Dual-Band Circularly Polarized Stacked Annular-Ring Patch Antenna for GPS Application

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***Abstract*—A dual-band circularly polarized stacked annular-ring patch antenna is presented in this letter. This antenna operates at both the GPS L1 frequency of 1575 MHz and L2 frequency of 1227 MHz, whose frequency ratio is about 1.28. The proposed antenna is formed by two concentric annular-ring patches that are placed on opposite sides of a substrate. Wide axial-ratio bandwidths (larger than 2%), determined by 3-dB axial ratio, are achieved at both bands. The measured gains at 1227 and 1575 MHz are about 6 and 7 dBi, respectively, with the loss of substrate taken into consideration. Both simulated and measured results are presented. The method of varying frequency ratio is also discussed.**

***Index Terms*—Annular-ring patch, circular polarization, dual-band, microstrip antennas.**

I. INTRODUCTION

WITH THE rapid development of the satellite communication and positioning system, more and more attention has been paid to circularly polarized (CP) antennas. The Global Positioning Satellite (GPS) system operates at 1575 and/or 1227 MHz with RHCP signals. To meet additionally important and demanding applications, antennas operating at both frequencies are needed.

Various dual-band circularly polarized patch antennas, which adopt the configuration of single-layer and single-feed, have been proposed in [1]–[5]. In [1], two pairs of arc-shaped slots, with different subtending angles, are placed at the edge of the circular patch. Perturbation, caused by the asymmetric slots, achieves the performance of circular polarization. Two orthogonal TM_{11} and TM_{12} modes are excited at different bands. A method similar to [1] is used in [2], which proposes a square patch, with T-shaped and Y-shaped slots, operating at the resonant frequencies of TM_{10} and TM_{30} modes. A low-frequency-ratio (about 1.21) CP antenna with a single layer and single feed is reported in [3]. Having an unequal lateral cross-slot as a perturbation structure on the ground plane, it has a bidirectional radiation. A slot-coupled square patch antenna with an S-shaped slot on the patch [4] operated at the two GPS frequencies, whose circular polarization bandwidth is about 0.6% at the high frequency, is presented. In all these designs, a perturbation method is used to achieve circular polarization, and the relative axial-ratio (AR) bandwidth is normally around 1% or less.

In [6]–[11], stacked patch antennas with dual-resonant units are presented and measured. With three layers of substrates and dual feed [6], the stacked antenna operating at both the L1 and L2 frequencies of GPS are excited by a cross slot, which is fed by a two-stage Wilkinson power divider network. In [7], with a dual-layer structure, two stacked corner-truncated square patches are excited by a single probe. In the design of [7] and [8], the reduction of substrate is achieved by a single feed, whose cost is the decrease of axial-ratio bandwidths and gains. In these three kinds of stacked structures[6]–[8], strong coupling exists between the two patches since the bottom patch acts as a ground plane when the top patch resonates.

In [12], the introduction of an annular-ring patch can reduce the dimension of the antenna compared to a circular patch with the same outer radius. Similarly, perturbation on an annular ring also makes the relative axial-ratio bandwidth less than 1%.

In this letter, a dual-band, dual-layer, dual-feed stacked annular-ring patch antenna excited by two orthogonal H-shaped slots, fed by a 3-dB hybrid, with axial-ratio bandwidths greater than 2% at L1 and L2 frequencies of GPS and slight coupling between the patches is proposed and measured. With the loss of substrate taken into consideration, the measured gains at L1 and L2 are about 7 and 6 dBi, respectively. In addition, the frequency ratio of the two bands can be varied from 1.28 to 1.83 by adjusting the radius of the patch.

II. ANTENNA DESIGN AND STRUCTURE

Fig. 1 shows the geometry and dimensions of the proposed stacked annular-ring patch antenna, which is fabricated with two layers of square FR4 ($Hs = 1$ mm, $\varepsilon = 4.5$, $\tan\delta = 0.02$) substrates, and the substrates are separated by an air layer with height $H = 10$ mm. This antenna is assembled with four nylon columns and eight nylon screws. Two concentric annular-ring patches, one smaller and the other one larger, are on the top and bottom of the upper substrate, respectively. The inside radius and outside radius of the top ring are $R1 = 22.8$ mm and $R2 = 26.6$ mm, respectively. The inside radius and outside radius of the bottom ring are $R3 = 29.2$ mm and $R4 = 37.1$ mm, respectively. The dimension of the patches is only about 0.87 times of that in [1].

