ELectronics EXpress

IEICE Electronics Express, Vol.9, No.2, 117–121

Directivity enhancement of circularly polarized microstrip antennas by chiral metamaterial covers

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Abstract: This paper presents the application of chiral metamaterial covers for improving the circularly polarized microstrip antenna performance. Semi-planar chiral metamaterial structures with a near zero refractive index are designed and utilized for enhancing the directivity of circularly polarized single and array patch antennas. Numerical results show that the directivity of the antennas is significantly improved.

Keywords: chiral metamaterial, circular polarization, microstrip antenna, directivity enhancement

Classification: Microwave and millimeter wave devices, circuits, and systems

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DOI: 10.1587/elex.9.117
Received November 21, 2011
Accepted December 15, 2011
Published January 25, 2012

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1 Introduction

Recently, metamaterials (MTMs) have attracted much attention due to their interesting properties such as negative refraction. The applications of metamaterials have been widely spread in many fields. One of the important applications of MTMs is directivity enhancement in antennas [1, 2]. In most cases, the antennas with linear polarization were considered. For instance, conventional metamaterials with low refraction property were used to achieve directive emission in dipole, microstrip and horn antenna configuration.

Chiral metamaterials (CMMs) have been proposed as an alternative for realizing the negative refraction index for circularly polarized (CP) waves in recent years. In fact, negative refraction can be realized in CMMs with a strong chirality, requiring neither negative ε nor negative μ. So far, several structures of chiral metamaterial such as twisted rosettes, twisted crosses, twisted U-SRRs, conjugated gammadion and L-shape have been proposed at microwave and optical frequencies [3, 4].

In this paper, first, the design method of CMMs with near zero refractive indices is presented at the desired frequency. Then, the effects of this cover on the performance of CP single and array patch antennas are examined. At the end, this paper is finished by a conclusion section.

2 Design of CMM covers

In order to investigate the effects of CMM covers on microstrip antennas, two covers are designed based on a twisted crosses unit cell [4] (Fig. 1 (a)). It is known that right-handed circularly polarized (RCP) and left-handed circularly polarized (LCP) waves are the eigen-states of the wave equation for chiral media [5]. The transmissions of RCP and LCP waves, $T_{\pm}$, and reflections, $R_{\pm}$, should be calculated for extracting their refractive indices. Therefore, numerical simulations are executed in the frequency range of 1 to 15 GHz using the frequency domain solver of CST Microwave Studio. Then, using a parameter retrieval method [6], the real and imaginary parts of RCP and LCP refractive indices are calculated as shown in Fig. 1 (b). It can be clearly seen that both of the refractive indices are almost zero at the frequency range around 10.3 GHz.

By changing the dimensions of the unit cell along the length and width, zero refractive indices can be obtained at the desired frequency. For example, by increasing the scale of the unit cell to 13 times, refractive indices are calculated as depicted in Fig. 1 (c). According to these results, the near zero refractive indices are seen at the frequency range around 1.25 GHz.

Consequently it is expected that the two mentioned covers can be used for directive emission at the mentioned frequencies due to the focusing effect. It is notable that these results are exact for a very large cover consisting of many unit cells. However, dimensions of the covers should be practically in the order of the antenna size. Therefore, the retrieved results should be considered as an initial value for an optimization process in order to achieve the optimum radiation characteristics.

