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A cross shaped spiral antenna radiating omnidirectional circularly and linearly polarized waves

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Abstract: A novel spiral antenna that simultaneously radiates circularly and linearly polarized waves is presented. The antenna achieved radiating omnidirectional circularly polarized waves by shaping a spiral antenna as its looks like a cross. Moreover, putting a parasitic element close to it, it succeeded in being utilized as a linear polarization antenna at the same time. This paper explains the reason why the antenna radiates multi-polarization waves and how the antenna is designed in order to utilizing frequencies. Experimental results of return losses, radiation patterns and axial ratios of a prototype antenna are shown for verifying its performance. The antenna can be expected to be used for multifunctional mobile communication devices, because it is a single feed and single layer printable antenna.

Keywords: circularly polarized antennas, multi-polarization antennas, RFID, GPS, omnidirectional antennas, multi-frequency antennas
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Simple multi-antennas will help to make multifunction mobile devices such as smartphones lighter and higher performance than current ones. For example multi-polarized and multi-frequency antennas will help to reduce the number of antennas. The cost of fabrication will be reduced, if the antenna can be made by a single layer and single port without a phase-shifter and ground plane. Moreover, the communication performance will be improved, by reducing the number of antennas and the influence of the size of a ground plane. Indeed, simple multi-polarized and multi-frequency antennas are necessary for developing smartphones. Although many multi-polarization antennas have been presented in the past, most of them need two feeding ports [1] and multi-layered structures [2].

A Loop antenna is good for making a simple circularly polarized wave antenna [3, 4, 5]. It does not always need wide ground. It can achieve to radiate circularly polarized waves by fed at one or two ports without phase-shifters [3, 4, 5]. However, there have been problems that should be solved for a loop antenna to be developed a multi-polarization antenna of mobile phones. For example, first, it is difficult to radiate circularly and linearly polarized waves simultaneously, and omnidirectional beam patterns. Second, it is also difficult to make in two-dimensional single layered structure. Third, a balun is necessary to convert into balance fed, because a loop antenna is usually fed by an unbalance feed.

An omnidirectional multi-polarization and multi-frequency loop/spiral antenna is presented in this paper. This antenna has solved the problems of loop antennas by making outer shape as a cross. We call the antenna "Crossed Spiral Antenna: CSA" due to the shape of the antenna which looks like a cross [4, 5]. First, closing up linear elements together in its center, CSA can radiate omnidirectional linear polarized waves. Moreover, at the frequency bringing a phase difference between horizontal and vertical elements, CSA radiates circularly polarized waves by only a single port without a phase shifter. Second, it is easy and cheap to be produced because its structure is very simple and single layer. Third, CSA is not necessary to be fed with a balun according to the report that L-shaped loop antennas can make balance themselves even if they are fed by coaxial cables [6]. For these reason,

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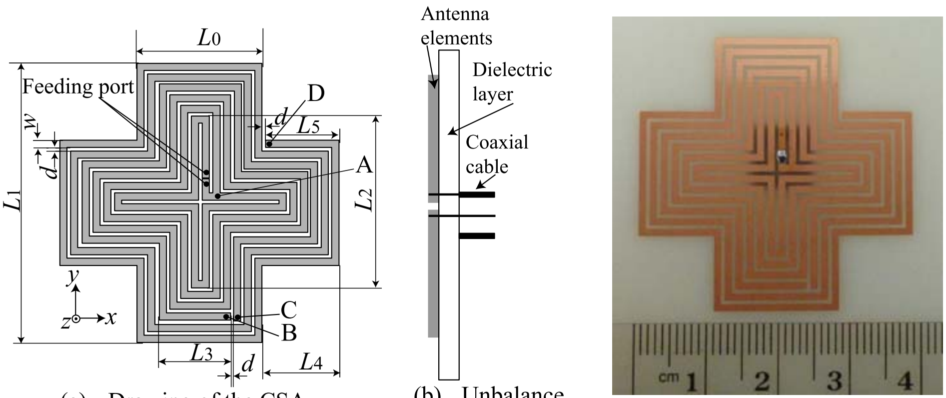
it is a suitable antenna for multifunctional communication devices which use both circularly and linearly polarized waves at two or more frequencies.

