easy production.

A large number of microstrip patches to be used in wireless applications have been developed. Various shapes such as square, rectangle, ring, disc, triangle, elliptic, pentagonal, kite-like, etc. have been introduced [2–5]. In comparison to patch elements, the antennas with slot configurations demonstrate enhanced characteristics, including wider bandwidth, less conductor loss and better isolation. Particularly, the multi-ring structure is a versatile approach for multi-band and broadband design. Also, feeding these structures could be simpler by using suitable line to ring techniques for circular slots.

Recently, researchers have become more interested in reducing the size of microstrip slot antennas to make them small enough for wireless terminal applications. Utilizing shorting pin, high dielectric constant material, and some novel techniques in feeding are some beneficial ways to get reduced sized antenna. Furthermore, PBG can be used in reducing the size of antennas. These structures which have some specific characteristics such as ability to suppression of surface waves, improving the radiation performance, and reducing the size of antenna are very attractive to use. In addition, they have been utilized in some papers [6–11].

In [9], a fork like PBG structure has been used to reduce the size of antenna. In [10], a PBG structure is used in order to achieve better impedance matching and harmonic suppression of microstrip patch antenna. In [11] it is shown that by employing PBG structures we can get an antenna with lower cross-polarization.

In this paper, we present a simple compact design of a triple-frequency annular-ring slot antenna, fed by a simple microstrip-line. The size of the presented antenna can be greatly reduced by embedding a pair of symmetric Y-shaped slots in the center circular patch. In the frequency range of interest, the presented antenna has four resonant modes, while the antenna without any embedded slots possesses has only three resonant modes. In the second design we have tried to make this antenna more compact and efficient by utilizing circular PBG structures. The very similar co-polarization radiation patterns differs our proposed antennas from previously presented multi-band antenna [12–18]. Also, the E-plane cross-polarization level of the second design is reduced by about 5.5 dB, 0.3 dB and 4 dB in the three resonant bands compared with the first design. Also, H-plane cross-polarization level of the second design has been reduced 3 dB in the three resonant bands.

2. THE GEOMETRY OF THE ANTENNA

Figure 1 shows our proposed antenna. It consists of three annular ring slots etched in the ground of a dielectric substrate with a size of $A \times B$, a permittivity of ε_r, thickness of h and loss tangent of $\tan\delta$. The diameter of the outer ring is D_1 where t_1 is its width. The middle annular ring has a diameter of D_2 and a width of t_2.

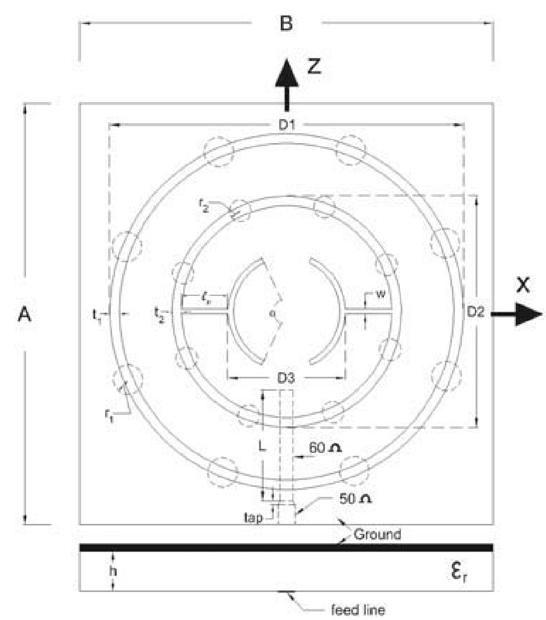

Figure 1. Geometry of the proposed triple-frequency annular-ring slot antenna.

A pair of Y-shaped slots is etched in the middle of the structure. Their diameters are D_3, width w and α as their opening angle. These slots are connected to the middle ring slot via a straight slot of length l_n. The rings are excited by an open ended 60 Ω microstrip transmission line of length L. This line is connected to a 50 Ω line by a tapered line with length tap. Good matching can be achieved by changing the length L.

