Compact Dual-Band Square-Ring Slot Antenna

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1. Introduction

Dual-band antennas have become very important in the applications of wireless local-area networks (WLANs) that employ multiple standards. Among these standards, IEEE 802.11b/g requires a band of 2.4-2.484 GHz; IEEE 802.11a, a band of 5.15-5.35 GHz and an additional band of 5.725-5.825 GHz; and HiperLAN2, a band of 5.47-5.725 GHz besides the band of 5.15-5.35 GHz [1]. Since these standards may be simultaneously used in many systems, there is a need for designing a single antenna that can cover all these bands. In recent years, many microstripline-fed slot antennas have been developed for dual-frequency operations [2]-[6]. Although novel in structure and clever in feeding design, these antennas (inclusive of ground planes), if scaled to cover the 2.4 GHz WLAN frequency band, are relatively large. Hence, the objective of this paper is to design a compact antenna that can support the 2.4/5 GHz bands. The size of the proposed microstipline-fed square-ring slot antenna can be greatly reduced by implanting a pair of symmetric bent slots in the center square patch. In the frequency range of interest, the proposed antenna has three resonant modes, whereas the antenna without any embedded slots possesses only two resonant modes. Some structural parameters of the embedded slots can be adjusted to move the two frequency bands and improve their corresponding impedance-matching characteristics.

2. Antenna Structure

Fig. 1 shows the proposed antenna structure, which is printed on a square microwave substrate with a side length of *G*, a thickness of *h*, a dielectric constant of ε_r, and a loss tangent of $\tan\delta$. Deposited on the topside of the substrate is the metal ground plane, etched with a square-ring slot of inner side length L_p and outer side length L_s. On the bottom of the substrate is a 50-Ω feeding microstipline with a width of w_f. In this study, FR4 substrates with h = 0.72 mm, ε_r = 4.4, and $\tan\delta$ = 0.02 were used. To design the antenna with miniaturization, we purposely fixed the ground plane size at G = 30 mm and chose L_p = 16 mm and L_s = 18 mm for the radiating square-ring slot. In the fixed ground plane etched with the pre-determined ring slot, a pair of bent slots with a width (w) of 0.5 mm was embedded in the center square patch of a conventional square-ring slot antenna so as to obtain the desired 2.4 and 5 GHz operating bands. The resultant antenna size is effectively much smaller than those of the antennas reported in [2]-[6], if all these antennas are scaled to have the same first operating band around 2.4 GHz. The bent slots, composed of a horizontal section of length ℓ_n and a vertical section of length ℓ_s, are embedded at the place of *s* away from the upper edge of the square patch. The 50-Ω feeding microstripline along the *y*-axis is extended across the square-ring slot with a protruded length of *t*, which acts as a tuning stub. Whenever the sizes of the bent slots are varied, the tuning stub has to be tuned again for optimized impedance matching in the two operating bands.

3. Return-Loss Characteristics

In this study, the return losses of many fabricated antenna prototypes were measured by using the Agilent N5230A network analyzer. The effects of the bent slots on the return loss will be studied in detail in this section. Fig. 2 shows the return losses of three antennas. The one without any embedded slots in the center square patch is called the reference antenna. Two additional antenna prototypes having the parameters of w = 0.5 mm, ℓ_n = 5 mm, ℓ_s = 6.5 mm were fabricated with s set equal to 3 and 8.5 mm (denoted as Antennas 1 and 2, respectively). For Antenna 1 (2) with s = 3 mm (8.5 mm), the upper edge of the bent slot is positioned above (below) the horizontal line bisecting the center square patch. The measured data of VSWR $\leq$ 2 impedance bands are also summarized in Table 1 for comparison. Note that with the protruded length (t) appropriately selected, two (three) resonant modes having different center frequencies can be excited in the displayed frequency range for the reference antenna (Antennas 1 and 2), as shown in Fig. 2. For Antenna 1, both the first and second resonant modes are excited at lower frequencies than are those of the reference antenna, and the third resonant mode is not impedance matched. For Antenna 2, all three resonant modes are impedance matched. As compared with the last two resonant bands of Antenna 1, the second resonant band of Antenna 2 is moved to a higher frequency location, whereas the third one, lower. These two resonant bands are close enough to form a wide upper operating band. Since the center frequency of the first resonant-band of Antenna 2 is also lower than that of Antenna 1, the dual frequency ratio, f_2 / f_1, where f_1 and f_2 refers to the first and second operating-band center frequencies, is significantly raised from 1.7 for Antenna 1 to 2.12 for Antenna 2. Although the upper operating band of Antenna 2 can cover the 5 GHz WLAN band, none of these antennas can be used for the 2.4 GHz WLAN band. With the slots tuned to ℓ_n = 5.2 mm and ℓ_s = 6.5 mm, the first resonant band of Antenna 3 is lowered to 2385.5-2487.5 MHz, wide enough to cover the required 2.4 WLAN band (see Fig. 3). In fact, Antenna 3 has a wider upper operating band than Antenna 2; inside the upper operating band of Antenna 3 that can still cover the 5 GHz WLAN band, impedance matching is also improved. Also shown in Fig. 3 is the simulated return-loss curve for Antenna 3 (by using Ansoft HFSS, a full-wave electromagnetic simulator), which agrees reasonably well with the measured one.