In this paper, it is shown first how CSA works as a circularly and linearly polarized antenna at each frequency. Next, the way to tune CSA in the utilize frequencies is shown. Then, the measurement results of S_{11} and antenna patterns are shown by using a prototype antenna which is designed to be used at 1.5 GHz and 2.45 GHz as a linearly and circularly polarized antenna, respectively. Note that 2.45 GHz and 1.5 GHz are chosen as target frequencies because those are a RFID and mobile communication band, respectively. The simulation and measurement results show that CSA is a good multi-polarization and multi-frequency antenna which radiates omnidirectional beam patterns. It might suit a mass production printable antenna, because the antenna can be made by printing.

2 Geometry of the CSA

The design of the CSA is presented in this section. The drawing of the antenna, which is tuned for radiating circularly polarized waves at 2.45 GHz and linearly polarized waves at 1.5 GHz simultaneously, is shown to introduce the structure of CSA in Fig. 1. This is made by winding wire into a spiral which mimics a cross-shaped path. The wire structure can be divided in two parts: inner and outer. The inner part is constituted a loop which is wrapped once following a cross-shaped path and a spiral antenna which is wound two and a half times counterclockwise from point A to point B. After making a small gap between points B and C, the outer part of the spiral antenna is wound from point C to D, along the same bending direction of the middle part. At points A, B and C the spiral wire is open. As a general design rule, this antenna will have good performances if the length "L_1" is set less than a quarter of the micro-strip wavelength at the linear polarization design frequency, and "L_2" is set smaller than the wavelength of the circular polarization design frequency.

A prototype of the proposed antenna design has been fabricated using a PCB of relative permittivity $\varepsilon_r = 4.3$, dielectric loss tangent $\delta = 0.018$, and



(a) Drawing of the CSA
(b) Unbalance feed
(c) Photo of the prototype CSA

Fig. 1. Geometry of the CSA.

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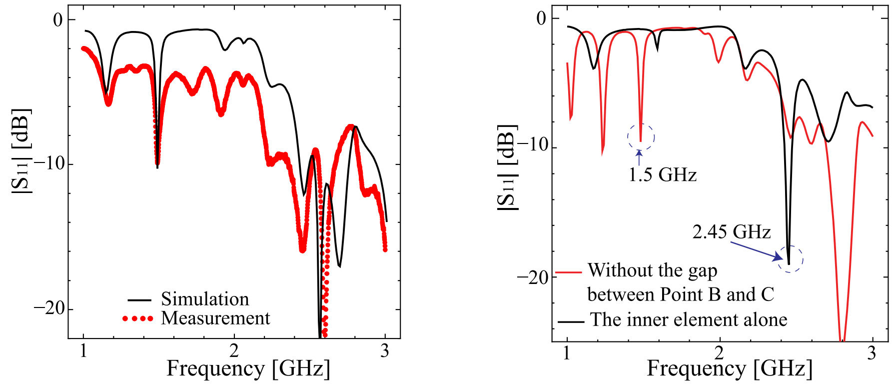
thickness 1 mm. The dimensions of the CSA are w = 1.0 mm, d = 0.5 mm, L_0 = 17.5 mm, L_1 = 39.0 mm, L_2 = 24.0 mm, L_3 = 10.0 mm, L_4 = 10.75 mm and L_5 = 10.25 mm. The prototype CSA is fed by unbalance feed using a coaxial cable as shown in Fig. 1 (b).

3 Characteristics of the CSA

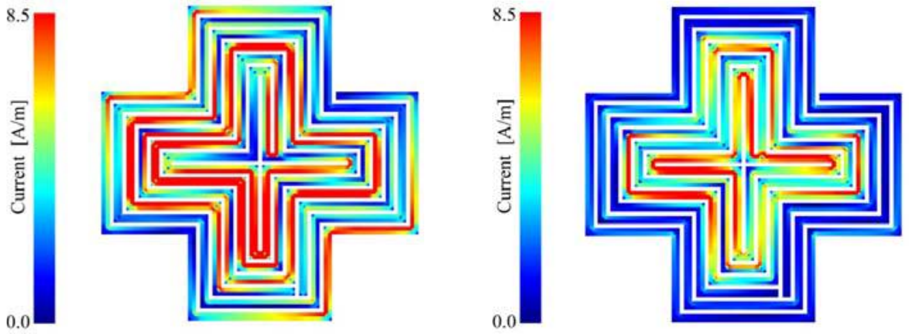
In this section the mechanism of radiating multi-polarized waves is explained by showing the characteristics of the CSA. The experimental measurements of return loss and beam patterns of the fabricated prototype antenna for the proposed design are reported and compared with method of moments simulations obtained by using the commercial software SONNET.

