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Bandwidth and Gain Enhancement for Probe-Fed CP Microstrip Antenna by Loading with Parasitical Patches

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Abstract—A novel probe-fed single-layer circularly polarized (CP) truncated microstrip antenna with enhanced CP bandwidth and gain is presented in this paper. The axial ratio (AR) bandwidth is broadened by loading with a circle of eight truncated square parasitical patches. Parameter analysis is made to investigate the effect of the loading structures on the AR property. For comparisons, both the unloaded and loaded truncated patch antennas with the same size are designed, fabricated and measured. The measurement results show that by adding the parasitical patches, the -10 dB impedance bandwidth was increased from 0.98 GHz (15.9%) to 1.42 GHz (21.5%), among which the 3-dB RHCP AR bandwidth has been increased from 200 MHz (3.3% at the center frequency of 6.04 GHz) to 780 MHz (12.6% at the center frequency of 6.19 GHz). The gain enhancement is about 0.5 dB $\sim$ 1.5 dB around the operating frequency range, and the maximum gain of the proposed antenna is about 9.1 dB. With the advantages of simple structure, wide CP bandwidth and considerable gain property, this antenna has potential application in wireless communications.

1. INTRODUCTION

With the advantages of better mobility, reduction in multipath reflections and stable signal quality between the transmitting and receiving devices, circular polarized (CP) antennas are widely used in the satellite communication, radar tracking, global positioning system (GPS), and radio frequency identification (RFID) systems. Microstrip antennas (MPAs) are one choice to design CP antennas for their advantages of flat shape, light weight, and low production cost. However, narrow impedance bandwidth and axial ratio (AR) bandwidth are the main disadvantage of the CP MPAs.

Several methods are used to solve the bandwidth problem. Dual- or multi-feed type can be adopted to increase the CP bandwidth. However, new feeding networks including additional circuit with power dividers or couplers are needed at the expense of complicating the antenna structure. Thus single-feed type is preferred for its compactness. However, the single-feed patch antenna suffers from inherently narrow AR and impedance bandwidths (1%–3%) [1–3].

The techniques used to ease this problem can be divided into two types. On one hand, radiating patches with suitable slots/stubs or stacked parasitical patches are designed to broaden the CP bandwidth. For example, slots with U-shape, E-shape or other shapes are proposed to generate CP radiation with AR bandwidth of more than 5% [4–6]. Air layer/foam substrate or stacked patches can also be used to increase the CP bandwidth at the expense of using thicker volume [7–10]. On the other hand, other single-feed techniques such as L-probe feed [11], C-type single feed [12], capacitive coupled feeds [13, 14], aperture coupling feed [15], and meandering probe (M-probe) feed [16, 17] can be used to improve the AR bandwidth of a patch antenna. Nevertheless, dual- or multi-layers are needed to design

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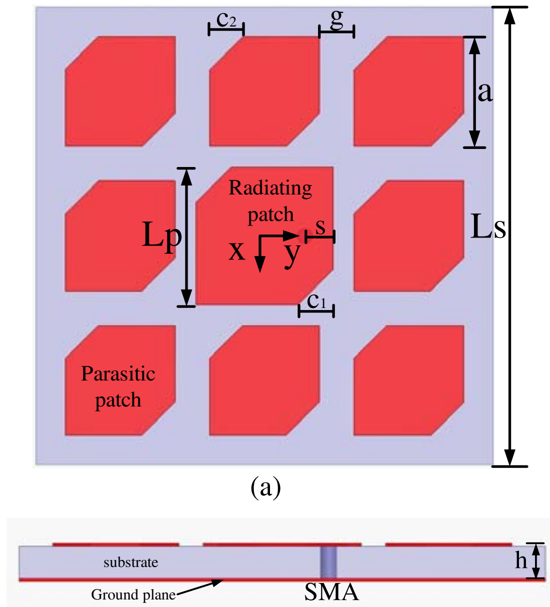


Figure 1. Geometry of the proposed broadband microstrip antenna: (a) top view and; (b) side view.

such kind of antennas which is not simple enough and may cause difficulty in compact array realization at higher frequencies.

