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COMPACT DUAL-BAND ANNULAR-RING SLOT ANTENNA WITH MEANDERED GROUNDED STRIP

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Abstract—A compact dual-band annular-ring slot antenna (ARSA) is proposed for use in 2.4/5 GHz wireless local-area networks (WLANs). With a meandered grounded strip embedded in the ring slot, three resonant modes were excited. With a pair of notches properly etched in the inner circular patch, the third resonant band was sufficiently lowered so that the second and third resonant bands are combined to form a wider upper operating band. If scaled to the same lower operating-band center frequency, the proposed ARSA measures only 53.6% the area of a conventional microstrip-line-fed ARSA. Measured and simulated results were found to agree reasonably well with each other.

1. INTRODUCTION

Due to the advantages of large impedance bandwidths and low profiles, printed slot antennas (PSAs) have received much attention in recent years. Some PSAs were designed to generate circularly polarized waves with desired handed senses [1–3]; some were further enhanced in their bandwidths [4–6]; others were developed to support dual-band operations [7–17]. For those microstrip-line-fed PSAs designed for dual-band operations, many of them are designed to cover the

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2.4/5 GHz wireless local-area network (WLAN) bands. In the past, different frequency bands of a PSA were produced by implementing disjoint slot lines [7, 8], by designing a novel feeding structure [9, 10], or by embedding in the slot a metallic patch or strip [11–13]. Although simple in structure, these antennas, inclusive of the ground planes, are still relatively large. In the literature, some PSAs have been developed that not only are compact but can also cover the desired 2.4/5 GHz bands [14–17]. In [14], the coupling between two bent slots in the same plane was enhanced for band broadening. In [15], the two slots are stacked on the two sides of the feeding stripline for producing equal radiation on both sides of the antenna. In each of [16] and [17], a pair of slotlines is embedded in the inner circular patch of the antenna for controlling the desired frequency bands.

This paper proposes a new antenna design that is different from those presented in [14–17]. A meandered grounded strip that substitute the slotlines of [16] and [17] is embedded in the annular-ring slot to connect the inner circular patch with the outer ground. This grounded strip can excite one more resonant band than those produced by a conventional annular-ring antenna without the grounded strip. Close scrutiny of the current distributions on the meandered grounded strip suggests that the inner circular patch can be perturbed so that the three resonant bands are varied to form the desired two operating bands.

2. ANTENNA CONFIGURATION

Figure 1 shows the geometry of the proposed microstrip-line-fed annular-ring slot antenna (ARSA), which is printed on a square microwave substrate with a side length of $G = 30$ mm, a height of $h = 0.7$ mm, a dielectric constant of $\varepsilon_r = 4.4$, and a loss tangent of $\tan\delta = 0.02$. On the top of the substrate is the ground plane symmetrically etched to form an annular-ring slot of outer radius $R_1 = 10.5$ mm and inner radius $R_2 = 8.5$ mm, leading to a slot width of 2 mm. On the bottom is a 50-Ω microstrip line with a width of $W_f = 1.3$ mm feeding the ARSA from the $-y$ direction. This feeding microstrip line is connected to a curved strip of angle β (referred to as the curved feeding section) at the end beneath the ring slot. Embedded in the ring slot is an arched metal strip that connects the inner circular patch and the outer ground through two radially directed strips. The one oriented in the y-direction is connected to the inner circular patch, and the other having an inclination angle of α measured from the right edge of the feeding microstrip line is connected to the outer ground. For simplicity, refer to the arched metal strip in the

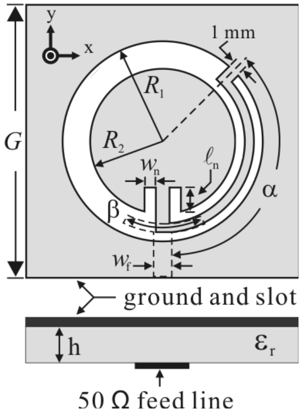

Figure 1. Geometry of the proposed annular-ring slot antenna.