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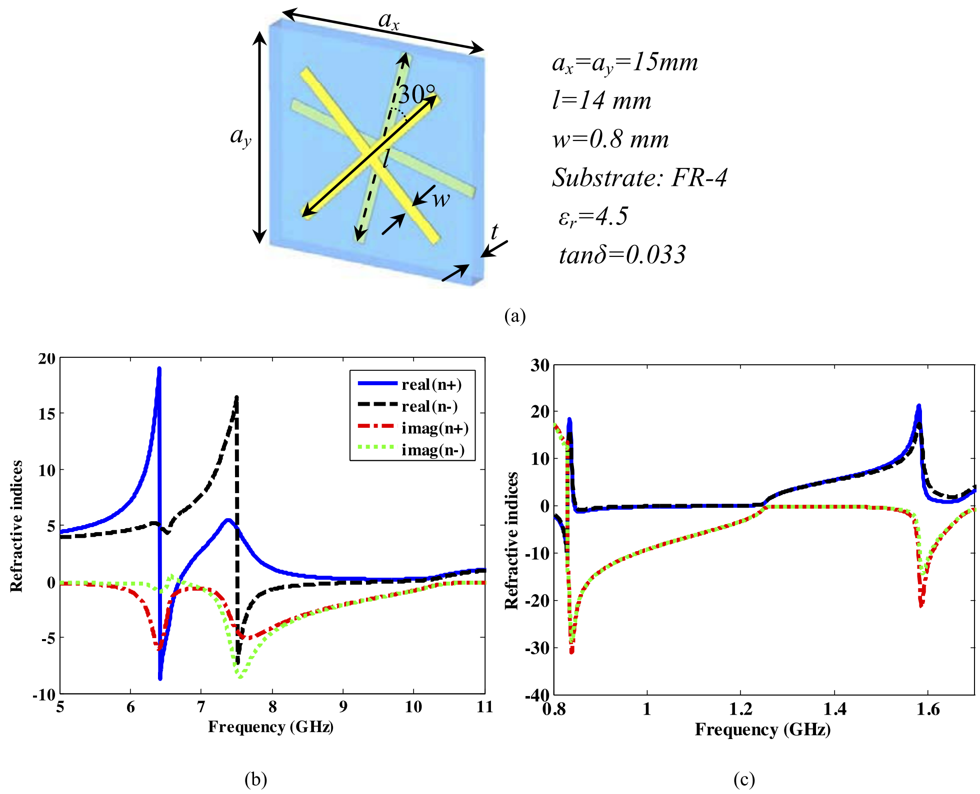

Fig. 1. (a) Structure of the twisted crosses unit cell (b) refractive indices of it, (c) refractive indices with increasing the scale of the unit cell to 13 times.

3 Numerical results and discussions

3.1 CP single patch antenna

For verification purpose, the first cover of the previous section is used for single patch with circular polarization. A single-feed LCP microstrip antenna is designed at 9.8 GHz by embedding a narrow slot located at the center of the circular microstrip antenna with an intersecting angle of 45° relative to the feed loci. Afterwards, the CMM cover is added to the antenna configuration as shown in Fig. 2 (a) and the space between them is optimized in order to obtain the best gain and AR results.

The numerical simulation shows that the optimized space is around 12.5 mm. The characteristics of this antenna with and without CMM cover are presented in Fig. 2 (b), (c), (d) and (e). The gain is increased from 7.3 dB to 10.5 dB at 9.8 GHz. The return loss and AR of the antenna with CMM cover slightly shifts due to the influence of the antenna loading. At 9.7 GHz, the gain is enhanced from 7 dB to 11 dB and the AR is improved.

3.2 CP array patch antenna

The second designed cover is added to LCP array patch antenna which is consisted of sixteen elements and is designed at 1.3 GHz. A single-point feed square patch with an appropriate perturbation is used as the element of this array (Fig. 3 (a)). The configuration of this array and feed network are considered to reach high gain, low AR and good impedance matching.

