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A New Omnidirectional Circular Polarization Microstip Antenna

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Abstract—The configuration of a new circularly polarized microstrip antenna with omnidirectional radiation pattern for GPS-L1 application is proposed in this paper. The designed antenna has a back-to-back rectangular-patch structure, and two patches are fed by coaxial cable connected with a Wilkinson power divider. The horizontal omnidirectional radiation pattern was achieved by both simulation and measurement. Axial ratio in the peak gain plane was around 3 dB ranging from 1.5 dB to 3.6 dB. The variation of RHCP gain in the horizontal omnidirectional circular polarization plane was smaller than ±1 dBic. And peak RHCP gain of the designed antenna was about 2.3 dBic.

1. INTRODUCTION

Omnidirectional circular polarization printed antenna had been invested for many years, because it not only highly increased the signal coverage area, but also improved immunity to multi-path distortion and polarization mismatch losses. Antenna presented in paper [1] consists of four printed arc dipoles that form a circular loop for horizontally polarized omnidirectional radiation with 31% bandwidth and 8 dBi peak gain; however, it was not for circular polarization application. Some early investigations for omnidirectional circular polarization microstrip antenna were concentrated on array of several circularly polarized microstrip antennas around a cylinder symmetrically in paper [2], and some were back-to-back coupled patch antennas fed by an orthogonal coplanar waveguide (CPW) in papers [3–6]. In paper [7], the back-to-back omnidirectional circular polarization microstrip antenna was achieved by using two ports without power divider, and radiation pattern could be rotated by a means of phase shift. All the previous works had achieved horizontal omnidirectional radiation pattern, and peak gain of the antennas was around 2 dBic and axial ratio on peak gain plan below 5 dB.

A new designed omnidirectional circular polarization antenna is proposed in this paper. The two truncated-corner patches of designed antenna were fed by coaxial cable connected with the power divider, which was different from any other previously done works. Using the power divider to generate two signals with the same amplitude and phase, which excited two back-to-back patches through coaxial cable. The designed antenna has horizontal omnidirectional circularly-polarized radiation pattern. The peak RHCP gain of the designed antenna was about 2.3 dBic and axial ratio on the peak gain plane around 3 dB ranging from 1.5 dB to 3.6 dB.

2. ANTENNA DESIGN

The designed antenna consists of four layers as shown in Figure 1(a), and two external layers are single-fed truncated-corner microstrip antennas with back-to-back structure, where s is the length of the square patch, c the truncated-corner length, d the length between the center point of the patch and the up edge of the substrate, and e the length of the feeding point away from the edge of the patch. Two internal layers turn out to be a classic Wilkinson power divider, and port 1 is fed with a SMA connector. The patches are connected with two ports of the power divider differently by coaxial probe.

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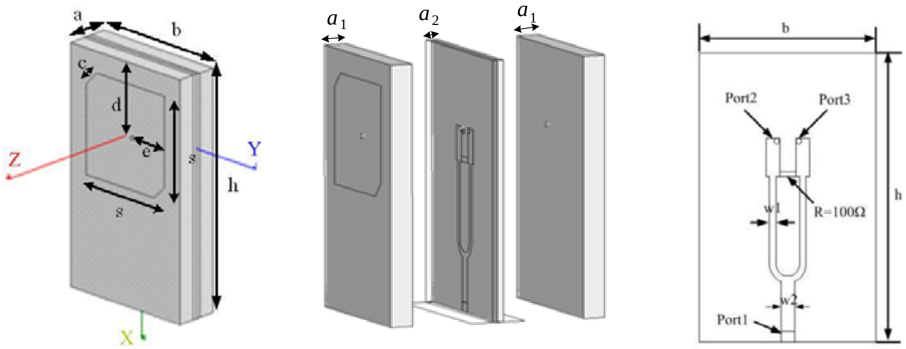

Figure 1. Model of the designed antenna.

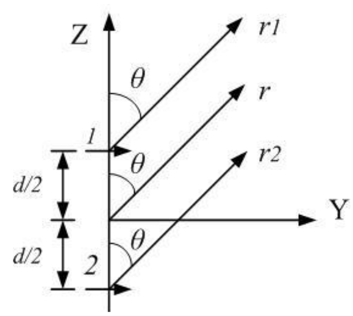

Figure 2. Geometry of a two-element array positioned along the z-axis.

