Single-feed Circularly Polarized Microstrip Antenna Loaded with a Periodic Structure Superstrate

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1. Introduction

Circularly polarized antennas (CPAs) are an interesting option for satellite and wireless communication systems. Microstrip patch antennas (MPAs) have been widely used as radiating elements in CPAs. There are two commonly used feeds for circularly polarized microstrip antennas (CP-MPAs), namely a single-feed and a dual-feed. Although the axial ratio (AR) bandwidth of single-feed CP-MPAs is narrow, they are very attractive because they allow a reduction in the complexity and RF loss of feeding network. There are many methods reports in the literature on single-feed CP-MPAs : square patch with truncated corners [1], U-slotted rectangular patch [2], and circular patch with slits [3]. Yo *et al*. [4] proposed an interesting method to get circular polarization by embedding two circular slots in the circular patch. However, the 10-dB return-loss and 3-dB AR bandwidths (ARBW) are only 5.6% and 1.3%, respectively. Therefore, many researchers are exploring methods and techniques to achieve wideband polarization characteristics, as well as wideband impedance bandwidth (ZBW) for CP-MPAs [5]-[6]. One technique for achieving wideband MPAs is the use of stacked elements or parasitic superstrate [5]. When the two or more layers are designed for the same frequency and polarization, an increase in bandwidth can be obtained. However, relatively few papers have provided detailed information for the CP-MPA. Most of the papers related to the studies of the superstrate effects are only for linearly polarized MPA (LP-MPA) and single-element of stacked patch. A combination of CP-MPAs with the periodic structures including frequency selective surface (FSS) [7] and electromagnetic bandgap (EBG) [8] has been fruitful. Using the filtering properties of such structures, it is possible to reduce surface wave, to achieve wide band and high gain. This has motivated us to study a periodic structure superstrate-loaded CP-MPA.

As one half-wavelength ($\lambda/2$) separation between FSS and ground plane is required for high gain CP-MPA antenna, it inevitably increases the profile and stringently limits the operation bandwidth of the antenna. A first work of the authors of this paper [9] has explored the possibility of using a periodic structure in a CP-MPA to achieve simultaneously ZBW, ARBW and gain enhancement. That work proved that it was possible to get such enhancement. In this paper, the wideband and yet low-profile technique of periodic structure superstrate is proposed. The working bandwidth of a 2.45 GHz single-feed CP-MPA is significantly enhanced. The dimensions of antenna are optimized to achieve good ARBW and ZBW using CST and IE3D.

2. Antenna Configuration and Design

The configuration and photograph of the proposed antenna is shown in Fig. 1. It consists of a periodic structure superstrate (PSS) of 4×4 square rings joined with diagonal-strips (SQR-DS) over a CP-MPA. The driven CP-MPA comprises a circular microstrip patch with two separated circular slot. The geometry of the CP-MPA was modified from the design presented in [3]. The driven CP-MPA and PSS are designed at the center frequency of 2.45 GHz on inexpensive FR4 substrate. The two layer structures are of the same material with a thickness h_1 = 1.6 mm and h_2 = 0.8 mm with a dielectric constant ε_r = 4.2. For periodic structure design, the dimensions of unit cell (period *p* and metallic square *a*) have been calculated by modelling a single unit-cell with a periodic boundary condition using the CST Microwave Studio. These dimensions were based on the paper [9] in which the characteristics of such periodic structure are detailed. The PSS is above the CP-MPA of 7.5 mm, which is about $\lambda_o/16$ at the 2.45 GHz. The ground plane size is 108 × 108 mm^2. The overall dimensions of the proposed antenna is 0.86 $\lambda_o \times 0.86\lambda_o \times 0.07\ \lambda_o$.

