Dual-frequency Dual-sense Circularly-polarized Slot Antenna Fed by Microstrip Line

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Dual-Frequency Dual-Sense Circularly-Polarized Slot Antenna Fed by Microstrip Line

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Abstract—A new design of a dual-frequency dual circularly-polarized slot antenna is presented. The dual-frequency is achieved using a single-layer microstrip-fed configuration coupled to a modified annular-slot antenna. The dual sense circular-polarization is obtained by four unequal linear slots which augment the annular slot. Experimental results show the proposed antenna has good circular polarization characteristics for both right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP). The 10 dB return loss impedance bandwidths for the lower (RHCP) and higher (LHCP) bands are 26.7% and 11.3%, respectively. The 3 dB axial-ratio bandwidths are 6.1% and 6.0% with respect to 1.5 GHz (RHCP) and 2.6 GHz (LHCP), respectively.

Index Terms—Dual circularly polarization, dual frequency, right-hand circular polarization (RHCP)/left-hand circular polarization (LHCP), slot antennas.
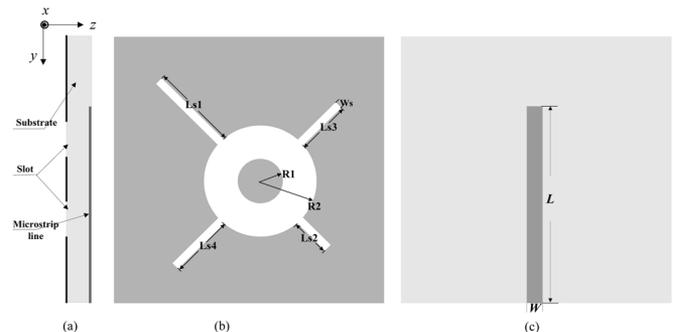

Fig. 1. Geometry of the dual-frequency dual circularly-polarized slot antenna. (a) Substrate, (b) slot, (c) microstrip line.

I. INTRODUCTION

IN THE recent decade, slot antennas have again become the subject of great interest to the engineering designer due to their miniaturization potential and relatively wide bandwidth. Several slot antennas are reported to achieve improved performances, particularly for broadband and circular-polarization applications. In [1], a typical circular-ring slot antenna utilizing a stripline hybrid coupler feed-network achieves good broadband circular-polarization performance. In [2], a circularly-polarized square-ring slot antenna is proposed which is fed by a series microstrip-line coupled to two orthogonal sides of the square-ring slot to achieve circular polarization characteristics. An annular-slot antenna array has recently been reported [3]. Various other slot combinations are reported to obtain compact/broadband circular polarization [4]–[7]. Annular slot antennas are also employed to obtain dual-frequency and multiple frequency operation by a shorted slot [8], or with a circular back-patch [9], or strip-line [10]. Recently, some techniques have been employed to provide dual circularly polarized antennas. In [11]–[14], a right-hand circular polarization (RHCP)/left-hand circular polarization (LHCP) antenna is achieved by PIN diode switching. In [15]–[17], dual circular-polarization is obtained by a feed network and two ports. A dual-frequency dual circularly-polarized patch antenna has been reported in [18], which consists of multilayer arrangement of two patches coupled to the feed points to

achieve dual circular-polarization. In comparison to this design, the proposed antenna is fabricated on a single layer and employs multiple slots.

In this paper, the single layer annular slot antenna is used to achieve dual-frequency and dual-sense circular-polarization by adjustment of the key antenna parameters, which are the inner and outer radii of annular-slot, the length of the four additional linear slots spurred from the annular slot and the length of microstrip feedline. The proposed antenna can provide broad impedance bandwidth and axial-ratio bandwidth. The right-hand CP and left-hand CP performance is realized simultaneously, for the first and second frequency, respectively. The proposed slot antenna can find useful application in indoor wireless communication systems and in satellite navigation systems.