Port 2 is used to feed the left microstrip patch shown in Figure 1(b), and port 3 feeds the right patch. The dielectric constant of the external layers is 16, thickness of the substrate $a_1 = 4\,\text{mm}$, and dielectric constant of the internal layers is 2.65, thickness $a_2 = 2\,\text{mm}$.

Assume that the antenna under investigation is an array of two circularly polarized microstrip antennas positioned along the z-axis, as shown in Figure 2. The total field radiated by the two elements, assuming no coupling and no difference in excitation between the elements, is equal to the sum of the two elements.

Electric field of circular polarization can be divided into two orthogonal linear electric fields, and time-phase difference between them is odd multiples of $\pi/2$. With the back-to-back structure, the distance between two elements $d = 0$ and $r_1 = r_2 = r$. So the electric field of element one in direction X can be given by:

$$E_1(\theta, x) = \frac{2aU_{01}}{\lambda_0 r}\, e^{-jk_0 r} \quad E_1(\varphi, x) = -j \cdot \frac{2aU_{10}}{\lambda_0 r}\, e^{-jk_0 r}$$

And electric field of element one in direction Y is given by:

$$E_1(\theta, y) = -j \cdot \frac{2aU_{01}}{\lambda_0 r}\, e^{-jk_0 r} \quad E_1(\varphi, y) = -\frac{2aU_{10}}{\lambda_0 r}\, e^{-jk_0 r}$$

Since elements one and two share one coordinate system, element two is left-hand circularly polarized compared with element one and with 180 deg phase delay at Y direction. So electric fields of element two in directions X and Y are given by:

$$E_2(\theta, x) = E_1(\theta, x) = \frac{2aU_{01}}{\lambda_0 r}\, e^{-jk_0 r} \quad E_2(\varphi, x) = j \cdot \frac{2aU_{10}}{\lambda_0 r}\, e^{-jk_0 r}$$
$$E_2(\theta, y) = -j \cdot \frac{2aU_{01}}{\lambda_0 r}\, e^{-jk_0 r} \quad E_2(\varphi, y) = -\frac{2aU_{10}}{\lambda_0 r}\, e^{-jk_0 r}$$

Because radiation patch has the same width and length, $U_{01} = U_{10}$ is achieved. The orthogonal linear electric fields in X direction (theta $= \pm 90$ deg) are $E(\theta, x) = E_1(\theta, x) + E_2(\theta, x) = \frac{4aU_{01}}{\lambda_0 r} e^{-jk_0 r}$,

$E(\varphi, x) = E_1(\varphi, x) + E_2(\varphi, x) = 0$, so antenna pattern is linear at theta $= \pm 90$ degrees. And two orthogonal linear electric fields $E(\theta, y) = -j \cdot \frac{4aU_{01}}{\lambda_0 r} e^{-jk_0 r}$ and $E(\varphi, y) = -\frac{4aU_{10}}{\lambda_0 r} e^{-jk_0 r}$ in Y direction have the same magnitude and time-phase difference of odd multiples of 90 deg, so the designed antenna is circularly polarized in direction Y.

The design procedure of the antenna is mainly divided into three steps:

(1) Design the single microstrip patch and place two patches symmetrically along the YOZ plane. Make sure that each patch works in GPS-L1 band.

(2) Design the power divider of the antenna. Two output ports must have the same amplitude and phase.

(3) Combine power divider with two patches and tune the whole antenna structure to guarantee that designed antenna performs perfectly.

3. RESULTS

The structure was modelled using Ansoft HFSS. The parameters of the optimized antenna are as follows (mm): $a = 6$ mm, $b = 32$ mm, $c = 2.4$ mm, $d = 16$ mm, $e = 9.35$ mm, $s = 22.7$ mm, $h = 52.6$ mm, $w_1 = 1.2$ mm, $w_2 = 2.5$ mm.

Figure 3 shows the object of the designed antenna connected with a SMA connector.

Gain of the circularly polarized designed antenna is determined by measuring the partial gains for two orthogonal linear polarizations. First, the polarizations of the linearly polarized source and reference antenna are set horizontally, and the gain G_H is measured, then the measurement is repeated for vertically polarized source and reference antenna, and the gain G_V is obtained. The total gain is the sum of the two partial gains. Figure 4 shows the antenna under test placed on a rotating platform in the anechoic chambers.