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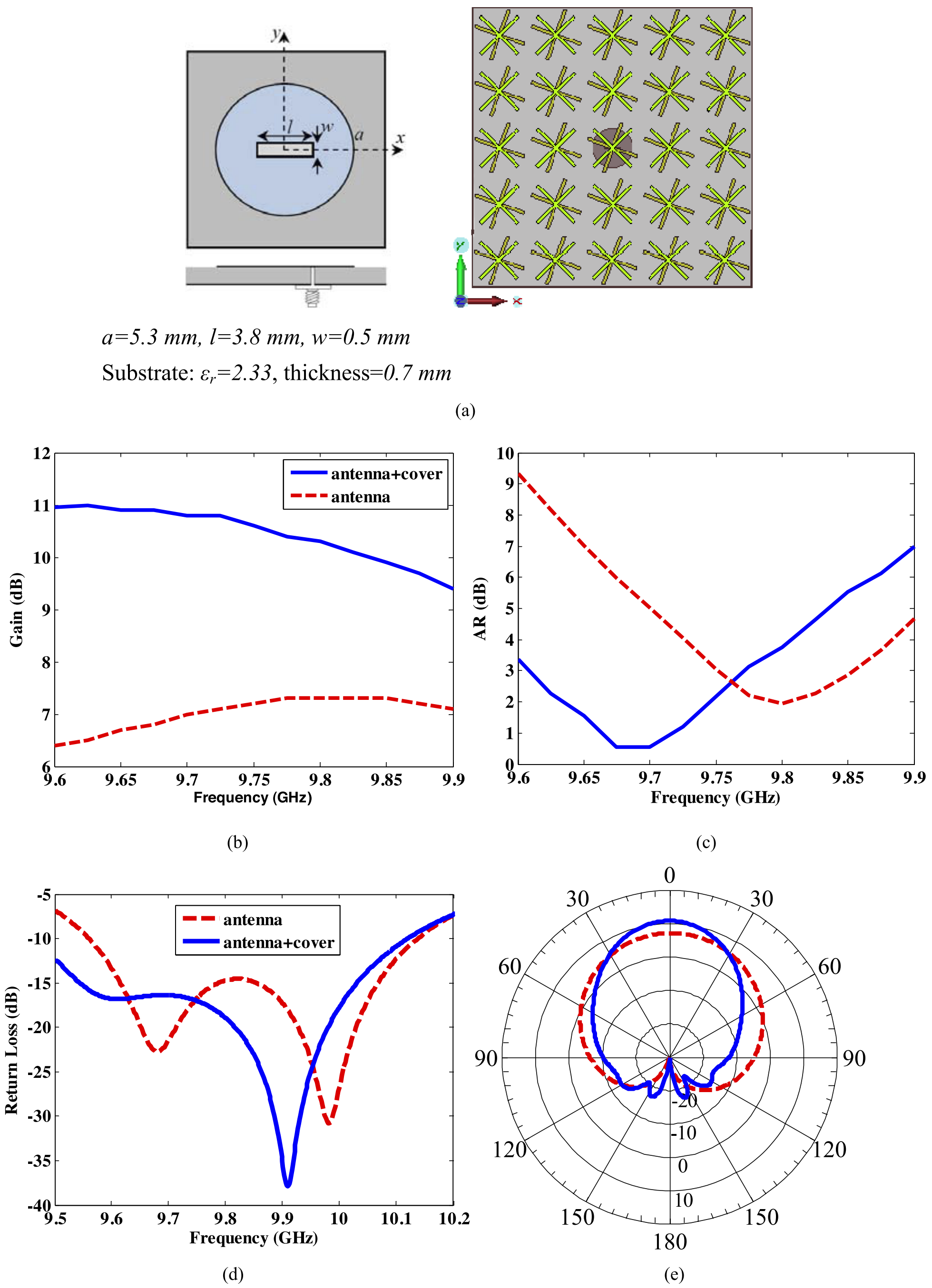

Fig. 2. (a) Structure of the single patch antenna with and without cover, (b) gain, (c) AR, (d) return loss (dB) and (e) polar diagram of LCP gain in the plane of $\varphi = 0$.

The results obtained from simulation are demonstrated in Fig. 3. It is seen that the gain is increased from 14.6 dB to 16.4 dB at 1.3 GHz. The return loss (S_{11}) and AR are slightly changed.

4 Conclusion

In this paper, a novel approach was presented based on the chiral metamaterial structures in order to enhance the directivity of CP microstrip antennas.