II. DESIGN OF SLOT ANTENNA FOR DUAL CIRCULAR POLARIZATION

The geometry of the proposed slot antenna is illustrated in Fig. 1. It comprises an annular slot combined with four orthogonal linear slot arms. The annular-slot inner and outer radii are $R1$ and $R2$ respectively and the four linear slot arm lengths are $L1, L2, L3$ and $L4$ with the same slot width Ws. The antenna is fabricated on an FR4 substrate, which has a relative permittivity of 4.2, a thickness of 1.52 mm and a loss tangent of 0.02. The groundplane size is 80 mm × 80 mm. The width of microstrip line, which is centered on the substrate, is $w = 3.0$ mm for a 50 Ohm impedance. The width Ws of the linear slot arms is 1mm. The slot arm width is selected for optimum bandwidth and matching. As this value is increased, the matching is lost, initially for the lower band ($Ws = 1.5$ mm). As Ws is reduced, the bandwidth of the high band is decreased.
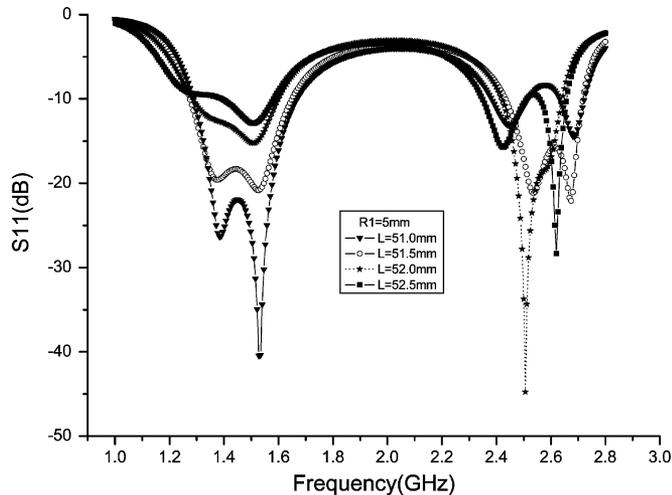
Fig. 2. Comparison of return loss for the proposed antenna for different feed-line lengths.

Fig. 3. Comparison of the return loss for the proposed antenna for different values of inner radius ($R1$).

For the conventional annular slot antenna, the resonant frequency may be approximated by:

$$f = \frac{c_0 \cdot K}{2 \cdot \pi \cdot \sqrt{\varepsilon_e}}, \quad K = \frac{2}{R1 + R2} \qquad (1)$$

where c_0 is velocity of light and ε_e is the effective dielectric constant of the substrate considering the annular and linear slots, which is relative to the slot guided wavelength, given in [1]. In the annular-slot, the introduction of the slot arms can be used to reduce the resonant frequency, and at the same time, provide a low and high frequency mode. They are also used to improve matching and are geometrically arranged to provide the necessary phase perturbation for circular-polarization. By adjusting the slot lengths, dual frequency operation is achieved by coupling a microstrip feedline to the annular-slot. The four unequal narrow slots are located at angles of 45°, 135°, 225°, 315° with respect to the feedline, which provide the necessary perturbation for circular polarization and degenerate the resonant modes into two frequencies. The lower resonant frequency is determined by the annular-slot dimensions and the length of the longest slot arm Ls1. According to the low frequency E-field distribution shown in Fig. 4(a), it can be seen that strong orthogonal fields are excited. One of the orthogonal linearly-polarized fields is produced in the annular-slot and linear slot Ls1, while the other field is realized in the annular slot and linear slots Ls3 and Ls4. By adjusting the length of Ls4 and Ls3, fields of nearly equal magnitude and with a phase difference of 90 degrees are realized, yielding circularly-polarized characteristics. In this case, for best axial-ratio and matching, the required difference in length between Ls1 and Ls4 is approximately one eight of the low frequency guide wavelength. The sense of polarization can be seen by looking at the phase sequence in Fig. 4(a). If Ls1 > Ls4, then RHCP is obtained in the positive z direction.