Adding co-planar parasitical patches is one technique can be adopted to improve the antenna bandwidth by the mutual coupling effect [18]. As we know, probe-fed single-layer microstrip antenna with wide impedance bandwidth and high gain properties can be achieved by loading with parasitical patches. The impedance bandwidth of the loaded one can be much wider than the unloaded type [19–21]. However, the CP case was not realized. In this paper, co-planar parasitical patches are added for broadening the CP bandwidth of truncated microstrip antenna. Parameter analysis is made to optimize the antenna, and the 3-dB AR bandwidth has been increased from 200 MHz (3.3% at the center frequency of 6.04 GHz) to 780 MHz (12.6% at the center frequency of 6.19 GHz) without increasing the antenna size. Meanwhile, the gain enhancement is about 0.5 dB $\sim$ 1.5 dB around the operating frequency range. The antenna is valuable in wireless communication systems for its extreme simple structure and wide CP bandwidth property.

2. ANTENNA DESIGN AND PARAMETERS ANALYSIS

2.1. Antenna Structure

The perturbation method is often used to excite the CP on the patch antenna. Truncated radiating patch is adopted to introduce two linear polarized (LP) degenerate modes perpendicular to each other and in phase quadrature. The polarization of the antenna can be changed from LP to CP by tuning the feeding position and the truncated geometry. The proposed antenna is shown in Fig. 1. The truncated square patch has a length of Lp and is printed on a substrate with thickness h, length Ls and relative permittivity $\varepsilon_r = 2.2$. Around the radiating patch eight co-planar truncated square parasitical patches with a size of a arranged in a square circle are printed on the upper plane of the same substrate, and the gap between each unit parasitical patch is g. The radiating patch, the square circle of parasitical patches and the substrate own the same coordinate center. The distance S between the location of the feed probe and the edge of the radiating patch can be optimized to obtain a good impedance match. Actually the antenna operates at two different resonant frequencies which are determined by the size of the radiating patch and the parasitical patches, respectively. Broad impedance bandwidth can be obtained by merging the two resonant points. The gap between the radiating patch and the parasitical patches is another vital factor which influences the impedance matching condition. For simplicity, it will not be discussed in detail here. The size of the truncated geometry c_1, c_2 for the radiating patch and co-planar parasitical patch, respectively, are the vital parameters determining the CP performance. The detailed parameter analysis for the CP characteristics is given in the next section.

2.2. Parameter Analysis

Parameter analysis is done for further understanding the working principle of the antenna. The vital parameters are analyzed with other parameters unchanged. Fig. 2 shows the simulated results of the proposed antenna with various truncated sizes for the radiating patch c_1, from 3.6 mm to 4.0 mm. The same as conventional unloaded truncated patch antenna, the truncated size plays a role on both the impedance matching and AR bandwidth for the loaded antenna, especially for the first resonant frequency point of the proposed type. However, the antenna gain is not influenced much.

Figure 3 shows the simulated results of the proposed antenna with various truncated sizes for the parasitical radiating patches c_2, from 3.4 mm to 3.8 mm. It can be found that both S-parameters and gain property are not affected much. However, the AR performance can be adapted in some extend by this factor. Based on the analysis above, the antenna performance can be optimized by tuning the truncated size of the radiating patch and co-planar parasitical radiating patches step by step. The results