The same figure can also be applied for the second design except for the circular PBG structures on the substrate. In [6], a PBG structure has been used to control harmonic frequencies of annular slot antennas and some formulas have been suggested for decreasing the level of these harmonic frequencies. During our researches we have distinguished that some restrictions exist in determining the number of PBG structures. Consider "a" and λ_s as a distance between elements of PBG structures and wavelength in the slots, respectively. In a frequency band which we want to perform miniaturization a range for the ratio a/λ_s is optimal: $0.05 < a/\lambda_s < 0.15$. Also, we should specify a relation between "a" and "r" (the radius of PBG structures' element) which should be $0.1 < r/a < 0.2$ for an optimal design. According to these limitations, we have chosen two PBG structures which have eight elements. These are shown by dashed circles in Figure 1 with radii r_1 and r_2 respectively. The dimensions of the first antenna (without PBG structures) and the second one (with PBG structures) are shown in Table 1.

Table 1. Specifications of proposed antennas on a substrate (Taconic RF-35) with $h = 0.762$ mm, $\varepsilon_r = 3.5$ and $\tan\delta = 0.0018$. All dimensions are in mm except α which is indicated in degrees.

	A	B	D_1	D_2	D_3	t_1	t_2	w	l_n	L	tap	α	r_1	r_2
Antenna 1	42.5	42	36	23.4	12	1	1	0.5	4.2	11.7	0.4	143	-	-
Antenna 2	38.5	38	34.4	22.6	10.6	1	1	0.5	5	9.7	0.4	145	1.5	1.1

3. NUMERICAL RESULTS

Figure 2 shows the return loss of the first antenna obtained by HFSS as a function of frequency for five different opening angles (α). It should be mentioned that $\alpha = 0°$ case corresponds to no Y-shaped ring slots, by being left only with the horizontal slots of length l_n. In this case, the center frequencies of the second and third modes make a wide VSWR ≤ 2 impedance bandwidth. As the angle (α) increases, the second and the third resonant modes are shifted to lower and higher frequencies respectively, resulting in a wider upper bandwidth than that in the previous case ($\alpha = 0°$).

By optimizing the angle α, we can obtain the most appropriate results. Figure 3 shows the experimental and simulation results obtained for $\alpha = 143°$. As can be seen, the proposed antenna is suitable

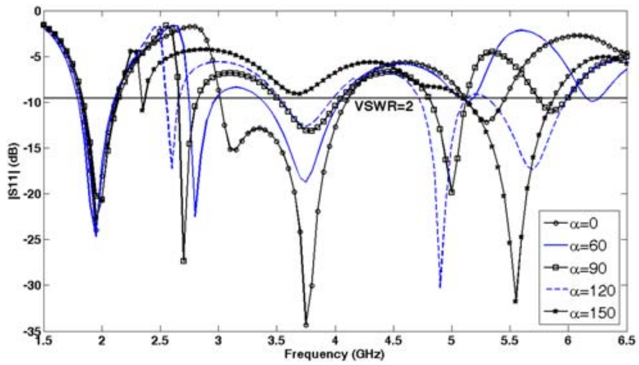

Figure 2. Return losses of the first antenna for five different opening angles (α) [deg].

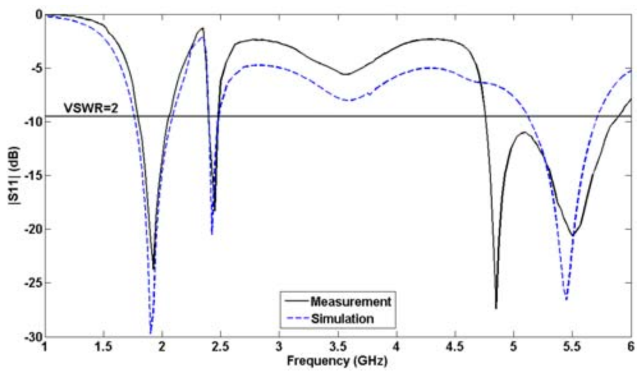

Figure 3. Return loss of the first antenna; measurement and simulation ($\alpha = 143°$).

for PCS-1900, the 2.4 GHz (2400–2484 MHz) and 5 GHz (5–5.9 GHz) commercial frequency bands.

Figure 4 shows simulated and measured return loss of the second antenna. The discrepancies between the measured data and the obtained results by HFSS could be due to inaccuracies in printing the Y-shaped slots, which are in the ground plane of the second antenna. It has shown in Figure 2 that the second resonant band is dramatically sensitive to the change of α.