In the same way, the resonant frequency of the high frequency mode is determined by the annular slot dimensions in combination with the length of shortest slot arm Ls2. As can be seen in the E-field distribution for the higher frequency in Fig. 4(b),
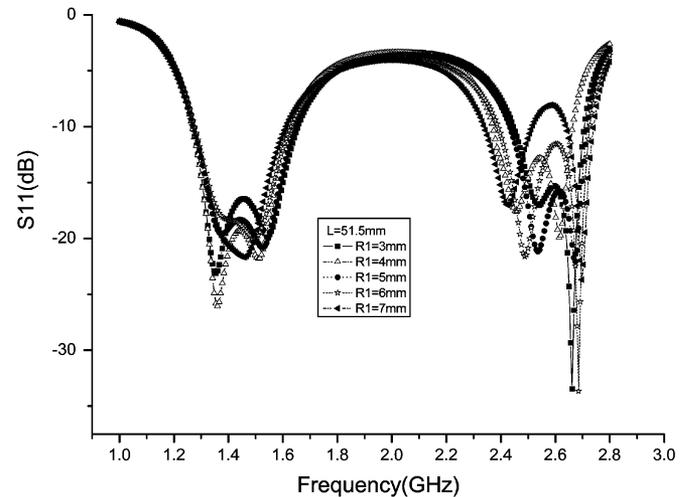
one of the linear-polarized fields is excited in the annular slot and linear slot Ls2, while the orthogonal field is realized in the linear slots Ls3 and Ls4. By adjusting the length of Ls3 and Ls4, orthogonal fields of nearly equal magnitudes and of 90 degree phase difference are produced, hence circularly polarized characteristics. In this case also, there is about one eight of a guide wavelength (for higher frequency) difference in the length's of Ls3 and Ls2 for best axial ratio and matching. For Ls3 > Ls2, then LHCP is obtained in the positive z direction. So, two independent circular-polarization senses can be realized simultaneously by adjusting the four lengths of the narrow linear slot arms. In order to provide best matching and optimum performance, a parametric study was made using a numerical solver based on these initial dimensions of antenna.

III. NUMERICAL ANALYSIS FOR THE DUAL-SENSE CIRCULARLY-POLARIZED SLOT ANTENNA

A parametric study of the proposed slot antenna was carried out in order to achieve broadband dual frequency operation and dual circular-polarization. To decrease the complexity of the design, the following antenna parameters are selected as: $R2 = 11.5$ mm, $Ls1 = 34.5$ mm, $Ls2 = 12.5$ mm, $Ls3 = 18.5$ mm, $Ls4 = 21.5$ mm, $Ws = 1.0$ mm.

Simulations are carried out using CST MWS based on the finite integration time-domain technique and an investigation of the antenna parameter dependence is made. The length of feedline L and inner radius $R1$ of circular patch are initially examined.

A. The Effects of Variation of the Length of Microstrip Line L

As the length of microstrip line L is varied, the coupling to the annular-ring slot is altered and the antenna performance is also varied. The return loss dependence on this parameter is shown in Fig. 2. It is observed that the matching of the dual-frequency slot antenna is very sensitive to this parameter. Thus, the length of microstrip line L needs to be optimized to provide circular polarization with good dual-frequency matching. In this paper,
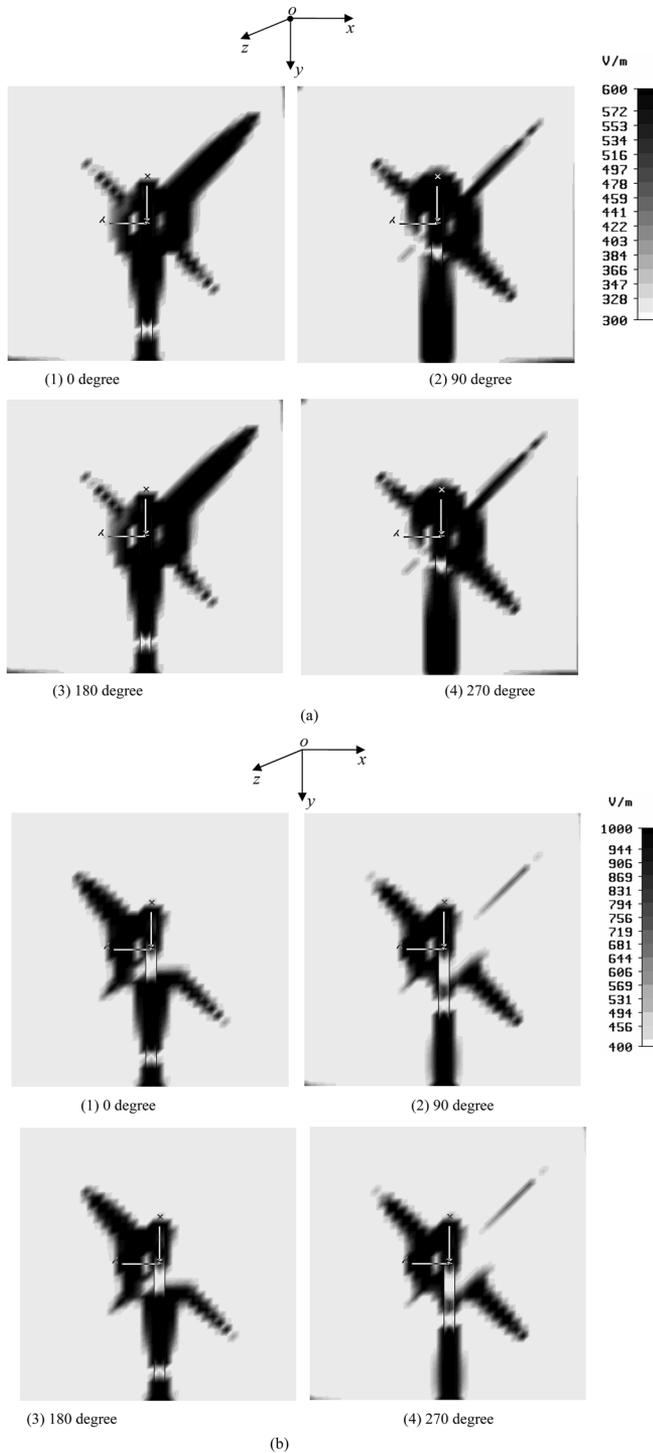
Fig. 4. The distributions and phase of the simulated electric field at (a) 1.5 GHz and (b) 2.6 GHz. (1) 0 degree, (2) 90 degree, (c) 180 degree, (d) 270 degree.

