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CPW-FED SQUARE SLOT ANTENNA WITH LIGHTENING-SHAPED FEEDLINE FOR BROADBAND CIRCULARLY POLARIZED RADIATION

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Abstract—A new broadband circularly polarized (CP) square slot antenna is evaluated numerically and verified experimentally. The proposed antenna uses a lightening-shaped feedline protruded from the signal line of the feeding coplanar waveguide (CPW). Two symmetrical F-shaped slits embedded in opposite corners of ground plane are designed to obtain an excellent CP bandwidth. By adjusting the dimensions of the lightening-shaped feedline, the CP bandwidth can be further enhanced. Measured results show that the 3 dB axial-ratio bandwidth of the proposed antenna can reach 51.7% (2150 MHz–3650 MHz), and the impedance bandwidth is as large as 60.2% (2150 MHz–4000 MHz) with VSWR ≤ 2. Measured results are in good agreement with the simulation. The proposed antenna can be easily fabricated because of the simple coplanar geometry.

1. INTRODUCTION

With the development of modern wireless communication, the design of the circularly polarized (CP) antenna is getting more and more popular. The advantage of a CP antenna over a linearly polarized antenna is that nearly constant signal can be achieved even if the received antenna's rotation angle changes. Due to the high Q nature, the obtained CP bandwidth is usually small [1]. Thus, the need for broadband CP antennas is inevitable. In the last decades, owing to the slot antennas, especially wide slot antenna which can provide much wider impedance bandwidth, many slot antennas have been used

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for the broadband CP antenna [2–4]. Moreover, due to attractive features such as wide impedance bandwidth, single metallic layer, low profile, and easy integration with active device or MMICs, printed wide slot antennas with a coplanar waveguide (CPW) feed have been increasingly investigated in the design of the CP antennas for axial ratio (AR) bandwidth enhancement [5–12]. In an early research, the conventional CP CPW-fed antenna has been capacitively coupled in the feeding network [5]. Broadband axial ratio (AR) bandwidth can be obtained by embedding square slots appropriate perturbation structures which can be constructed by loading a cross patch [7] or a ground T-shaped metallic strip [8] or a pair of inverted-L grounded strips [9]. It can also be constructed by an inverted-L tuning stub extended from the signal line and a pair of grounded strips [10]. The slot antenna with enhanced impedance and AR bandwidth was obtained in [11] by using the lightening-shaped feedline. The antenna has introduced vertical and horizontal tuning stubs to widen the VSWR ≤ 2 impedance band effectively. The design antenna of [11] has been measured to exhibit a CP bandwidth larger than 45%.

In this paper, a novel CPW-fed CP square slot antenna with excellent CP and impedance bandwidth is presented. In the proposed antenna, a lightening-shaped feedline is protruded from the center signal strip of the feeding CPW, and a tuning stub are embedded in the feeding structure. In addition, two symmetrical F-shaped slits embedded in the opposite corners of ground plane are constructed, which can introduce more resonant branches. Novel symmetrical F-shaped slits introduce more resonant branches. As a result, the axial ratio bandwidth of the proposed antenna has been further enhanced compared with all the above-mentioned antennas proposed in [11]. Moreover, the antenna can be easily fabricated on PCB. Measurement results are in very good agreements with the simulations illustrating that the optimum 3-dB AR bandwidth can reach 51.7%, which is completely covered by the VSWR ≤ 2 impedance bandwidth.

2. ANTENNA DESIGN

The geometry of the proposed broadband CP square slot antenna is shown in Fig. 1. The antenna is etched on a square 0.8 mm FR4 substrate, relative permittivity $\varepsilon_r = 4.4$ and loss tangent of $\tan\delta = 0.02$. The overall dimensions of the antenna is $60 \times 60 \times 0.8\,\text{mm}^3$. The antenna is fed by a 50-Ω CPW with a signal strip of width $Wf = 4.2\,\text{mm}$ and two identical gaps of width $g = 0.3\,\text{mm}$. The lightening-shaped feedline is used for enhancing the AR bandwidth. The lightening-shaped feedline is formed by extending the signal strip