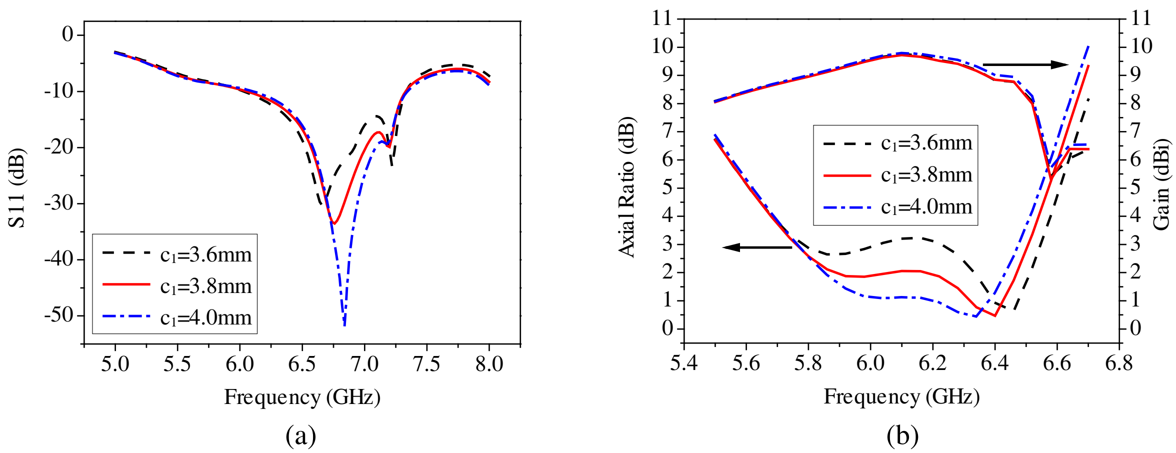


Figure 2. Simulated results of the proposed antenna with various truncated size for radiating patch c_1, other parameters are the same as listed in Table 1. (a) S_{11}; (b) AR and gain.

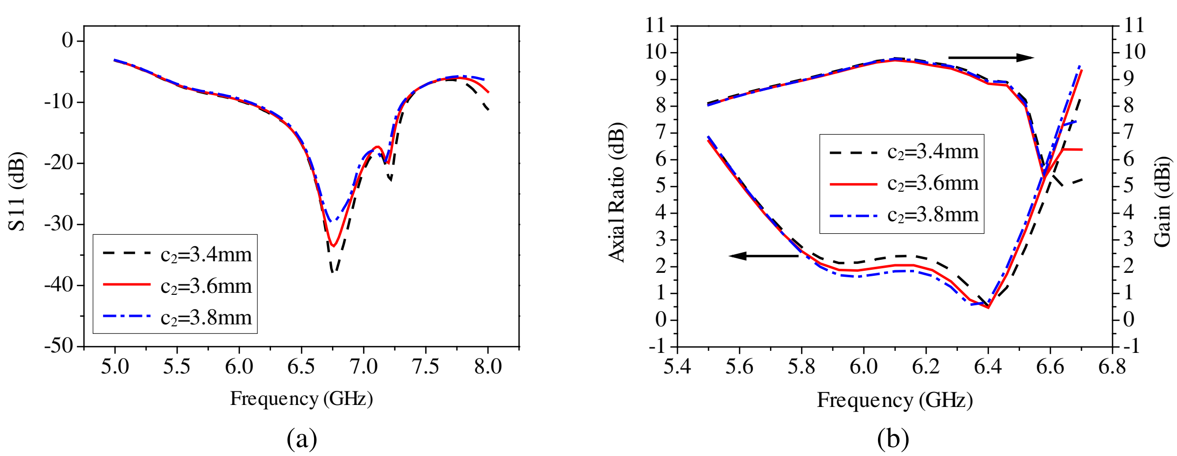


Figure 3. Simulated results of the proposed antenna with various truncated size for the parasitical radiating patches c_2, other parameters are the same as listed in Table 1. (a) S_{11}; (b) AR and gain.

show that the two linear polarized (LP) degenerate modes can be tuned by the truncated geometry of both the radiating patch and co-planar parasitical patches.

For comparisons, the unloaded truncated square patch antenna is also designed, and the results are given in Fig. 4 and Fig. 5. It can be found that S-parameter shifted a little to the higher band with the $-10\,\text{dB}$ impedance bandwidth increased from 1.26 GHz to 1.32 GHz by adding the parasitical patches, which is shown in Fig. 4. Fig. 5 shows the axial RHCP AR curve and gain curve of the antenna. With the truncated part in the orthogonal direction, LHCP can be realized accordingly. Compared