In Fig. 2 (a) the measured results for S_{11} are shown. They compare very well with the simulated ones. The results also show that the prototype antenna has good S_{11}characteristics, which are −10 dB or less, at 1.5 GHz and 2.45 GHz for mobile phones. Some other resonances also appear at 2.6 GHz and at 2.7 GHz. The resonance appearing at 2.6 GHz has an important meaning for a circularly polarized wave, which is radiated around the frequency that two resonances are closely corresponded each other. Resonance at 2.7 GHz has been appeared only in simulation data because the feeding way of the simulation model is an approximate structure of the realistic structure. Note that radiation patterns at those frequencies cannot be categorized as either a circular polarization or a linear polarization. Therefore character-



(a) CSA simulated and measured S_{11}.

(b) Return losses of the inner elements and antenna without the gap between B and C.



(c) Simulated current distribution at 1.5 GHz.

(d) Simulated current distribution at 1.5 GHz.

Fig. 2. Return loss and simulated current distribution at 1.5 GHz and 2.45 GHz.

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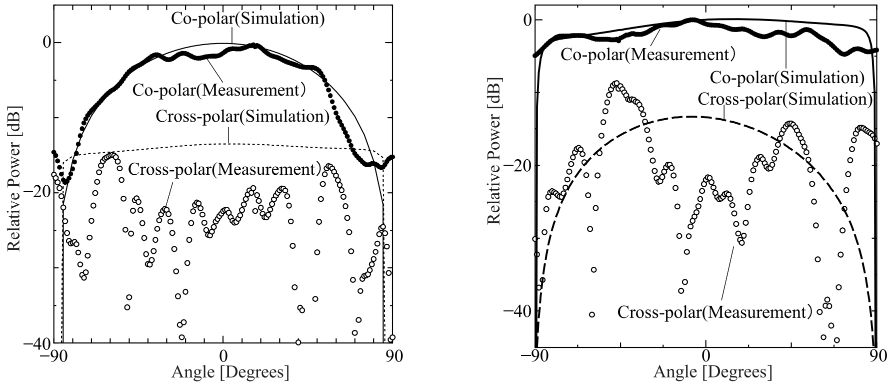
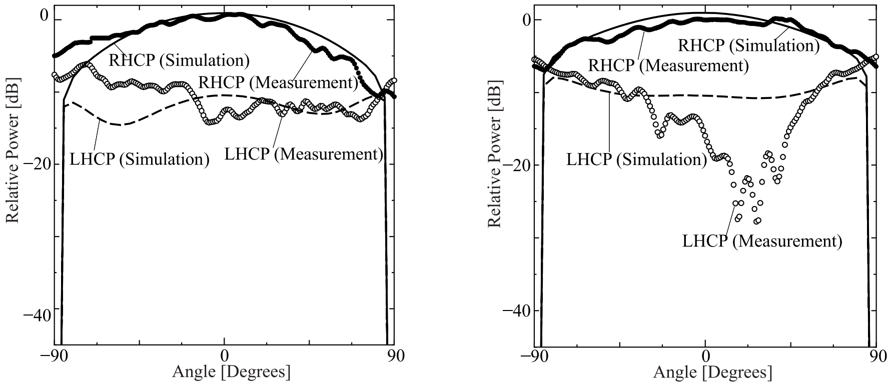
istics at only target frequencies, 1.5 GHz and 2.45 GHz, are discussed in this paper.

In Fig. 2 (b) the simulated results for S_{11} of the inner element alone and the antenna without the gap between B and C. The results show that the whole element of the antenna works for 1.5 GHz and the inner element works for 2.45 GHz. Therefore, the gap between B and C takes the role switching active elements, the inner or whole, according to each frequency. In Fig. 2 (c) and (d) show the simulated current distribution at 1.5 GHz and 2.45 GHz, respectively. The whole antenna structure is taking part to the formation