Fig. 5. Antenna parameters for frequency ratios of 1.75:1, 1.91:1 and 2.65:1.

the value of this parameter for the proposed antenna is selected as $L = 51.5$ mm.

B. The Effects of Variation of the Inner Radius of Annular-Slot R1

Fig. 3 illustrates the return loss plots of the dual-frequency antenna for different values of annular slot inner radius $R1$. It is clearly seen that the upper frequency shows heavy dependence
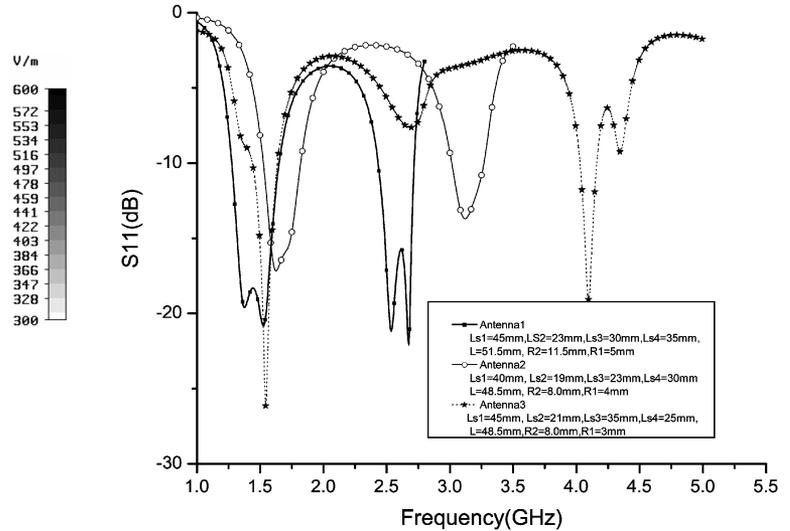
on this parameter. The matching at this frequency is therefore realized by appropriate choice of inner radius $R1$ and feedline length L, whereas matching at the lower frequency is determined mainly by feedline length. The appropriate $R1$ size is selected as 5 mm.

The distributions of electric field are simulated by using CST MWS and are shown in Fig. 4(a) for the lower frequency of 1.50 GHz and Fig. 4(b) for the upper frequency of 2.60 GHz. It can be seen in this figure that fields exist on the edge of longer slot arms for lower frequency, whereas on the other hand, the distributions of electric field on the edges of short slot arms are strong at the high frequency. The frequency ratio is 1.75:1. By tuning the length of the slot arms, the change in frequency ratio of the two circularly-polarized operating frequencies can only be changed by about 5%, because the matching degrades. The annular slot dimensions as well as the length of microstrip line need to be changed to achieve a broader range of frequency ratios, typically in the range 1.7:1 to 2.7:1. The parameter values and S11 response for frequency ratios of 1.75:1 (2.674 GHz/1.528 GHz), 1.91:1 (3.117 GHz/1.625 GHz) and 2.65:1 (4.095 GHz/1.545 GHz) are shown in Fig. 5.