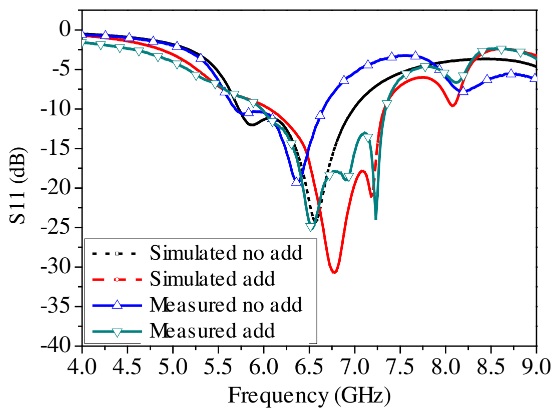
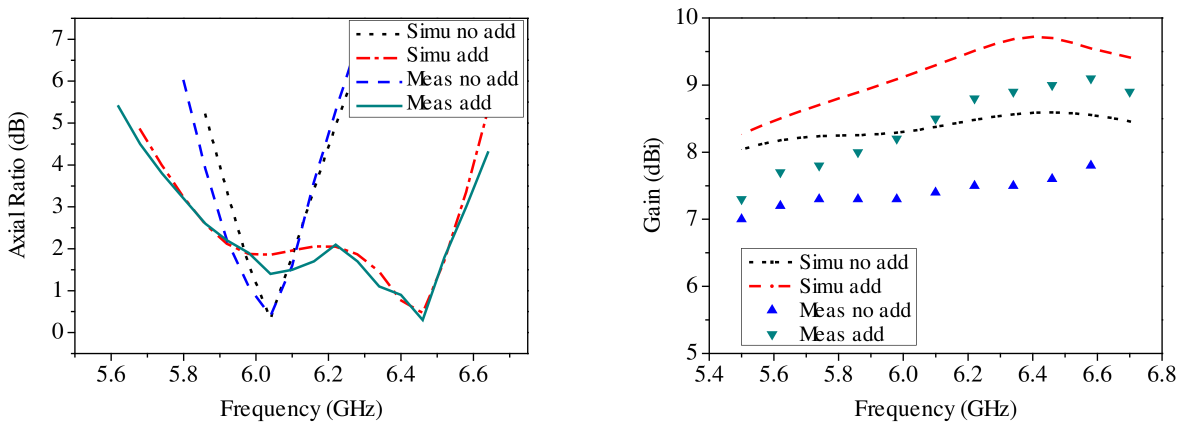
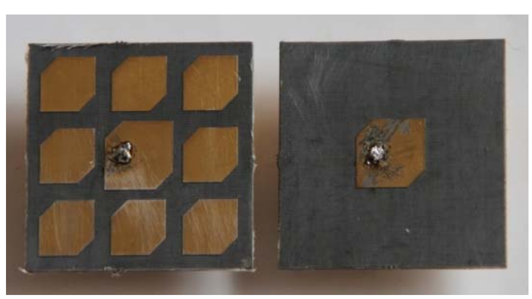


Figure 4. Simulated and measured reflection coefficients of the two antennas.



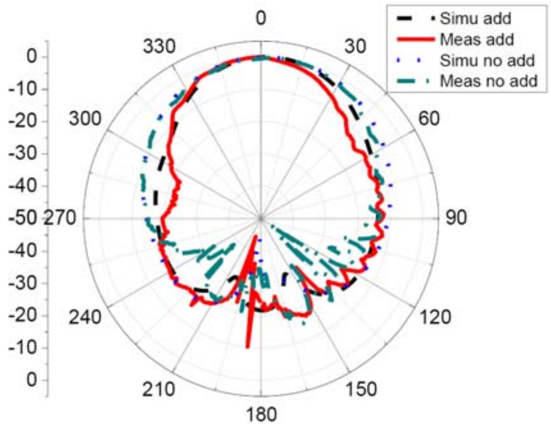
(a) (b)

Figure 5. The simulated and measured far field results of the two antennas: (a) AR; (b) Gain.