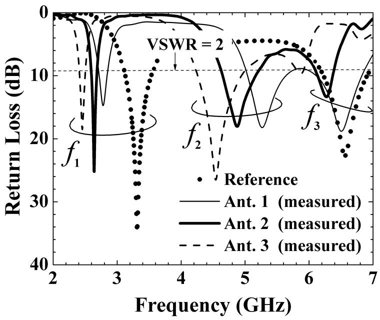

Figure 2. Measured return losses for the reference antenna and Antennas 1–3.

ring slot together with the two radially directed metal strips as the meandered grounded strip. The curved feeding section on the bottom of the substrate and the meandered grounded strip in the slot are chosen to have the same width of 1 mm. The arched metal strip and the curved feeding section are aligned in the radial direction, midway in the slot. A pair of notches with width w_n and length ℓ_n beside the y-directed section of the meandered grounded strip is created in the inner circular patch. Note that the feeding curved section acts as a tuning stub for impedance matching, whereas the meandered grounded strip can excite one additional resonant mode, leading to a total of three resonant bands. In addition, the pair of notches can not only lower the first and third resonant bands but also make the second and third resonant bands combined into a wider operating band.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The simplest ARSA is the one without the meandered grounded strip, the curved feeding section, and the pair of notches. Let such an antenna that is fed from the edge of the substrate by a 50-Ω microstrip line of length 9.7 mm be called the reference antenna. The measured return-loss (RL) curve for the reference antenna is shown in Fig. 2. This antenna has two VSWR $\leq$ 2 resonant bands, one centered at 3333 MHz with a bandwidth of 419 MHz and the other at 6568 MHz with a bandwidth of 715 MHz. For convenience, the former (latter) can also be referred to as the lower (upper) operating band since these two bands are separated from each other (that is, these two bands are not overlapped). None of these two bands can cover either of the two desired WLAN bands around 2.45 and 5.5 GHz. A strategy of overcoming this problem is to perturb the ring structure so that 1) the resonant-band center frequencies can be lowered, 2) more resonant bands can be produced, and 3) adjacent resonant bands can be overlapped to form a wider single operating band. The proposed feeding and perturbed-slot structures for the ARSA can lead to the above characteristics. Experimental results for the antennas developed in the design process are given below.

Also shown in Fig. 2 are the RL curves of the three antennas (Antennas 1–3) having, besides $w_n = \ell_n = 0$, different sets of α and β. Their operating-band data (i.e., the resonant-band data, since these bands are disjoint) are also summarized in Table 1, in which f_{ci} is the center frequency of the ith VSWR ≤ 2 operating band. In the presence of the meandered grounded strip, each of the three antennas has one more resonant band than does the reference antenna. As evidenced from Fig. 2 and Table 1, the larger the value of α, the lower the resonant-band center frequencies. Once α is varied, the angle β

Table 1. Structural parameters, measured VSWR ≤ 2 operating bandwidths, and the corresponding center frequencies (f_{ci}) for Antennas 1–7; $\varepsilon_r = 4.4$, $\tan\delta = 0.02$, $h = 0.7$ mm, $G = 30$ mm, $R_1 = 10.5$ mm, $R_2 = 8.5$ mm, and $W_f = 1.3$ mm.

	α deg	β deg	ℓ_n mm	w_n mm	f_{c1} MHz	BW1 MHz, %	f_{c2} MHz	BW2 MHz, %	f_{c3} MHz	BW3 MHz, %	f_{c2}/f_{c1}
Ant. 1	135	38	0	0	2781	130, 4.67	5352	592, 11.06	6451	776, 12.02	1.92
Ant. 2	156	43	0	0	2639	92, 3.48	4913	617, 12.55	6248	260, 4.16	1.86
Ant. 3	175	66	0	0	2456	86, 3.50	4608	720, 15.62	5866	47, 0.73	1.88
Ant. 4	156	43	0.5	1.5	2584	106, 4.10	4962	634, 12.77	6177	307, 4.97	1.92
Ant. 5	156	43	1.5	1.5	2530	103, 4.07	5071	654, 12.89	5963	374, 6.27	2.00
Ant. 6	156	43	3.0	1.5	2402	99, 4.12	5236	1142, 21.81	-----	-----	2.18
Ant. 7	156	43	2.6	1.5	2440	110, 4.50	5250	1280, 24.38	-----	-----	2.15

has to be appropriately changed to achieve impedance matching. The optimized values of β for Antennas 1-3 with the values of α given in Table 1 were found by using the commercial full-wave electromagnetic simulator Ansoft HFSS.