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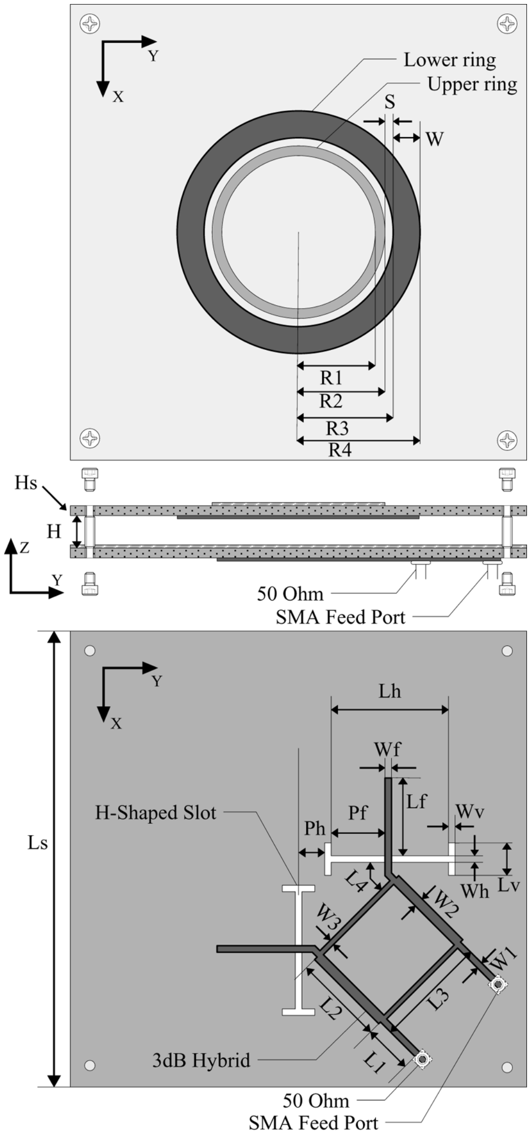

Fig. 1. Geometry of the proposed antenna.

With the loss of the substrate taken into consideration, a thin substrate should be adopted. Using an annular-ring can achieve an antenna within relatively small dimensions and at the same time decrease the coupling between the two patches. To further control the coupling, a gap of 2 mm between the two rings is required, namely the S should be larger than 2 mm. In addition, since the frequencies of L1 and L2 are quite close, the dimensions of the rings have to be nearly the same, which might increase the coupling between the two patches. Thus, the larger ring for low frequency has to be printed on the bottom of the upper substrate in order to enlarge its dimensions and at the same time shrink the radius of the top ring.

The top layer of the lower substrate is the ground. Dual feed is adopted to achieve wide axial-ratio bandwidths. Two orthogonal H-shaped apertures were etched on the ground. A 3-dB hybrid, which functions as the feeding network, is on the bottom of the lower substrate. The positions and dimensions of the apertures and 3-dB hybrid are listed in Table I, respectively. The feeding port is shown in Fig. 1. As the 3-dB hybrid has two ports, the

TABLE I
DIMENSIONS AND POSITION OF APERTURE AND 3-dB HYBRID ON THE LOWER SUBSTRATE

Parameter	Lh	Wh	Lv	Wv	Lf	Wf
Value(mm)	36	2	10	2	24	2
Parameter	Ls	L1	W1	L2	W2	L3
Value(mm)	140	18	1.8	27.4	3.0	33.1
Parameter	W3	L4	Ph	Pf		
Value(mm)	1.6	6	7	17.5		

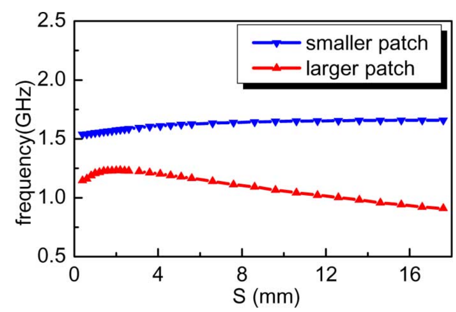

Fig. 2. Simulation results of frequencies of smaller and larger patches with the changing of S.

antenna can support both LHCP and RHCP. When measuring the antenna in the RHCP mode, the antenna is fed from one port, and a 50-Ω load is attached to the other one.