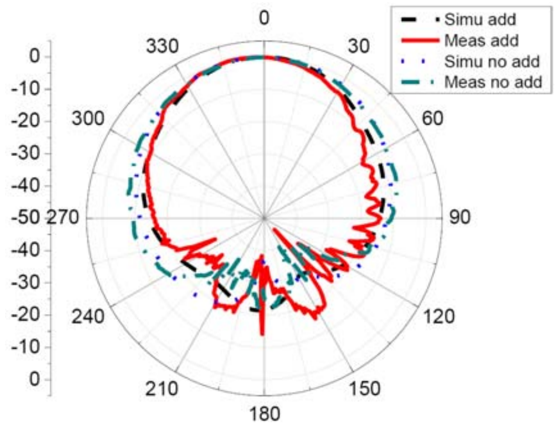


(a) (b)

Figure 6. Photos of the proposed antenna. (a) loaded type; (b) unloaded type.



(a)



(b)

Figure 7. Simulated and measured radiation patterns of both the proposed antenna and the unloaded type at 6.1 GHz: (a) YOZ-plane; (b) XOZ-plane.

Table 1. Parameters of the antenna (unit: mm).

Ls	g	a	Lp	h	c_1	c_2
50	2.3	12	15	3	3.8	3.6

with unloaded antenna, the 3 dB AR bandwidth of the loaded type was broadened quadruplely, from 190 MHz to 780 MHz, while gain enhancement about 0.5 $\sim$ 1.6 dB is achieved around the operating frequency range. This is because the field distribution of the proposed antenna is more uniform, which is like an antenna array owning more effective aperture efficiency within the radiating area. Thus gain enhancement can be realized accordingly.

3. RESULTS AND DISCUSSION

As shown in Fig. 6, prototypes of both unloaded and loaded antennas are fabricated to validate the predictions. The loaded and unloaded types are shown in the left and right sides, respectively. Based on the HFSS simulation software, the parameters of the two antennas are optimized and given in Table 1. An Agilent N5230A network analyzer is used to measure the S-parameters. For comparison, both the simulated and measured reflection coefficients of the two antennas are given in Fig. 4. The results show that by adding the parasitical patches, the -10 dB impedance bandwidth was increased from 0.98 GHz (15.9%) to 1.42 GHz (21.5%). The measured bandwidth of the unloaded type is little narrower than simulated one, and that of the loaded type is a little wider than the simulated results. The discrepancy may be attributed to the fabrication toleration and measurement errors. However, the agreement between the measured and simulated results is acceptable.

Figure 5 shows both the simulated and measured far-field results of the two antennas at the axial direction. The measured 3-dB AR bandwidth has been increased from 200 MHz (3.3% at the center frequency of 6.04 GHz) to 780 MHz (12.6% at the center frequency of 6.19 GHz). The gain enhancement is about 0.5 dB $\sim$ 1.5 dB around the operating frequency range, and the maximum gain of the proposed antenna is about 9.1 dB, which is described in Fig. 5(b). Measured gains of the antennas are a little lower than the simulated ones. The difference between the simulation and measurements can be explained as follows: (a) the fabrication toleration such as the SMA soldering; (b) the loss from the substrate including the unexpected loss from the material and the metal loss from the radiating patch and the ground plane; (c) the measurement errors such as the measurement environment and the mount effect. Finally, the measured radiation patterns were taken at 6.1 GHz for both YOZ and XOZ planes, shown in Fig. 7, and verify the bore-sight radiation characteristic. Good agreement between the simulated and measured results can be obtained. It can be found that the beamwidth of the proposed antenna is narrower than the unloaded type with the half-power beamwidth (HPBW) decreased for about $15^\circ \sim 25^\circ$ in the two planes.

4. CONCLUSION

In this paper, a simple probe-feed CP patch antenna with enhanced AR bandwidth is proposed. By loading with a square circle of truncated square parasitical patches around the truncated radiating patch, the 3 dB AR bandwidth of the proposed antenna was about four times wider than the unloaded antenna, and the gain enhancement is about $0.5\,\mathrm{dB} \sim 1.5\,\mathrm{dB}$ around the operating frequency range. Both antennas are designed and fabricated. The measured results confirm the analysis. Besides truncation method, other perturbation methods, such as adding slots or stubs, can also be introduced to design broadband CP patch antennas with an extremely simple structure. This co-planar parasitical concept can be used to design novel antennas with multi-function applied in the wireless communication systems in future.

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