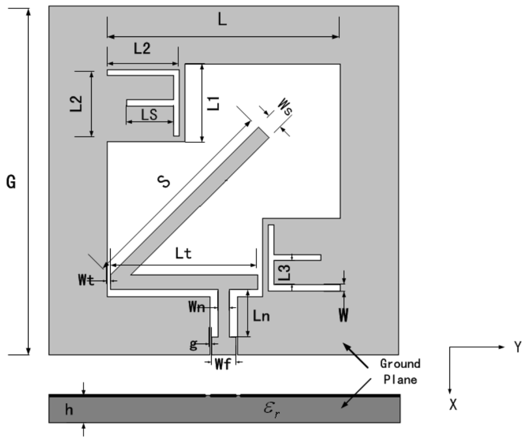


Figure 1. Geometry of the proposed circularly polarized slot antenna.

of the CPW in the $-y$ direction to the lower left corner of the slot (the horizontal section) and the protruding into the slot at an inclined angle of 45° with respect to the x axis (the slant section). Two feed sections are with the same width of Ws. The lengths of the horizontal and slant feed sections are Lt and S, respectively. The gap between the horizontal and the left edge is Wt. On the other hand, the two small grounded squares in the opposite corners of ground plane have equal length and width of $L1$, in which the F-shaped slits are embedded to further enlarge the AR bandwidth of the antenna. Both the length and width of each F-shaped slit are defined to $L2$, and the middle slit has a length of Ls. The distance between middle slit and the top of the F-slits is $L3$. The middle slit has a great effect on the AR bandwidth but very little influence with impedance bandwidth. Each side of the F-shaped slits has the same width of $W = 1\,\text{mm}$. So, the lightening-shaped feedline with two symmetrical F-shaped slits embedded in the opposite corners of ground plane accounts for the enhancement of the AR bandwidth. In addition, a tuning stub with the width of Wn and length of Ln is embedded in the feeding structure in order to enlarge the impedance band. Hence, a CPW-fed square slot antenna with lightening-shaped feedline for the circularly polarized radiation is achieved.

3. SIMULATED AND MEASURED RESULTS

3.1. Parameters Analysis

The characteristics of the proposed CP antenna have been simulated by Ansoft High Frequency Structure Simulator (HFSS) software and measured by Agilent N5230A network analyzer. In order to design the high performance broadband CP square slot antenna, a detailed parametric study of the antenna is made.

The effects of adjusting the length Ln of the tuning stub on return loss are first studied. Fig. 2 exhibits the return loss of the antenna with different Ln. The lengths Ln with four different widths, 7.2, 8.2, 9.2 and 10.2 mm, are analyzed while other parameters are fixed. It can be seen from Fig. 2 that the length of the tuning stub Ln has a great effect

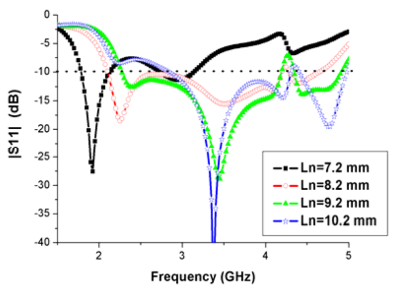


Figure 2. Simulated results of S_{11} for the proposed antenna with different Ln.

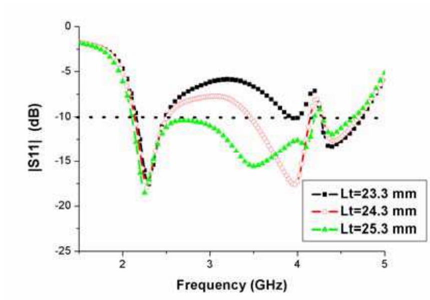


Figure 3. Simulated results of S_{11} for the proposed antenna with different Lt.

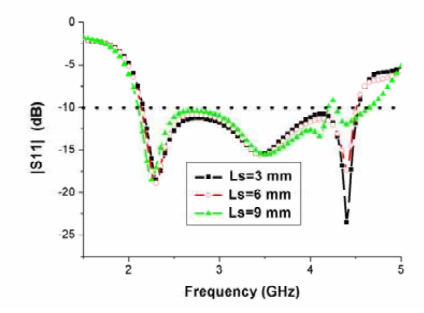


Figure 4. Simulated results of S_{11} for the proposed antenna with different Ls.