Because the two frequencies of the dual-band antenna are relatively close, a single-band 3-dB hybrid is used. The center frequency of the 3-dB hybrid is 1.4 GHz. By adjusting the parameter of the 3-dB hybrid, it can operate at both the L1 and L2 frequencies with an equal power at the output ports, with phase shift of about 90° between them and S_{11} lower than -13 dB.

III. Parametric Study

With $R1 = 22.8$ mm, $R2 = 26.6$ mm, and $W = 7.9$ mm fixed, Fig. 2 shows the simulated results (using HFSS) of high resonant frequency and low resonant frequency of the two patches by varying S from 0.4 to 17.6 mm, without the 3-dB hybrid (two ports assigned at the two feeding lines with equal amplitude and 90° phase shift). When S is larger than 2 mm, with S increased, the inner and outer radii of the large patch increase, which makes the low frequency decrease. When S is less than 2 mm, strong coupling exists between the two patches, which makes the high frequency lower and low frequency decrease even more rapidly. A probable explanation for this is that the adjacent patches might act as a parallel capacitor to each other, which enlarges their equivalent electrical length. This explication is also suitable for the slight variation of high frequency when S is larger than 4 mm since the increasing gap between patches gradually decreases the coupling between them.

Coupling between the two patches affects the adjustment of the frequency ratio. Fig. 3 shows the simulated results of the frequency ratio of the two resonant frequencies under the same condition as that in Fig. 2. When S is larger than 2 mm, the frequency ratio monotonically increases with the increasing of S. In this proposed structure, with S larger than 2 mm, variation of the frequency ratio from 1.28 to 1.83 can be easily achieved

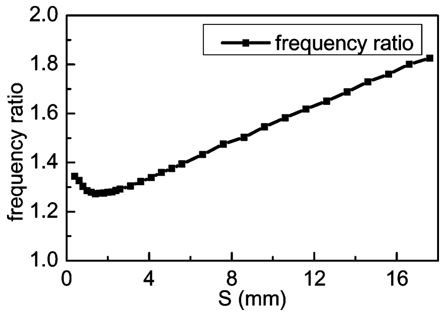

Fig. 3. Simulation results of frequency ratio with the changing of S.

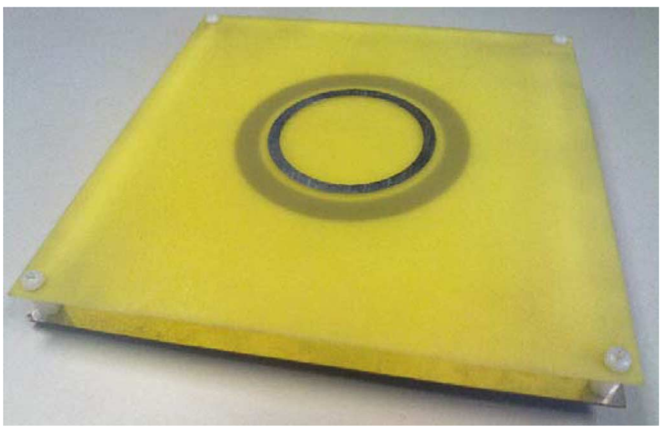

Fig. 4. Photograph of the fabricated antenna.

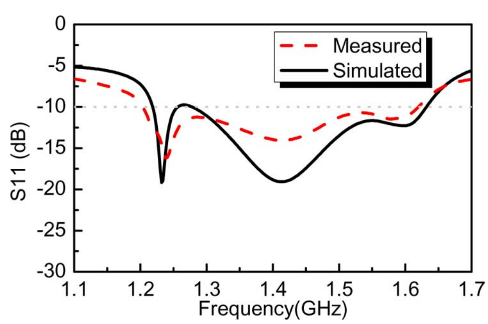

Fig. 5. Simulated and measured S_{11}.