Of course, the design goal of producing operating bands to cover the two WLAN bands is not yet accomplished. Although the first resonant bands of Antennas 1–3 are very close to the desired band of 2.4–2.484 GHz, their second and third resonant bands are still separated and far from enclosing the band of 5.15–5.825 GHz. We can examine the electrical currents distributed on these antennas to determine how to proceed in the design. Among them, the main current distributions on the ground of Antenna 2 simulated also using Ansoft HFSS are re-sketched in Fig. 3. In this figure, the half-guided-wavelength routes of the electric current distributions are denoted by the dashed lines drawn beside the current distributions. Obviously, these routes have the longest length at 2640 MHz (the simulated f_{c1}) and the shortest at 6350 MHz (the simulated f_{c3}). Note that the currents around the y-directed section of the meandered grounded strip are stronger for f_{c1} and f_{c3} than for f_{c2}. Hence, we expect that a perturbation created near the y-directed strip in the inner circular patch would more significantly affect f_{c1} and f_{c3} than f_{c2}. The perturbation is chosen to be a pair of notches with length ℓ_n and with pre-selected width $w_n = 1.5$ mm embedded around the y-directed

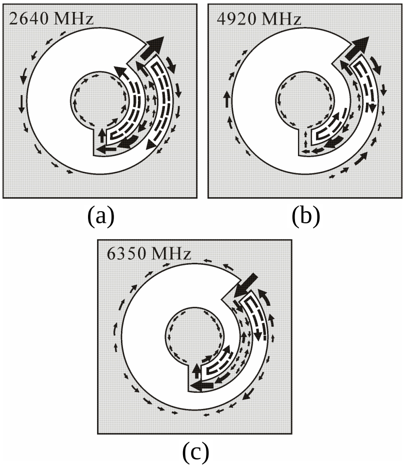

Figure 3. Electric current distributions on the ground of Antenna 2 at the simulated resonant-band center frequencies of (a) 2640 MHz, (b) 4920 MHz, and (c) 6350 MHz.

strip in the inner circular patch. Shown in Fig. 4 are the RL curves of Antennas 4, 5, and 6 with $\ell_n = 0.5$, 1.5, and 3 mm, respectively. With the second resonant-band center frequency remaining roughly the same, the larger the value of ℓ_n, the lower the first and third resonant-band center frequencies. In fact, the third resonant-band center frequency is lowered more pronouncedly than the first. For Antenna 6, which has the largest ℓ_n among the three antennas, the third resonant-band center frequency is lowered enough so that the second and third resonant bands are sufficiently close to each other to form a wider single operating band, i.e., the upper operating band.

Although wide enough, the two operating bands of Antenna 6 are still a little bit too low to completely enclose the two desired WLAN bands. The tendency shown in Fig. 4 that the first and third resonant-band center frequencies decrease with the increase of ℓ_n suggests that ℓ_n be slightly decreased in order to achieve the design goal. As ℓ_n is decreased from 3 to 2.6 mm, Antenna 7 is measured to possess the operating bands of 2385–2495 and 4610–5890 MHz (see Fig. 5), enough to cover the two WLAN bands. For comparison purpose, the measured RL curve for Antenna 2 is plotted again in Fig. 5. These results reveal that the pair of notches is very effective in forming the upper operating band and shifting the lower operating band (i.e., the first resonant band) to the desired frequency location. Also presented in Fig. 5 is the simulated RL curve for Antenna 7. Reasonable agreement between the simulation and the measurement can be observed. Note that if Antenna 7 and the reference antenna are designed to have the same

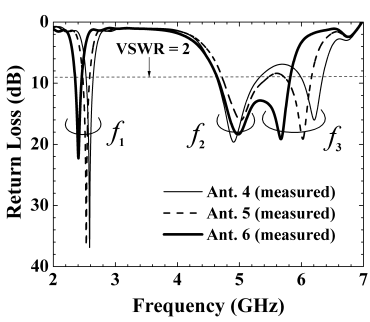

Figure 4. Measured return losses for Antennas 4–6.