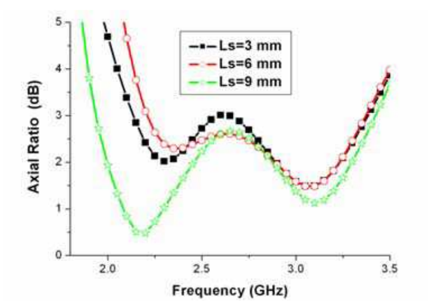


Figure 5. Simulated axial ratio of the antenna with different Ls.

on the impedance bandwidth. When the length of the horizontal feed section of Lt varies, the return loss curves are shown in Fig. 3, which illustrates that with increasing the horizontal feed section length of Lt, the impedance bandwidth can be broadened.

Then the effects of tuning the length Ls of middle of the F-shaped slit with three different lengths of 3, 6 and 9 mm are analyzed. Fig. 4 shows the return loss of the antenna with different Ls, and it can be seen that with the change of the Ls, the impedance bandwidth of the antenna varies slightly. The simulated axial ratio of the antennas with different Ls is shown in Fig. 5. It indicates that the variety of lengths Ls has a great impact on the 3-dB AR bandwidth. Thus, the 3-dB AR bandwidth can be easily tuned by changing the length of the middle tub of the F-shaped slits. Moreover, the VSWR ≤ 2 impedance bandwidth seems to change little with the variation of Ls.

3.2. Measured Results

After the optimization, the geometric dimensions of the proposed antenna are as follows: $G = 60.0$ mm, $L = 40.0$ mm, $L1 = 14.0$ mm, $L2 = 13.0$ mm, $L3 = 4.0$ mm, $Ls = 9.0$ mm, $W = 1.0$ mm, $Lt = 25.3$ mm, $S = 36.0$ mm, $Ws = 2.5$ mm, $Ln = 8.2$ mm, $Wn = 2$ mm, $Wt = 0.3$ mm, $Wf = 4.2$ mm and g=0.3 mm.

The measured and simulated return losses are shown in Fig. 6. It can be seen from Fig. 6 that the measured and simulated results are in good agreement. the measured impedance bandwidth for 10-dB return loss is from 2150 to 4000 MHz, which shows about 1850 MHz bandwidth (60.2%). The antenna performs a wide bandwidth due to the two resonant modes which are excited by the lightening-shaped feedline and F-shaped slits. The simulated surface current distributions are presented in Fig. 7, for these two resonant modes. In Fig. 7(a),

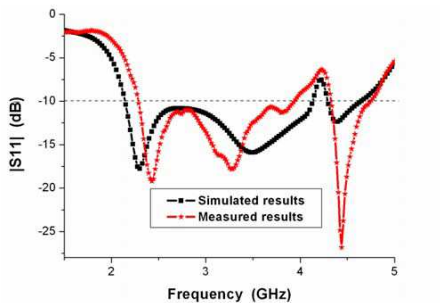


Figure 6. Simulated and measured S_{11} of the proposed antenna.

the simulation results show that the first resonant mode is mainly influenced by lightening-shaped feedline. Fig. 7(b) shows that the second surface current distribution is mainly formed by the two E-shaped slits. Fig. 8 presents the simulated radiation efficiency of the antenna. The radiation efficiency of the antenna is about 50% to 60%. It can be seen that although the efficiency shows some level of decrease with the improvement of impedance bandwidth, it is acceptable for the circularly polarized antenna.

The measured and simulated AR results of the proposed antenna are plotted in Fig. 9. The little discrepancies between the simulated and measured results are caused by the limited accuracy of the etching process used and the antenna testing system. It is seen that the CP bandwidth of 3-dB axial ratio is 1500 MHz (2150 MHz–3650 MHz). The 3-dB AR bandwidth of proposed antenna can reach 51.7%.

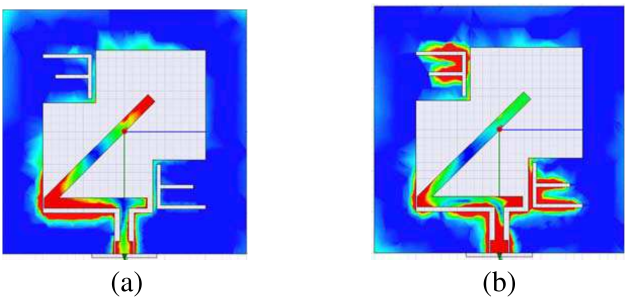


Figure 7. Simulated surface current distributions of the antenna: two resonant modes (a) 2.45 MHz; (b) 3.15 MHz.