IV. MEASURED RESULTS

According to the results of the numerical analysis, the optimized parameters of the proposed slot antenna dimensions are as follows: $R2 = 11.5$ mm, $Ls1 = 34.5$ mm, $Ls2 = 12.5$ mm, $Ls3 = 18.5$ mm, $Ls4 = 21.5$ mm, $R1 = 5$ mm, $L = 51.5$ mm, W $s = 1.0$ mm. The measured and simulated $S11$ are shown in Fig. 6. The measured results are in good agreement with simulation. The measured results show the (10 dB return loss) input impedance bandwidth for the lower frequency (RHCP) is about 389 MHz from 1.265 to 1.654 GHz, representing 26.7% with respect to 1.46 GHz, and the bandwidth of the higher frequency (LHCP) is about 292 MHz from 2.446 to 2.738 GHz, representing 11.3% with respect to 2.59 GHz. Fig. 7 illustrates a plot of the measured and simulated axial ratio against frequency. The measured 3 dB axial-ratio bandwidth for the low band is
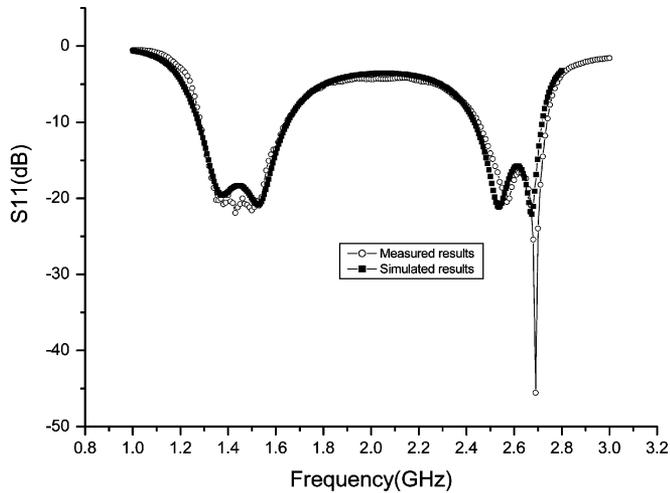
Fig. 6. The measured and simulated results of S11 for the proposed antenna.
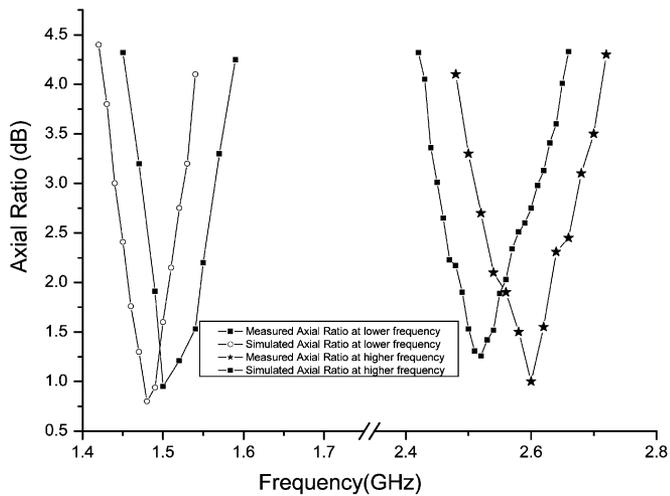

Fig. 7. The measured and simulated axial-ratio against frequencies for the proposed antenna.
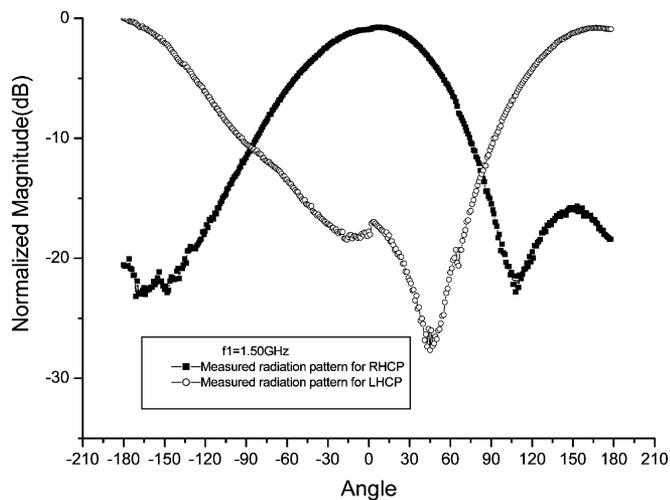