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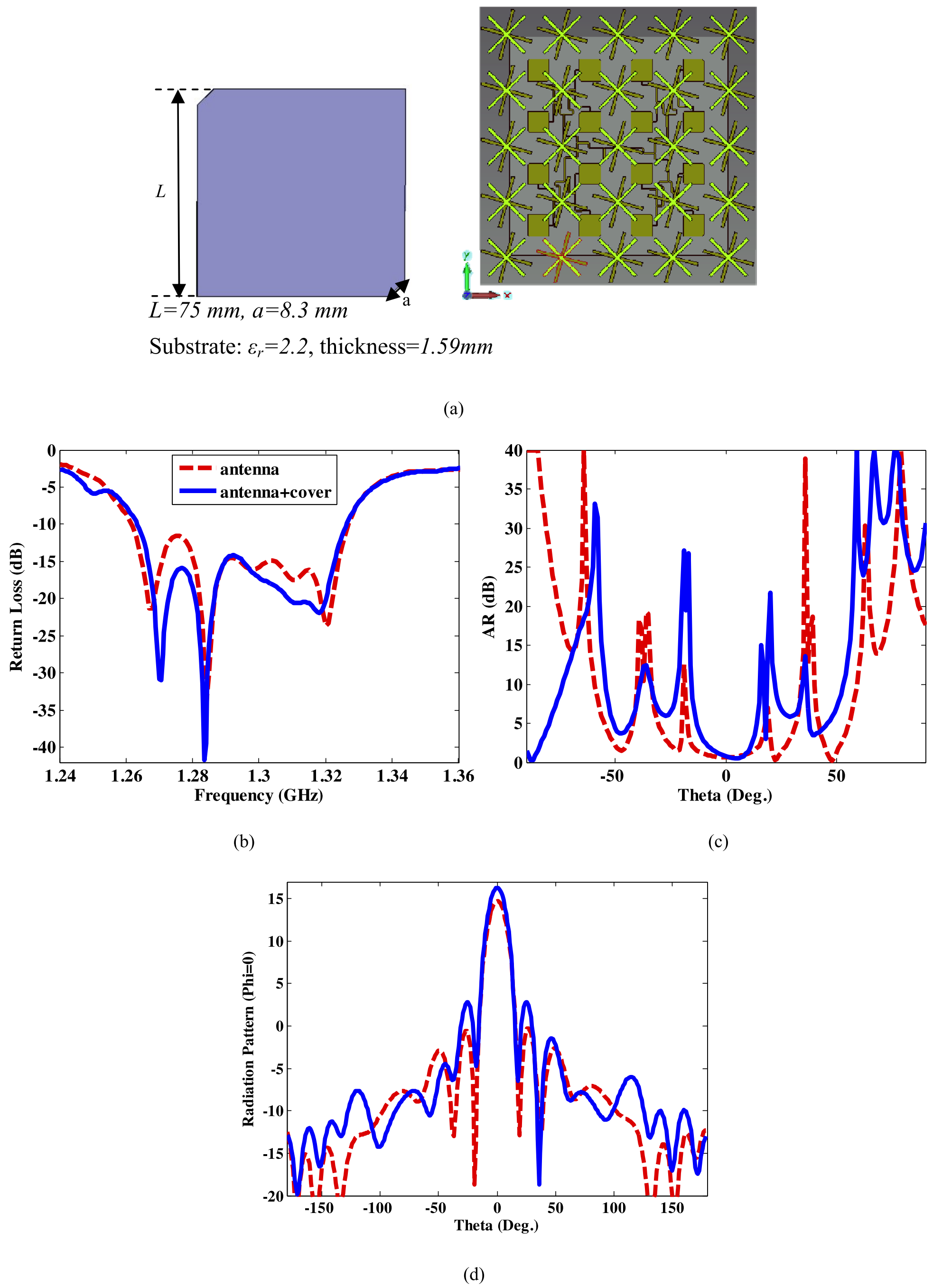

Fig. 3. (a) Structure of the element of the array patch antenna and the array with cover, (b) return loss (dB), (c) AR and (d) LCP gain in the plane of $\varphi = 0$.

CMM covers with approximately zero refractive indices were designed; then the proposed covers were applied to single and array patch antennas. Numerical results showed significant enhancement of the directivity of the antennas.

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