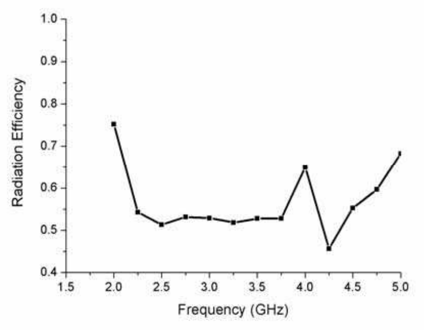


Figure 8. Simulated radiation efficiency of the of the proposed antenna.

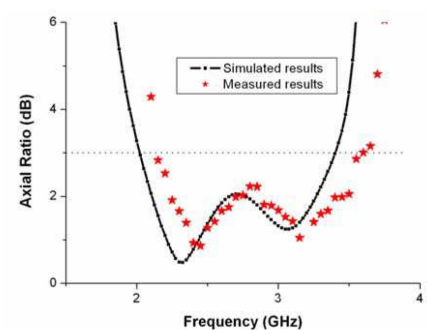
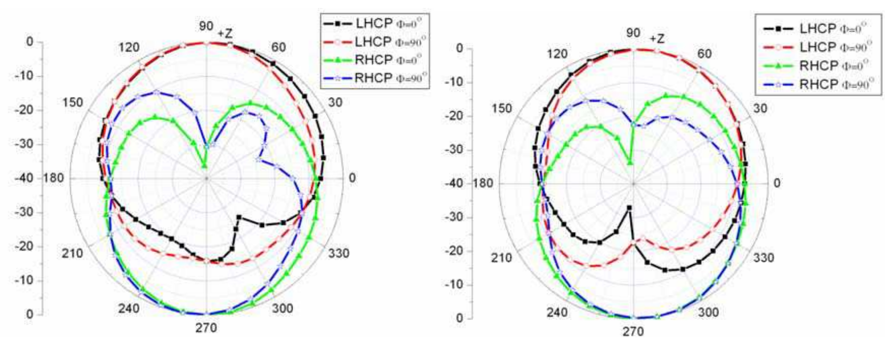


Figure 9. Simulated and measured the axis ratio of the proposed antenna.

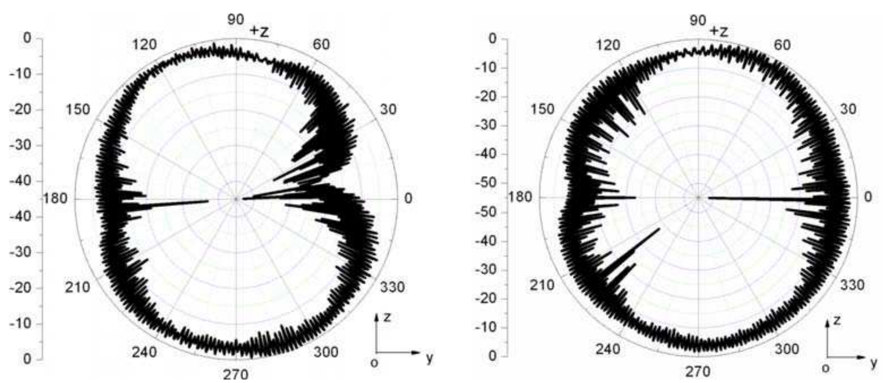
Figure 10 shows the simulated normalized radiation patterns in XOZ-plane and YOZ-plane at 2.45 GHz and 3.15 GHz. Shown in Fig. 11 is the measured total normalized radiation patterns in XOZ-plane. The left-hand CP (LHCP) and right-hand CP (RHCP) radiation patterns are excited in $+z$ and $-z$, respectively.

Figure 12 shows the maximum measured gains in CP bandwidth of the antenna. It can be seen that the antenna gain of around 5 dBi has been obtained. The photo of the fabricated antenna is shown in Fig. 13, which exhibits a compact size.



(a) (b)

Figure 10. Simulated normalized radiation patterns for RHCP and LHCP at 2.45 GHz and 3.15 GHz, respectively (a) 2.45 GHz (b) 3.45 GHz.



(a) (b)

Figure 11. Measured normalized radiation patterns at 2.45 and 3.15 GHz in the YOZ plane, respectively (a) 2.45 GHz, (b) 3.45 GHz.