Fig. 8. Measured radiation patterns at 1.5 GHz for the proposed antenna.

92 MHz, from 1.474 to 1.566 GHz for RHCP, corresponding to about 6.1% with respect to 1.5 GHz, and the measured axial-ratio bandwidth for the high band is 155 MHz, from 2.512 to
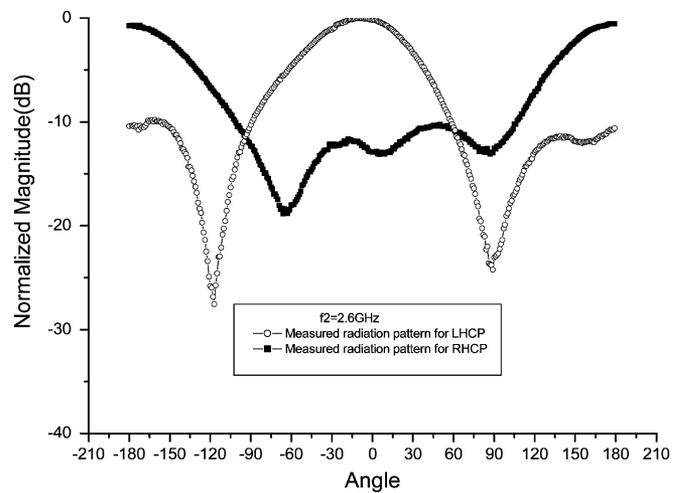

Fig. 9. Measured radiation patterns at 2.6 GHz for the proposed antenna.
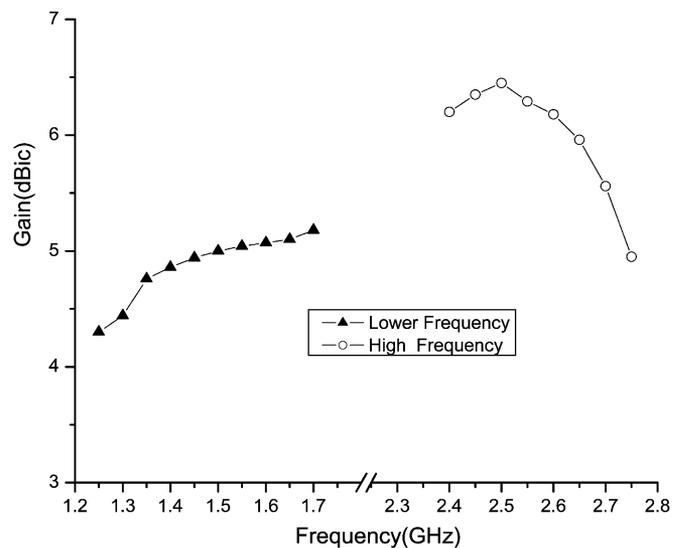

Fig. 10. The measured peak gain variation with frequency.

2.677 GHz for LHCP, corresponding to about 6.0% with respect to 2.6 GHz.

The measured RHCP and LHCP radiation patterns are measured and are illustrated in Figs. 8 and 9 for frequencies of 1.5 and 2.6 GHz, respectively. The cross polarization is better that 17 and 12 dB for the low and high frequency respectively. The peak measured gains of for the low and high frequencies are 5.2 and 6.3 dBic, respectively, as seen in Fig. 10.

V. CONCLUSION

A novel dual-frequency dual-circular polarization slot antenna fabricated on a single layer is examined. The proposed antenna can provide wide impedance bandwidths of 26.7% for first band and 11.3% for second band, respectively. The axial-ratio bandwidths achieved are greater than 6% for RHCP and LHCP, respectively. The proposed antenna can be applied to multiband multipolarized systems to mitigate interference effects.

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