3. Simulation and Measurement Results

To validate the design principle, a prototype antenna was fabricated and measured. Figure 2 (a) presents the simulated and measured results of the return loss for the CP-MPA with PSS, and simulated one for the CP-MPA alone case. It is clearly seen that the return loss of the CP-MPA with PSS is deeper than the CP-MPA alone. For the ZBW defined by 10-dB return loss (RL), the CP-MPA with PSS provides an ZBW of 240 MHz (2.32-2.56 GHz), or 10%, which is about 4 times wider than the corresponding CP-MPA alone (60 MHz or 2.44 %). It is observed that the measured results toward the higher frequency, while maintaining similar response. The discrepancy between the measured and simulated results could be due to the fabrication tolerance and the use of FR4 substrates. Besides, the ARBW and realized gain are also presented. The comparison of the simulated and measured results of the CP-MPA, along with PSS as well as the CP-MPA alone is given in Fig. 2 (b). We note that bandwidth for AR≤ 3 dB is increased from 1% to 10% by adding the PSS. The ARBW of the CP-MPA with PSS is 11.4% (290 MHz, 2.32-2.61 GHz), whereas for the CP-MPA alone, it is only 1.22% (30 MHz, 2.43-2.46 GHz), implying an improvement of 867%. It attains a reasonable gain level around 7.5-8.0 dBi across the overlapped frequency band.

In order to investigate the gain improvement by use of the PSS, the distributions of the simulated electric field at 2.45 GHz for the CP-MPA with and without the PPS are presented in Fig. 3. It is observed that the PSS has a focusing effect. The phase distributions of the electric field with the PSS are observed to be more uniform than one without the PSS leading to an increase in effective aperture area and gain. Figure 4 shows the measured far-field radiation patterns in the SATIMO near-field anechoic chamber at the Chinese University of Hong Kong. The antenna excites left-hand CP (LHCP) and the cross polarization is right-hand CP (RHCP). Very good broadside radiation patterns are observed and the cross-polarization in the principal planes is seen to be less than -20 dB.

4. Conclusion

With the use of a periodic structure superstrate, a wideband and high gain CP-MPA was designed. The utilization of the proposed periodic structure as superstrate not only significantly enhances its gain, impedance and AR bandwidths, but it also reduces the antenna profile. The fabricated prototype attained an overlapped bandwidth (RL ≥ 10 dB and AR ≤ 3 dB) of 10.1% (2.328-2.576 MHz). Average gain of 8 dBi has been achieved across the overlapped bandwidth. The 20 dB difference can be observed between LHCP and RHCP radiation. From measured results, the front-to-back ratio is more than 30 dB.

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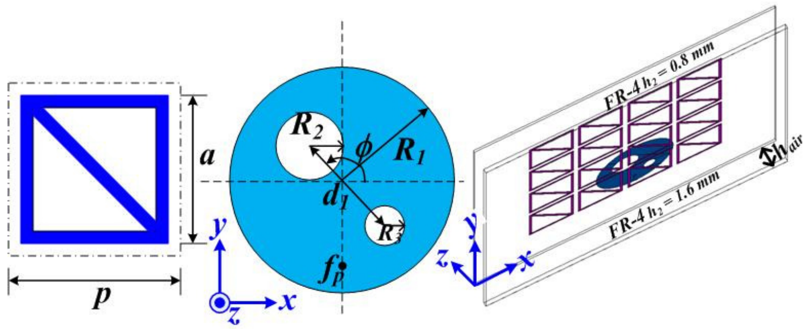
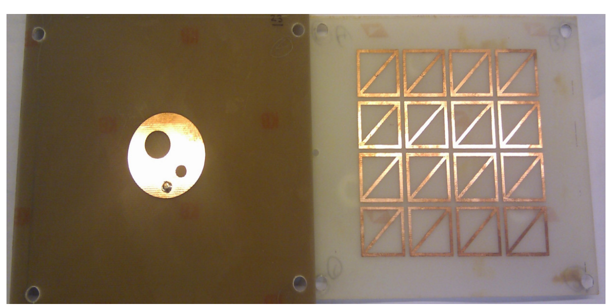
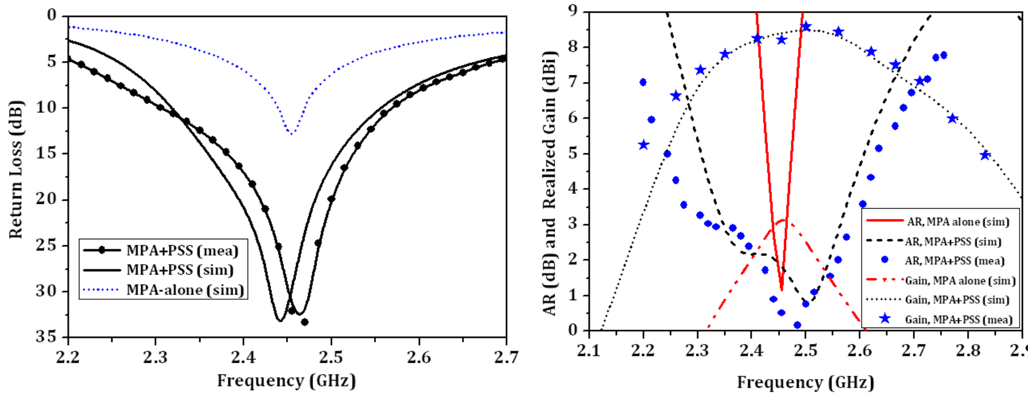