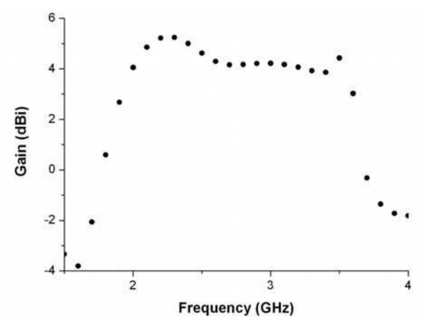


Figure 12. The measured peak gain versus frequency.

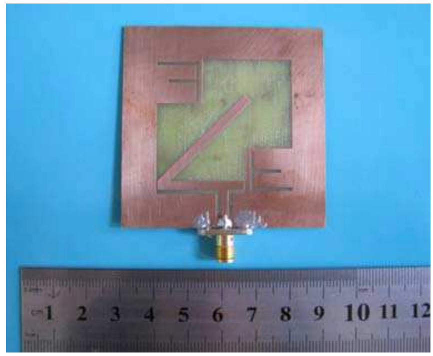


Figure 13. Fabricated broadband circularly polarized antenna.

4. CONCLUSION

A new CPW-fed square slot antenna with lightening-shaped feedline for the circularly polarized radiation has been proposed. The structure obtained good broadband circularly polarized characteristics. The antenna has been successfully designed, simulated, fabricated and measured, showing the advantages of compact, good broadband CP performances. Agreement between simulated and measured results is satisfactory.

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REFERENCES

1. Lin, Y. F., H. M. Chen, and S. C. Lin, "A new coupling mechanism for circularly polarized annular-ring patch antenna," *IEEE Trans. Antennas Propag.*, Vol. 56, 11–16, Jan. 2008.
2. Xu, R. P., X. D. Huang, and C. H. Cheng, "Broadband circularly polarized wide-slot antenna," *Microwave Opt. Technol. Lett.*, Vol. 49, 1005–1007, May 2007.
3. Tseng, L. Y. and T. Y. Han, "Microstrip-fed circular slot antenna for circular polarization," *Microwave Opt. Technol. Lett.*, Vol. 50, 1056–1058, Apr. 2008.

4. Shi, S., K. Hirasawa, and Z. N. Chen, "Circularly polarized rectangularly bent slot antennas backed by a rectangular cavity," *IEEE Trans. Antennas Propag.*, Vol. 49, No. 11, 1517–1524, Nov. 2001.
5. Qing, X. M. and Y. W. M. Chia, "Broadband circularly polarized slot loop antenna fed by three-stub hybrid coupler," *Electron. Lett.*, Vol. 35, 1210–1211, Jul. 1999.
6. Chu, Q. X. and S. Du, "A cpw-fed broadband circularly polarized square slot antenna," *Microwave Opt. Technol. Lett.,* Vol. 52, No. 2, 409–412, Feb. 2010.
7. Chou, C. C., K. H. Lin, and H. L. Su, "Broadband circularly polarized cross-patch-loaded square slot antenna," *Electron Lett.*, Vol. 43, 485–486, 2007.
8. Iwasaki, H., "A circularly polarized small-size microstrip antenna with a cross slit," *Electron Lett.,* Vol. 44, 1399–1401, 1996.
9. Sze, J. Y., K. L. Wong, and C. C. Huang, "Coplanar waveguide-fed square slot antenna for broadband circularly polarized radiation," *IEEE Trans Antennas Propag.,* Vol. 51, No. 8, 2141–2144, Aug. 2003.
10. Sze, J. Y. and C. C. Chang, "Circularly polarized square slot antenna with a pair of inverted-L grounded strips," *IEEE Trans Antennas and Wireless Propagation Lett.,* Vol. 7, 149–151, 2008.
11. Sun, J. Y., C I. G. Hsu, Z. W. Chen, and C. C. Chang, "Broadband CPW-fed circularly polarized square slot antenna with lightening-shaped feedline and inverted-L grounded strips," *IEEE Trans. Antennas Propag.,* Vol. 58, 973–977, Mar. 2010.
12. Wang, C. J. and C. H. Chen, "CPW-fed stair-shaped slot antennas with circular polarization," *IEEE Trans. Antennas Propag.*, Vol. 57, No. 8, 2483–2486, Aug. 2009.