4. Radiation Characteristics

The far-field patterns of Antenna 3 in both the *x*-*z* and *y*-*z* planes at the three resonant-band center frequencies were measured by using the NSI-800F-10 far-field antenna measurement system. As shown in Fig. 4, the measured patterns agree quite well with the simulated ones, especially for the co-polarized fields. The patterns have very low cross-polarization levels except for the third resonant-mode patterns in the *x*-*z* plane. In fact, the first two and the third resonant-band radiation patterns of Antenna 3, respectively, are very similar to the first and the second resonant-band radiation patterns of the reference antenna. The antenna gains of Antenna 3 around the lower and upper operating bands were measured to be around 1dBi and 4 dBi, respectively.

5. Conclusion

In this paper, a microstripline-fed square-ring slot antenna with its center patch embedded with bent slots has been proposed for 2.4/5 GHz dual-band applications. The slot area of the proposed antenna can be reduced to only 58% that of a conventional square-ring slot antenna when both antennas are designed to have the same lower operating band. The antenna has demonstrated very similar co-polarization radiation patterns in both operating bands and very low cross-polarization levels in the first two resonant bands.

Table 1: Characteristics of Some Antenna Prototypes with L_P = 16 mm, L_S = 18 mm, h = 0.72 mm, w_f = 1.4 mm, ε_r = 4.4, $\tan\delta$ = 0.02, and G = 30 mm. In the table, the impedance band is the frequency range where VSWR $\leq$ 2.

	s (mm)	ℓ_n (mm)	ℓ_s (mm)	w (mm)	t (mm)	f_{c1}, BW_1, % (MHz)	f_{c2}, BW_2, % (MHz)	f_{c2}/f_{c1}
Reference	0	0	0	0	3.6	3191, 177, 5.5	6038, 296, 4.9	1.89
Ant. 1	3	5	6.5	0.5	3.0	2696, 110, 4.0	4610, 397, 8.6	1.70
Ant. 2	8.5	5	6.5	0.5	3.8	2570, 98, 3.8	5452, 1213, 22.2	2.12
Ant. 3	8.5	5.2	6.5	0.5	4.0	2436, 103, 4.2	5345, 1375, 25.7	2.19

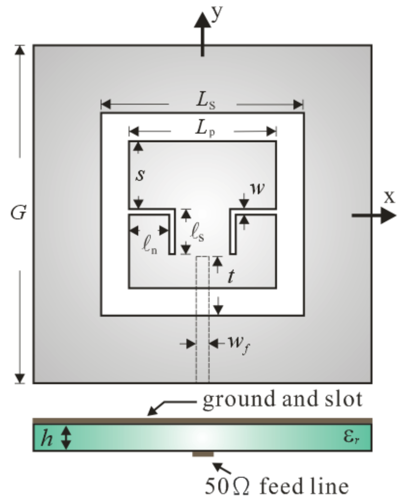

Figure 1: Geometry of the proposed dual-band square-ring slot antenna

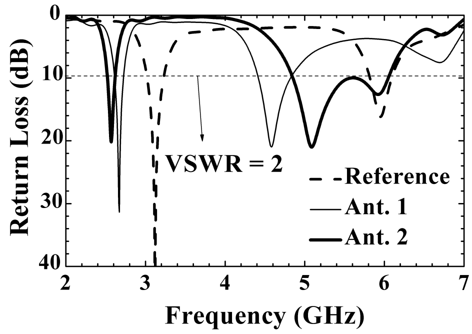

Figure 2: Measured return losses of the reference antenna and Antennas 1 and 2.

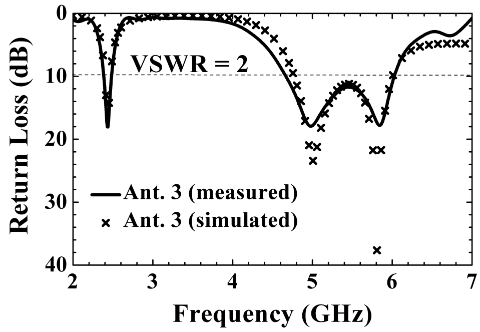

Figure 3: Measured and simulated return losses of Antenna 3.

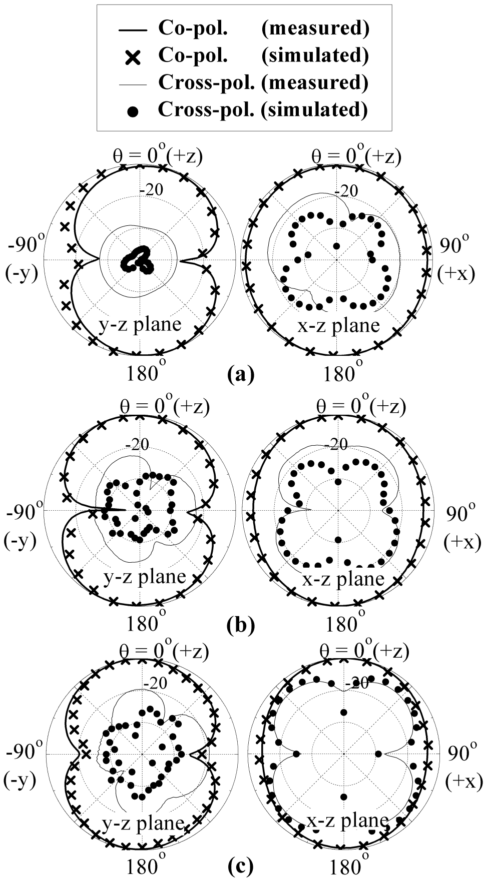

Figure 4: Far-field radiation patterns of Antenna 6 at (a) 2443 MHz, (b) 5010 MHz and (c) 5810 MHz.

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