The experimental results prove that the antenna with PBG structures occupies less area than the other one without PBG structures. Our first antenna needs 33% and 56% of the area of the antennas presented in [17] and [18] respectively, if they scale

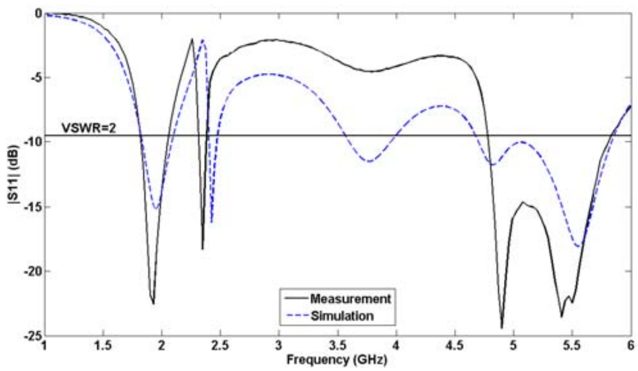

Figure 4. Return loss of the second antenna; measurement and simulation ($\alpha = 145°$).

to cover the 1.9 GHz band on a substrate having $\varepsilon_r = 3.5$ but the second antenna only needs 25% and 42% area of antennas in [17] and [18] respectively. Furthermore, it is found that the first and the second operating frequencies of the proposed antennas approximately correspond to the circumference of the annular-ring slot being about $0.73\lambda_s \sim 0.92\lambda_s$. It is also noted that the wavelength in the slot λ_s is determined to be about 0.78 free-space wavelengths from [18].

4. RADIATION CHARACTERISTICS

The far-field patterns of the proposed antennas in both the x-y (H-plane) and z-y (E-plane) planes at the three resonant-bands were obtained by Ansoft HFSS software. As shown in Figures 5 and 6, the patterns for both antennas have very low cross-polarization (the co- and cross-polarized fields correspond to E_θ and E_ϕ, respectively) levels and the three frequencies have the very same polarization planes that differ our presented antennas from latest developed multi-band antennas [12–18].

The cross-polarization level in the E-plane at the lower band of antenna without PBG is relatively high, which is expected to be due to the diffractions from the edges of the small ground plane. This cross-polarization level can be decreased by enlarging the ground plane size. By changing the ground plane dimensions from $42.5 \times 42\,\text{mm}^2$ to $46.5 \times 46\,\text{mm}^2$, the cross-polarization level decreases from $-7\,\text{dB}$ to $-16\,\text{dB}$. The antenna with PBG structures has a better cross-polarization level in all three bands. As can be seen from Figures 5 and 6, the cross-polarization levels of E-plane of the second antenna have