Figure 5 shows the simulated and measured S_{11}. Bandwidth of the simulated result is about 16 MHz, and that of the measured one is about 25 MHz. Typically, practical designs bandwidth limit of microstrip antenna is from 2% to 5%, which is 31 MHz to 78 MHz at GPS-L1 band (center frequency is 1.57542 GHz), because of which, both simulated and measured S_{11} are acceptable.

In order to simulate mutual coupling between two patches, power divider is removed from the designed antenna. Figure 6 shows simulated S_{11} and S_{12} of the antenna without power divider, and two patches are fed by port 1 and port 2 differently. The level of mutual coupling between two patches is lower than -12 dB at GPS-L1 band.

Figure 7 shows the simulated radiation patterns when *phi* $= 90$ deg. The RHCP radiation pattern is dominant, so the designed antenna is right-hand circularly polarized. And RHCP pattern is 13 dB bigger than LHCP pattern. Simulated and measured RHCP gain patterns against theta when *phi* $=$ 0 deg and *phi* $= 90$ deg also can be found in Figure 7. Both simulated and measured radiation patterns at *phi* $= 90$ deg plane are omnidirectional, and half-power beamwidth is 90 deg from *theta* $= -45$ deg to *theta* $= 45$ deg. Simulated peak RHCP gain is 2.5 dBic, and that of the measured one is 2.3 dBic.

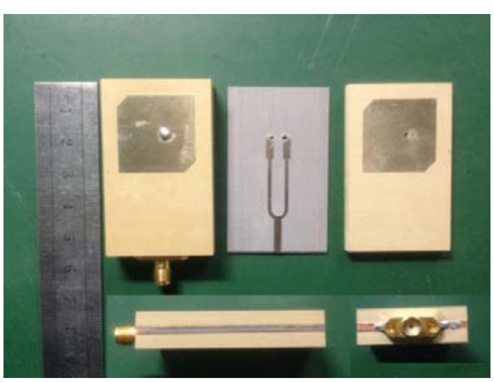

Figure 3. Object of the designed antenna.

Figure 4. Antenna under test.

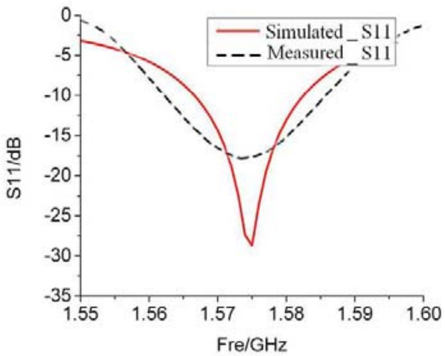

Figure 5. Simulated and measured S_{11}.

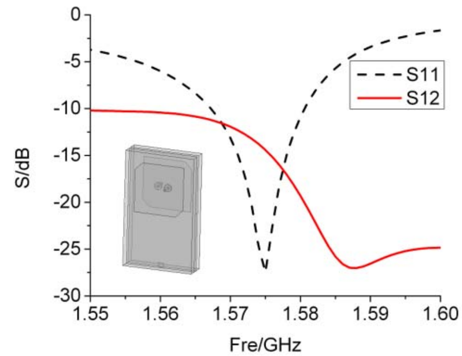

Figure 6. Simulated S_{11} and S_{12} without power divider.

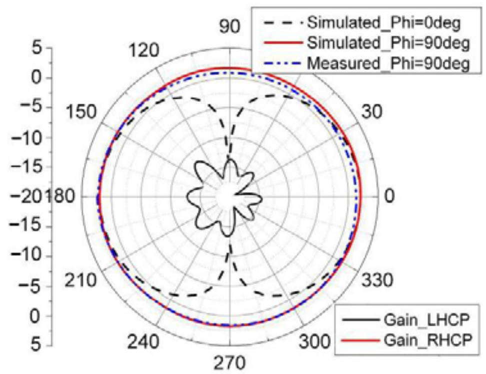

Figure 7. Simulated and measured gain pattern.