(a)



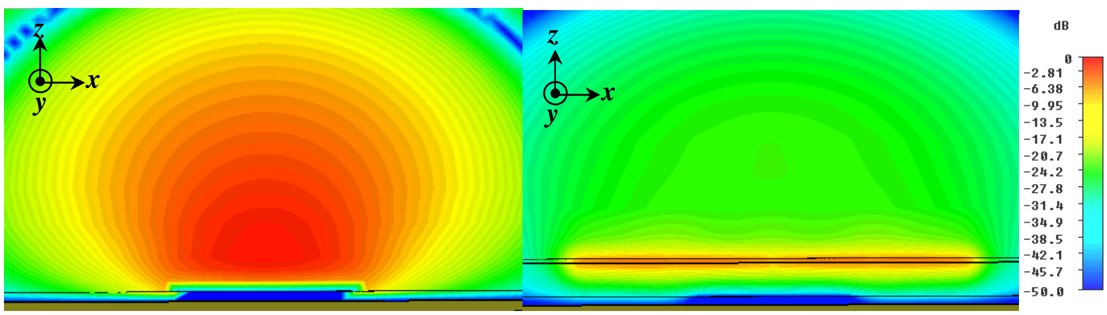
(b)

Figure 1: (a) Unit cell of PSS and antenna configuration and (b) the photograph of the proposed antenna. Geometry parameters are (dimensions: mm) : p = 20, a = 18, R_1 = 15.6, R_2 = 5.4, R_3 = 2.4, d_1 = 13.8, f_p =11, ϕ = 135°, h_{air} = 7.5.



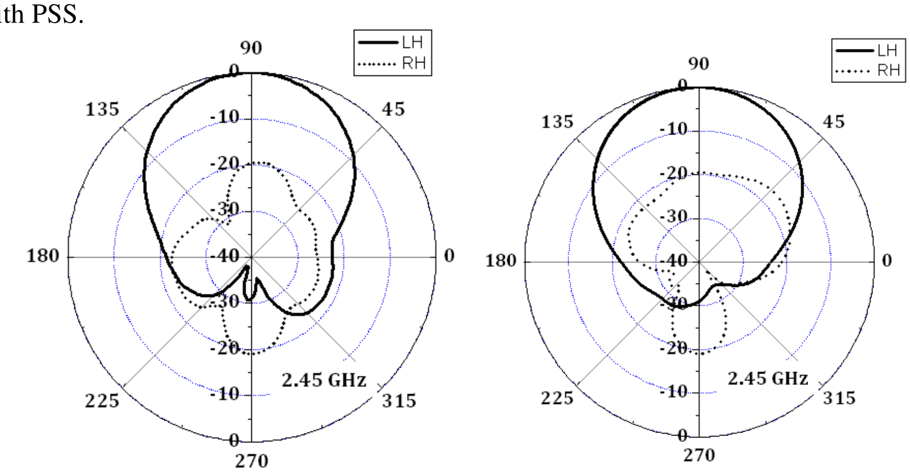
(a) (b)

Figure 2: Comparison of simulated and measured results of the CP-MPA with PSS and CP-MPA alone (a) return loss and (b) AR and realized gain.



(a) (b)

Figure 3: Distributions of the electric field at 2.45 GHz of antennas (a) CP-MPA-alone and (b) CP-MPA with PSS.



(a) (b)

Figure 4: Measured radiation patterns of antenna in two orthogonal planes at 2.45 GHz (a) x-z plane (b) y-z plane.