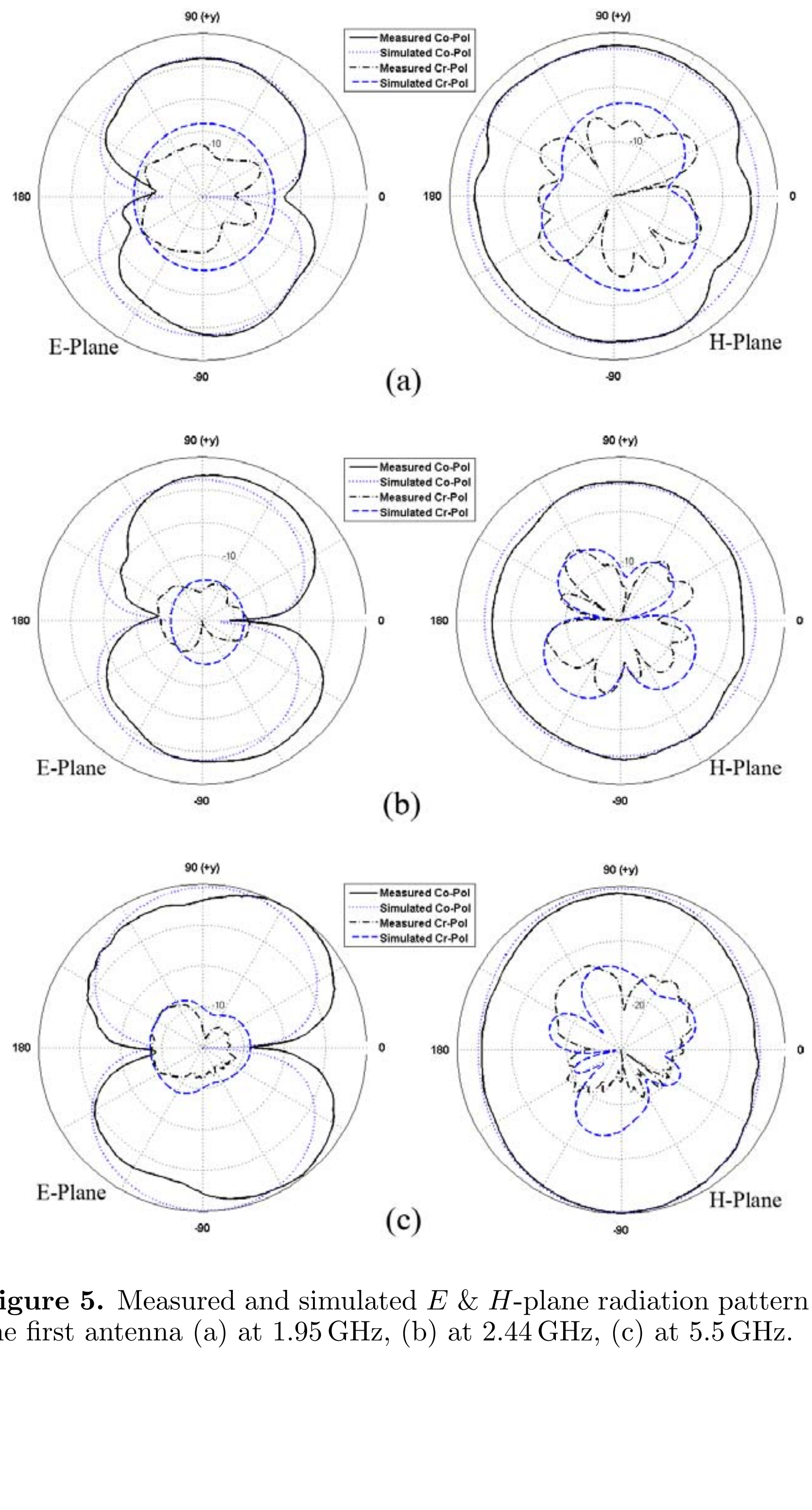

Figure 5. Measured and simulated E & H-plane radiation pattern of the first antenna (a) at 1.95 GHz, (b) at 2.44 GHz, (c) at 5.5 GHz.