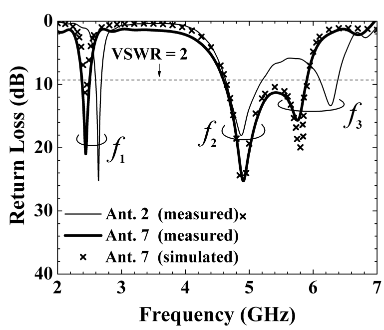

Figure 5. Measured return losses for Antennas 2 and 7, and simulated return losses for Antenna 7.

lower operating-band center frequency, the area of the former is only 53.6% that of the latter.

The far-field patterns of Antenna 7 in both the yz plane (E-plane) and the xz plane (H-plane) at 2450, 4900, and 5750 MHz were measured by using the NSI-800F-10 far-field antenna measurement system in the WavePro FFC-700 far-field antenna measurement

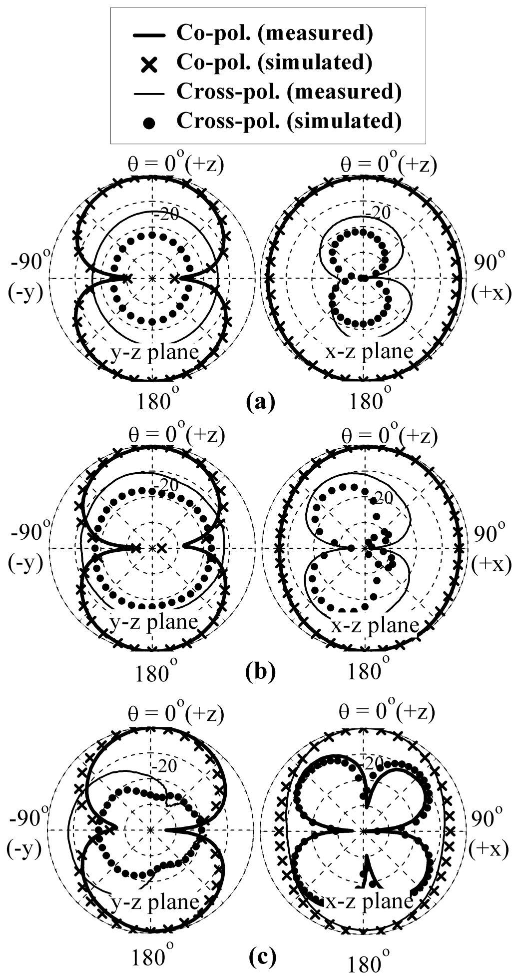

Figure 6. Measured and simulated far-field radiation patterns for Antenna 7 at (a) 2450 MHz, (b) 4900 MHz, and (c) 5750 MHz.

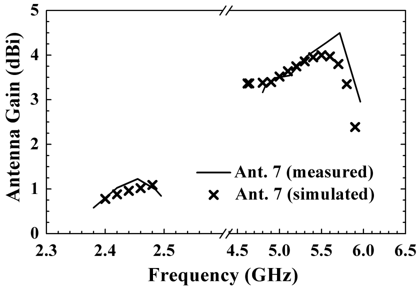

Figure 7. Measured and simulated antenna peak gains for Antenna 7 in the two operating bands.

anechoic chamber. As can be seen in Fig. 6, the co-polarized patterns are very similar to those of an electric dipole, whereas the cross-polarized ones are smaller at lower frequencies. The measured patterns agree reasonably well with the simulated ones, especially for the co-polarized fields. As shown in Fig. 7, the measured and simulated peak antenna gains for Antenna 7 are also in good agreement. These gains are around 1 dBi for the lower operating band and 3.6 dBi for the upper.

4. CONCLUSIONS

A novel dual-band microstrip-line-fed ARSA has been proposed for 2.4/5 GHz WLAN operations. By appropriately perturbing the ring slot, we have successfully designed an ARSA whose area is about 46% smaller than that of a conventional ARSA if the two antennas are scaled to the same lower operating-band center frequency. The measured results were found to be in reasonable agreement with the simulated data.

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