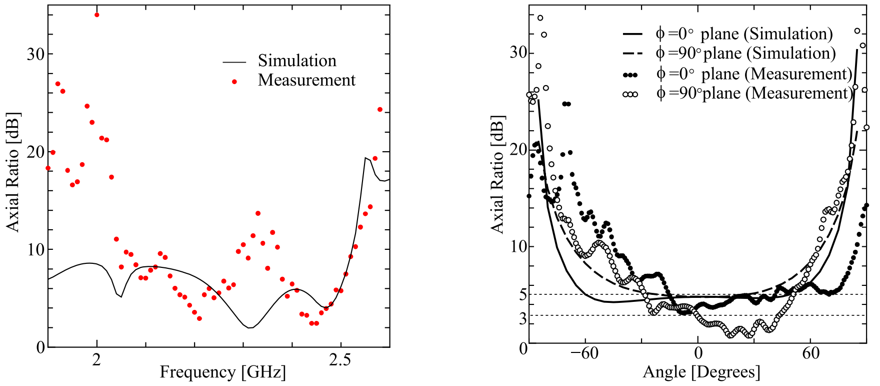
(a) Antenna Pattern; ϕ = 0° plane, linearly polarized waves at 1.5 GHz.

(b) Antenna Pattern; ϕ = 90° plane, linearly polarized waves at 1.5 GHz.



(c) Antenna Pattern; ϕ = 0° plane, linearly polarized waves at 2.45 GHz.

(d) Antenna Pattern; ϕ = 90° plane, linearly polarized waves at 2.45 GHz.



(e) Frequency Characteristics of Axial ratio of circularly polarized waves

(f) Axial ratio of circularly polarized waves at ϕ = 0° and ϕ = 90° principal planes at f = 2.45 GHz.

Fig. 3. Antenna beam patterns and axial ratios of circularly polarized waves.

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of the LP radiation mode at 1.5 GHz and the inner part of the antenna is responsible for the CP radiation mode at 2.45 GHz.

In Fig. 3 (a) and (b), we show the antenna beam patterns for the linearly polarized waves by comparing simulated results and experimental measurements for the $\phi = 0°$ and $\phi = 90°$ planes taken at 1.5 GHz. Linearly polarized radiation is achieved at 1.5 GHz with cross-polarization discrimination better than −17 dB within all beam-width. The following beam pattern far-field cuts refer to azimuth cuts at 0° and 90° with an elevation angle range covering the −90° to +90° hemisphere. In this contest the +z axis is normal to the antenna PCB plane and centered with the center of the inner loop. The $\phi = 0°$ cut is the plane through the x-z axes as shown in Fig. 1.

In Fig. 3 (c) and (d), the beam patterns for the circularly polarized antenna are reported for simulated and experimental results at the $\phi = 0°$ and $\phi = 90°$ planes for the frequency of 2.45 GHz. It is shown that the predominant polarization is right-hand, with a half power beamwidth of at least 140°.

In Fig. 3 (e) and (f) we show the axial ratio comparison between simulations and experimental results. The axial ratio of the prototype CSA is minimum at 2.45 GHz and the bandwidth less than 5 dB is about 100 MHz. Beamwidth that the axial ratio is less than 5 dB is about 100° range in the $\phi = 0°$ plane and 60° range in the $\phi = 90°$ plane. Although a desirable axial ratio should be 3 dB or less, the target axial ratio was set 5 dB or less because the antenna is for the mobile. In fact, the presented antenna achieves 3 dB at a little bit lower frequencies and its measurement data achieve 3 dB even in 2.45 GHz.

The calculated gain and efficiency for the CP radiating mode were 1.2 dB and 77% respectively and −4 dB and 20% for the LP radiating mode.

4 Conclusion

A very simple design for a single layer planar CSA antenna, which radiates circularly polarized waves and linearly polarized waves simultaneously at two different frequencies with a wide half-power beamwidth has been presented. Numerical results have been compared with experimental measurements at 1.5 GHz and 2.45 GHz proving the effectiveness of the proposed design. Wide angle beam-width of at least 140° of right-hand circular polarization and 100° of co-polarization has been demonstrated at resonance frequencies of 2.45 GHz and 1.5 GHz of the prototype antenna, respectively. Circular Polarization radiation is achieved at 2.45 GHz with Axial Ratio better than 5 dB over a beam width of 60°.

In addition to the previous results, which showed remarkable agreement between experimental measurement and simulations, the fact that no phase shifting components are used for the generation of circular polarized waves and no balun is necessary to make balance of the feed, indicates that the CSA is a very interesting antenna for applications such as smartphones and small wireless communication devices, where simplicity is a key factor for

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mass production.

For the future work, various design variations from the original concept proposed in this paper are also under study. In particular, the design which achieves circular polarization and linear polarization respectively at the 1.58 GHz and 1.8 GHz is currently under examination.

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