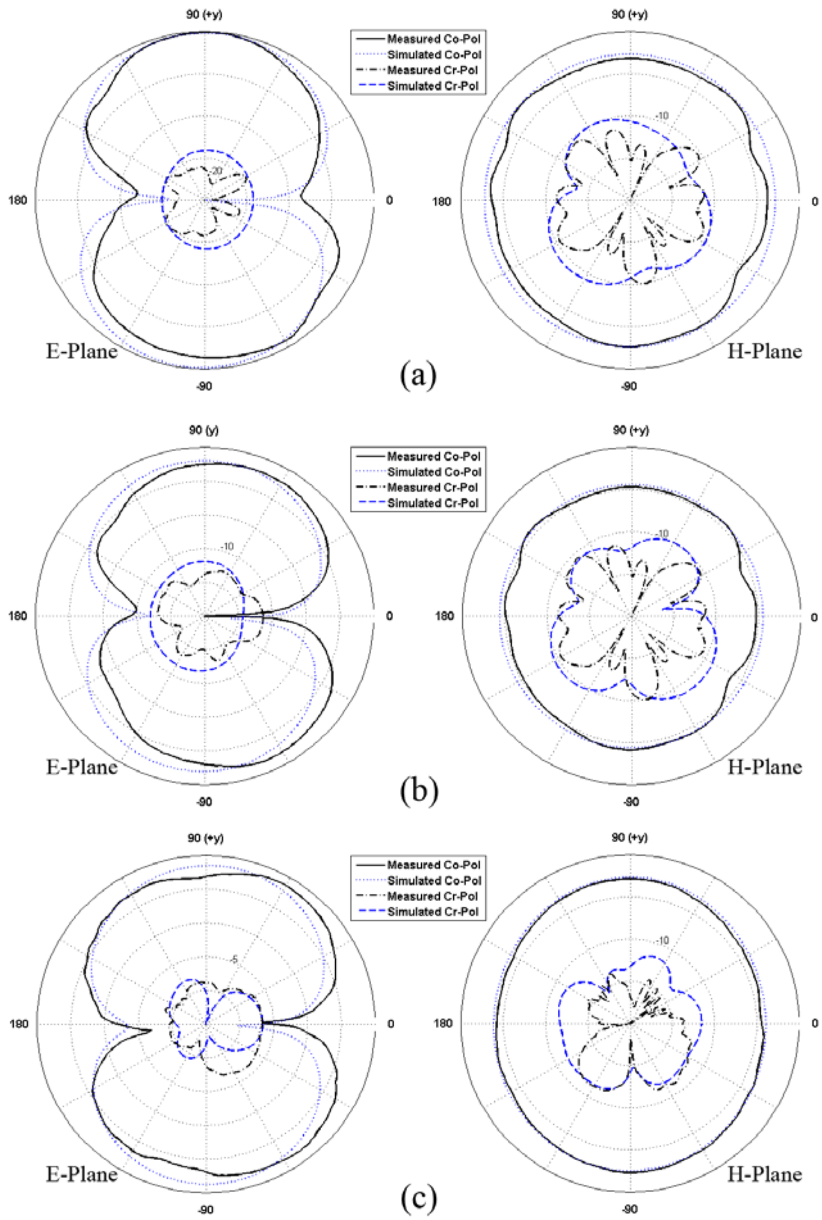

Figure 6. Measured and simulated E & H-plane radiation pattern of the second antenna (a) at 1.9 GHz, (b) at 2.44 GHz, (c) at 5.5 GHz.

been decreased 5.5 dB, 0.3 dB and 4 dB compared to the first antenna for three resonant-bands respectively and the cross-polarization level of H-plane of second antenna for all resonant-bands is reduced by an amount of 3 dB. It can be observed from radiation patterns of these antennas that they are suitable for triple band applications. The gains of the first antenna in three resonant-bands are 0.5 dBi, 1.5 dBi and 4.3 dBi respectively. The gains of second antenna in its three resonant-bands are 3.1 dBi, 0.8 dBi and 0.1 dBi respectively. It should be mentioned that the measurement of the second resonant-band center frequency of antenna with PBG structure has been performed at 2.37 GHz instead of 2.44 GHz.

Figure 7(a) shows a photograph of the proposed antenna without PBG structures and Figure 7(b) shows the second one with PBG structures.

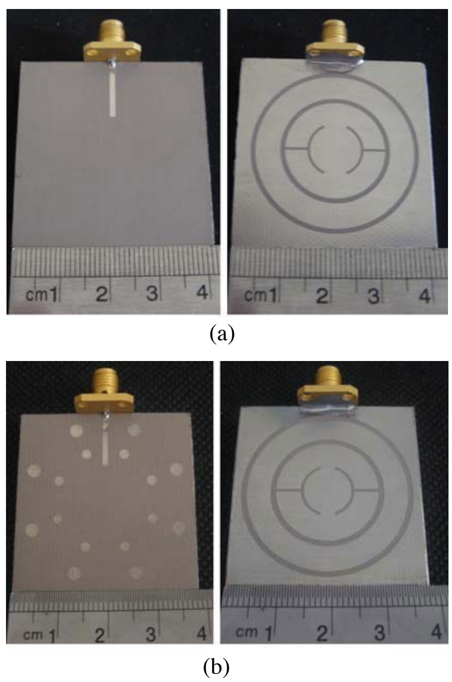

Figure 7. Photograph of the presented antennas. (a) First antenna. (b) Second antenna.

5. CONCLUSION

In this paper, two microstrip-line-fed annular-ring slot antennas with center patches embedded by Y-shaped slots have been proposed for PCS-1900, 2.4/5-GHz triple-band applications. The second antenna is the enhanced version of the first one. The improvement in radiation pattern achieved by utilizing PBG structures and this method has led to obtain a smaller antenna than the first one. The substrate area of the presented antenna without PBG structures is reduced more than 44% compared with that of a conventional annular-ring slot antenna. This reduction is more than 58% for the second antenna with PBG. Both of them have demonstrated very similar copolarization radiation patterns and very low cross-polarization levels in all three operating bands. By employing PBG structures, the second antenna presented 5.5 dB, 0.3 dB and 4 dB lower cross-polarization level in the E-plane of three resonant-bands respectively, and 3 dB lower cross-polarization level in the H-plane of all three resonant-bands compared to the first design.

ACKNOWLEDGMENT

The authors wish to acknowledge Iran Telecommunication Research Centre (ITRC) for partial financial support of this study on contract No. TMU 87-06-32.

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