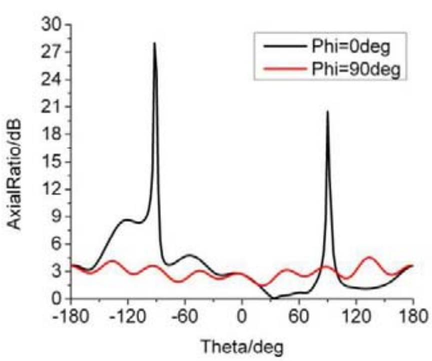

Figure 8. Axial ratio on *phi* = 0 and *phi* = 90 plane.

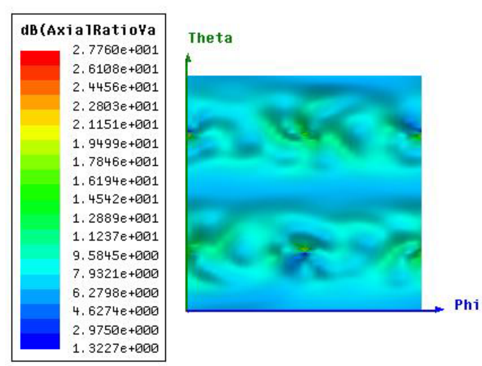

Figure 9. Axial ratio in the 3D radiation sphere.

The variation of the gain in the horizontal plane is in the range of ±1 dBic. Simulated directivity is 2.9 dBic, and measured gain is 2.3 dBic, so efficiency of the antenna is about 87%.

Figure 8 shows the axial ratio of the antenna with theta when $phi = 0$ deg and $phi = 90$ deg. AR in main radiation plane ($phi = 90$ deg) changes back and forth around 2.6 dB ranging from 1.5 dB to 3.6 dB, and 3 dB RHCP beamwidth on $phi = 0$ deg is 60 deg.

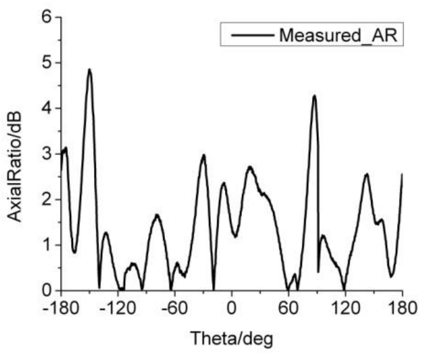

Figure 10. Measured AR on $phi = 90$ deg plane.

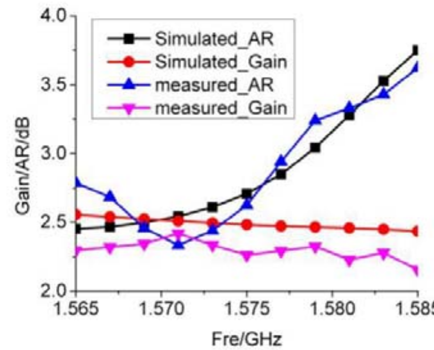

Figure 11. Simulated and measured gain/AR against frequency.

Figure 9 shows the AR in the whole radiation sphere. X axis is about *phi* changing from 0 deg to 360 deg and Y axis about theta changing from 0 deg to 360 deg. The value of the AR is reflected with different colors.

Figure 10 shows the measured AR against theta on $phi = 90$ deg plane, and percentage of AR lower than 3 dB is more than 90% on this plane.

Figure 11 shows the simulated and measured gain/AR against frequency in the direction of positive Z axis. Measured results agree well with the simulated ones, and both simulated and measured results show that RHCP gain will decrease with the increase of axial ratio. Bandwidth of AR lower than 3 dB is 15 MHz, and absolute gain of the designed antenna at center frequency is more than 2.2 dBic. Measured gain is lower than that of simulated one because of the loss of power divider.

4. CONCLUSION

A new omnidirectional circular polarization microstrip antenna is proposed in this paper. The designed antenna is with a back-to-back structure, and the two rectangular patches are fed by coaxial cable which is connected with the Wilkinson power divider. The antenna has horizontal omnidirectional circularly-polarized radiation pattern. Peak RHCP gain of the antenna is about 2.3 dBic, and axial ratio on the peak gain plan is around 3 dB ranging from 1.5 dB to 3.6 dB.

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