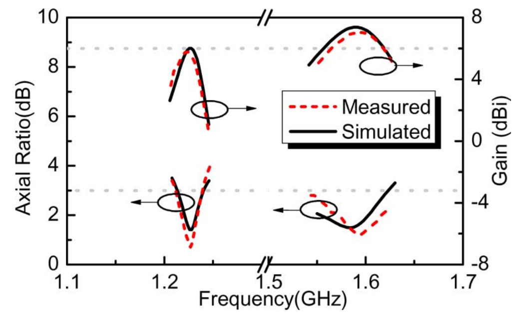

Fig. 6. Simulated and measured axial ratio and gain.

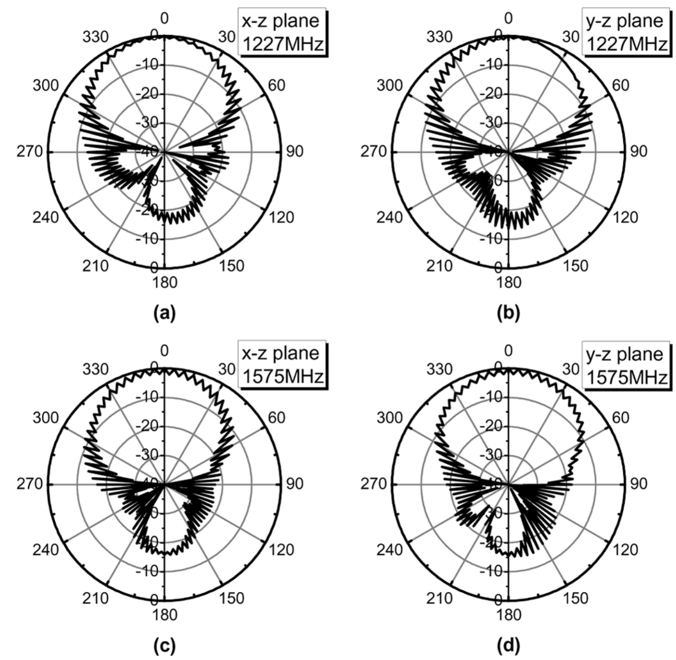

Fig. 7. Measured radiation pattern. (a) 1227 MHz at xz plane. (b) 1227 MHz at yz plane. (c) 1575 MHz at xz plane. (d) 1575 MHz at yz plane.

by only adjusting the gap between patches. When S is less than 2 mm, strong coupling exists between the two patches, which makes the frequency ratio increase and difficult to control.

IV. Simulated and Measured Results

The proposed antenna is fabricated and measured. Fig. 4 is a photograph of the assembled antenna. Fig. 5 shows the simulated and measured S_{11} with good consistency between them. Although good matching is observed from 1227 to 1575 MHz, not all of them are due to good antenna matching. Because a 3-dB hybrid is used, the 50-Ω load can absorb all reflected power even when the antenna works at mismatched frequency points. The AR of right-hand circularly polarized (RHCP) radiation at 1227 and 1575 MHz is 0.7 and 1.9 dB, respectively. Simulation and measurement of AR and gain at these two bands are presented in Fig. 6, in which relative axial-ratio bandwidths determined by 3-dB axial ratio are larger than 2%. About 6- and 7-dBi gains at the broadside of the antenna are illustrated at 1227 and 1575 MHz, respectively. Normalized radiation pattern at 1227 and 1575 MHz at xz plane and yz planes are plotted in Fig. 7, respectively.

V. Conclusion

A novel dual-band antenna structure of stacked annular-ring patches operated at GPS L1 and L2 frequencies, whose frequency ratio is 1.28, is presented in this letter. This antenna is excited by two orthogonal H-shaped apertures fed by a 3-dB hybrid. Relatively small dimensions are achieved by the application of the annular ring. It has relative axial-ratio bandwidths larger than 2% at both bands. Measured gains at the broadside direction at L1 and L2 are about 7 and 6 dBi, respectively. The method of varying the frequency ratio is also discussed in this letter.

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